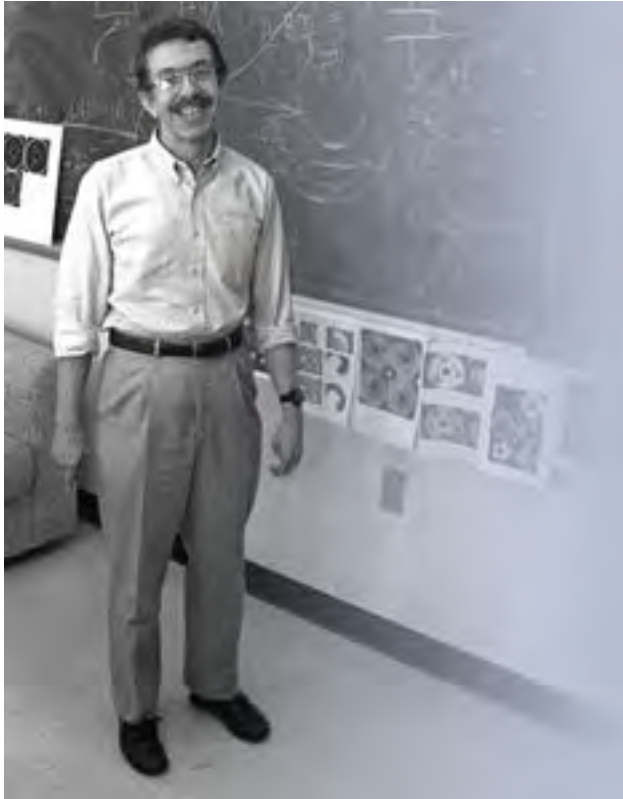


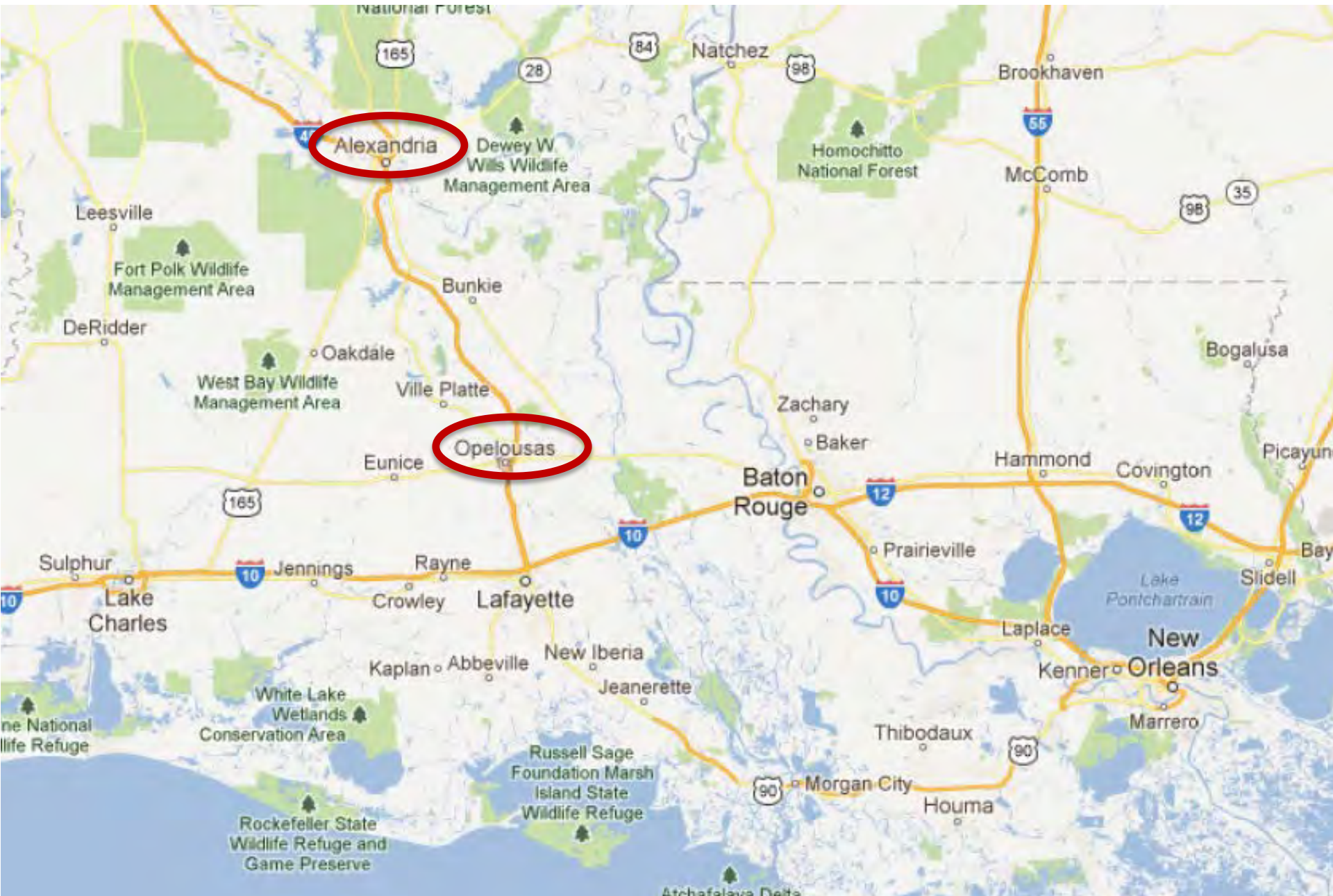
Harry L. Swinney

Adventures in Nonlinear Dynamics



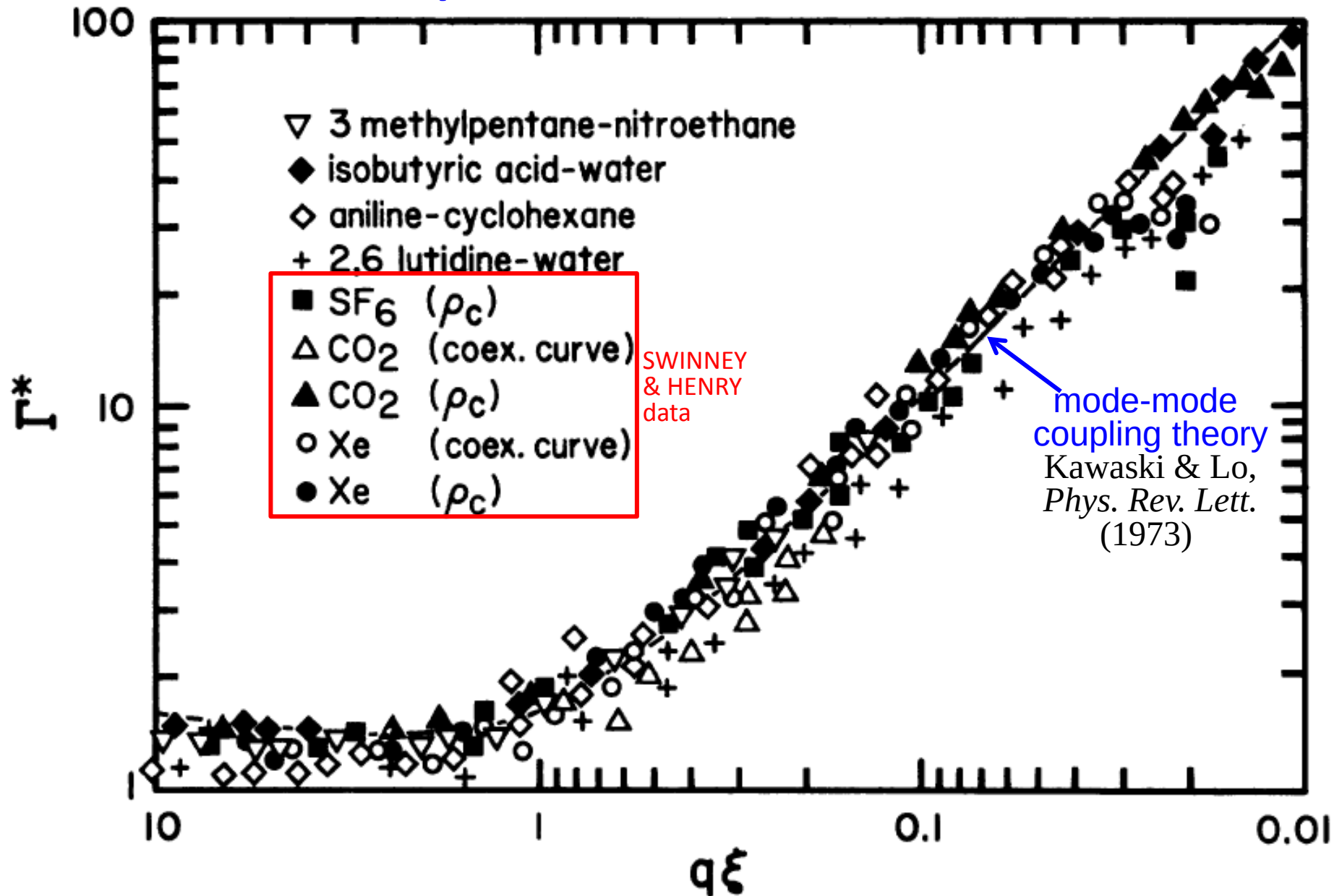
Dynamic critical phenomena – onset of chaos in fluids –
chemical chaos – reaction-diffusion pattern formation – granular
dynamics – planetary fluid dynamics – leaf edges –
fractal growth – collective behaviour of bacteria

Harry and me



Decay rate of order parameter fluctuations near critical points:

Swinney & Henry, *Phys. Rev. A* (1973)





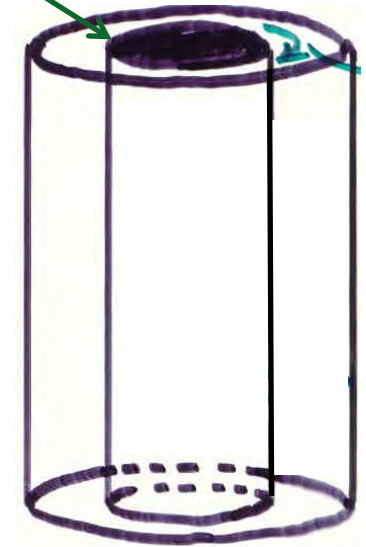
Jerry Gollub

Transitions in Couette-Taylor flow

(fluid between two cylinders)

Jerry Gollub and Harry Swinney
City College of New York, 1975

inner cylinder rotates

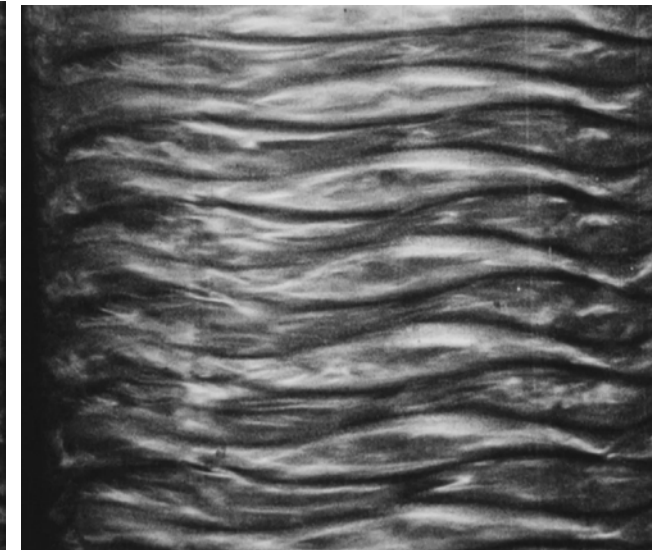
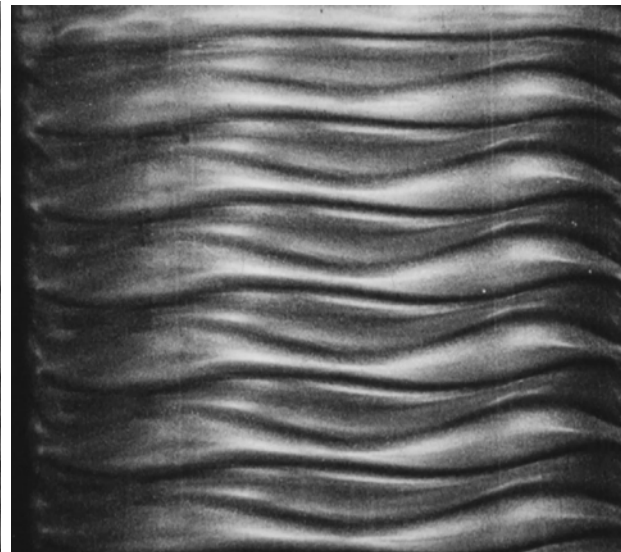
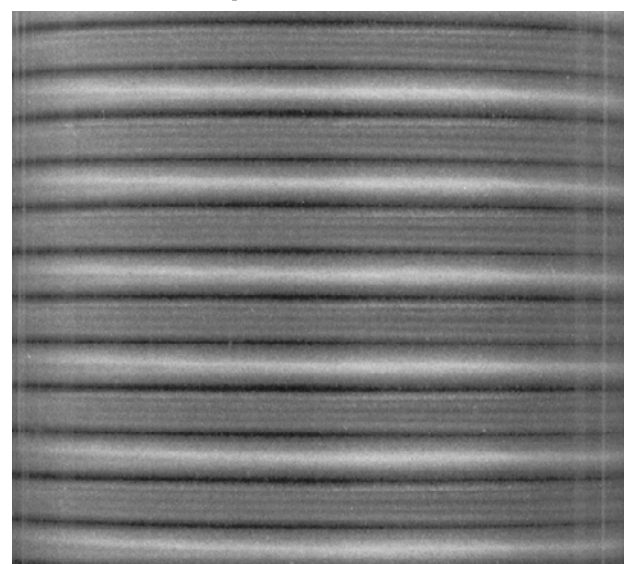


increasing Reynolds number 

time-independent vortices

wavy vortices

turbulent flow



movies by M. Gorman and H. Swinney (1979)

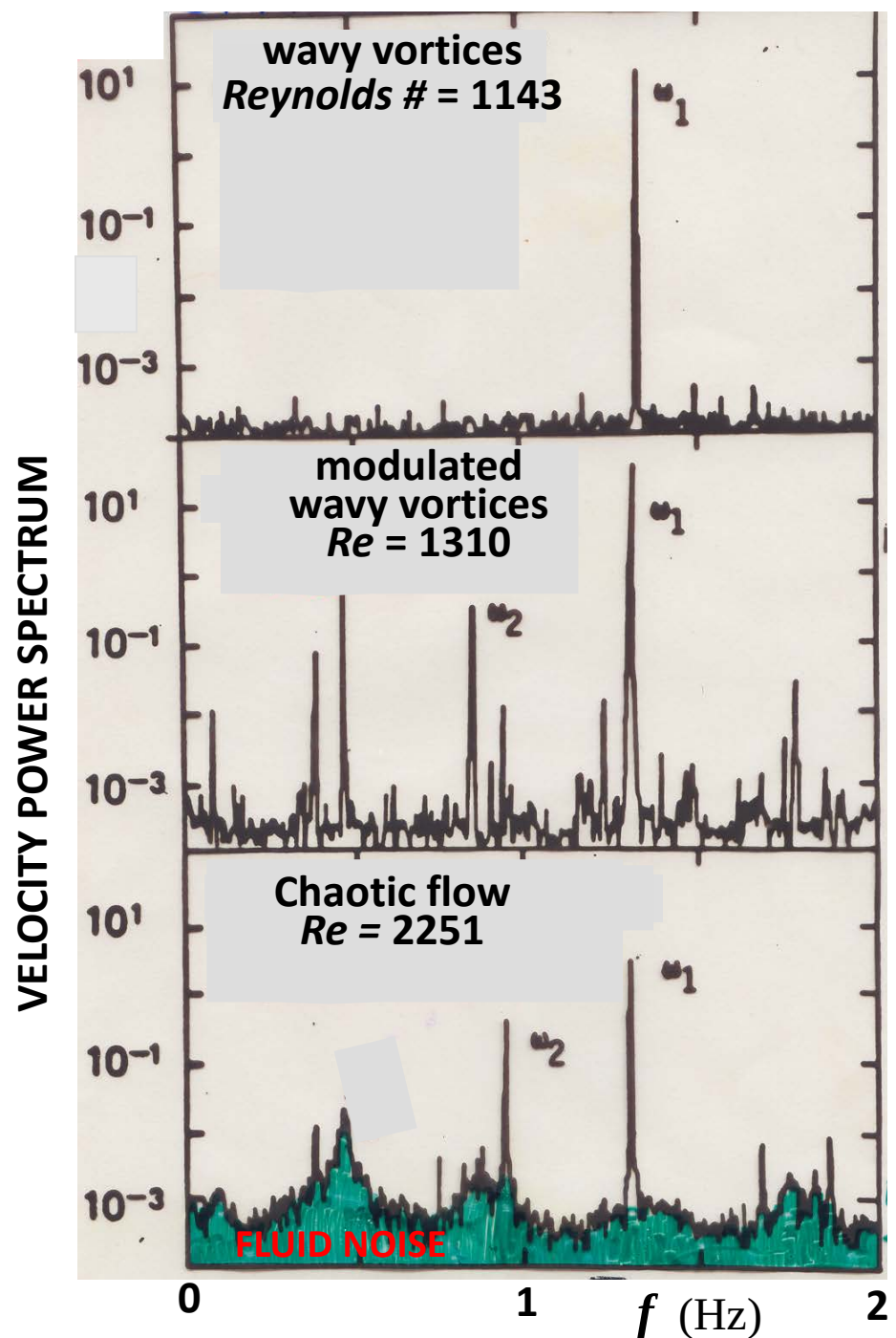
Onset of chaos

in Couette-Taylor flow

observed in
velocity power spectra

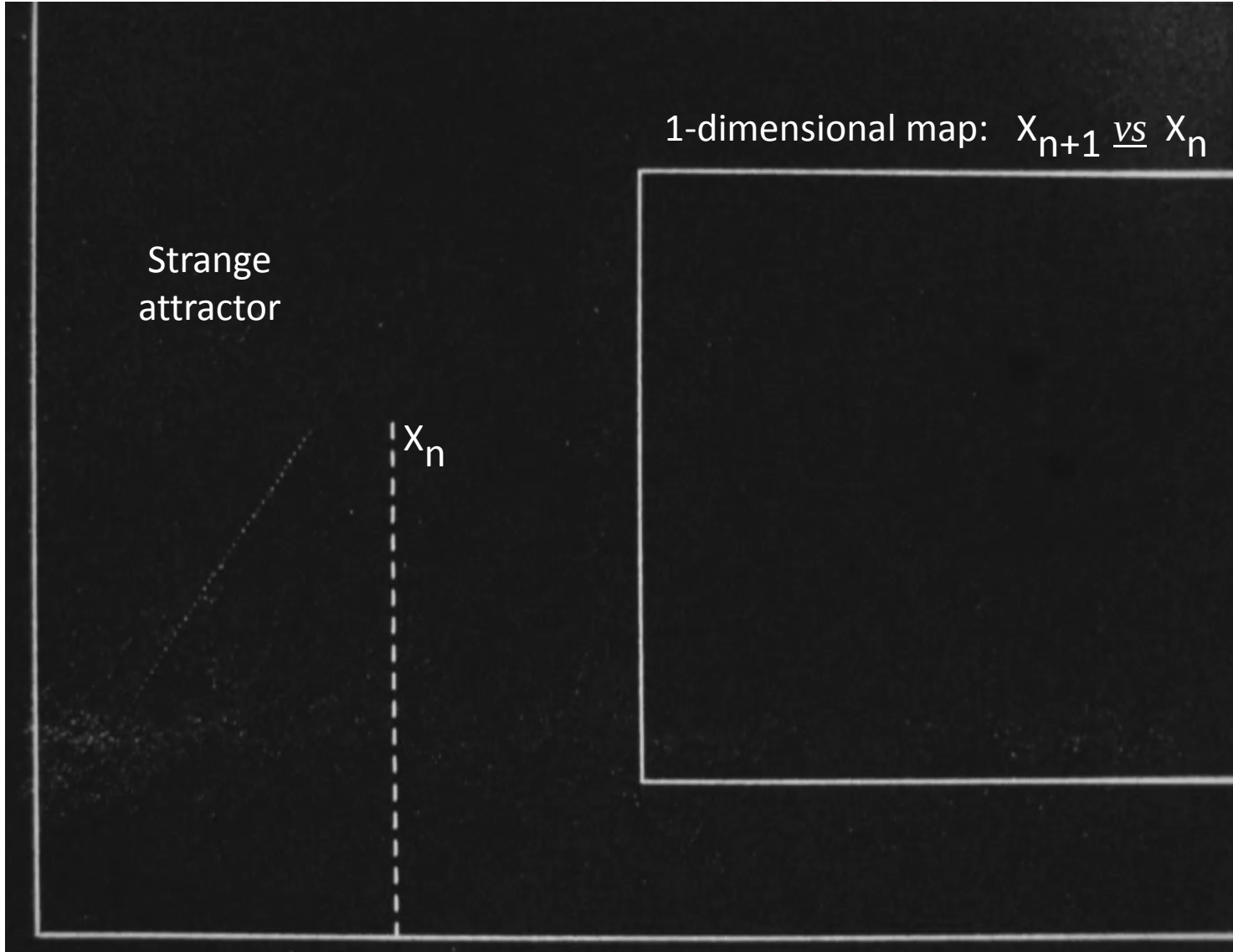
Gollub & Swinney
Phys. Rev. Lett. (1975)

Fenstermacher, Gollub, & Swinney
J. Fluid Mech. (1978)



Deterministic chaos described by 1-dim. map from Belousov-Zhabotinsky reaction experiment

16 mm movie: Roux, Swinney, & Shaw (1981)



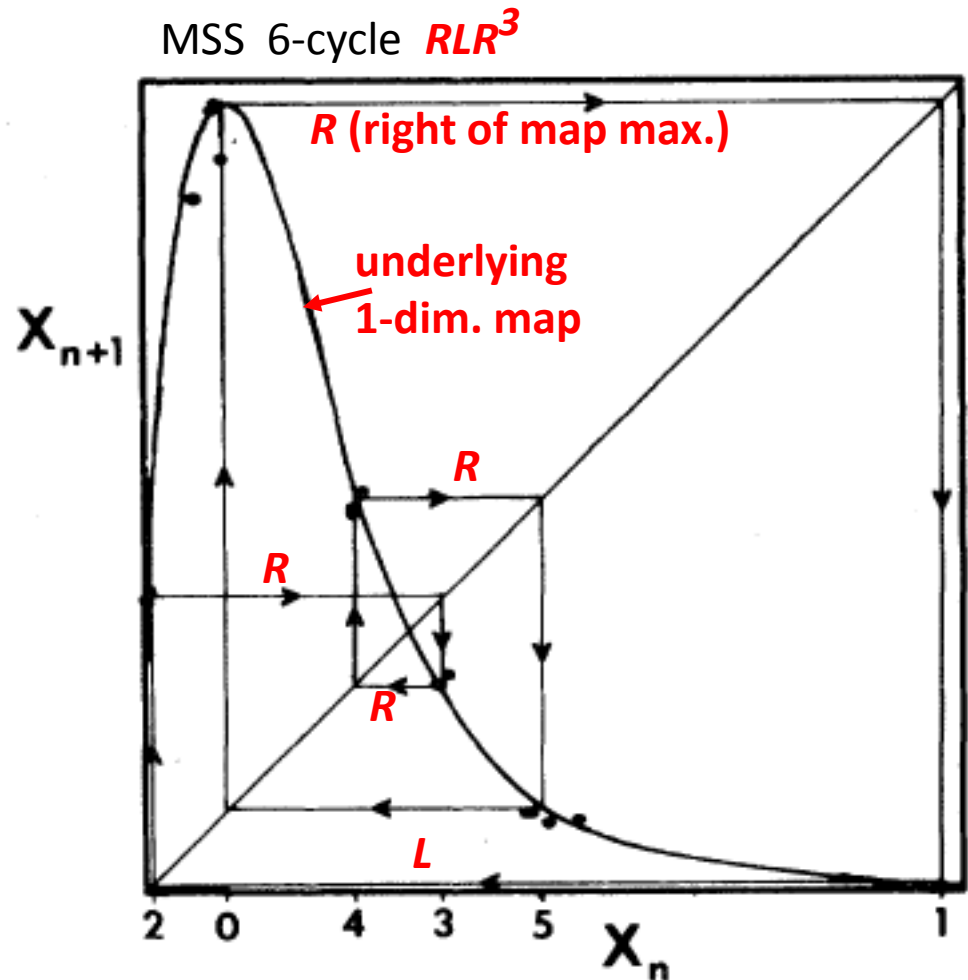
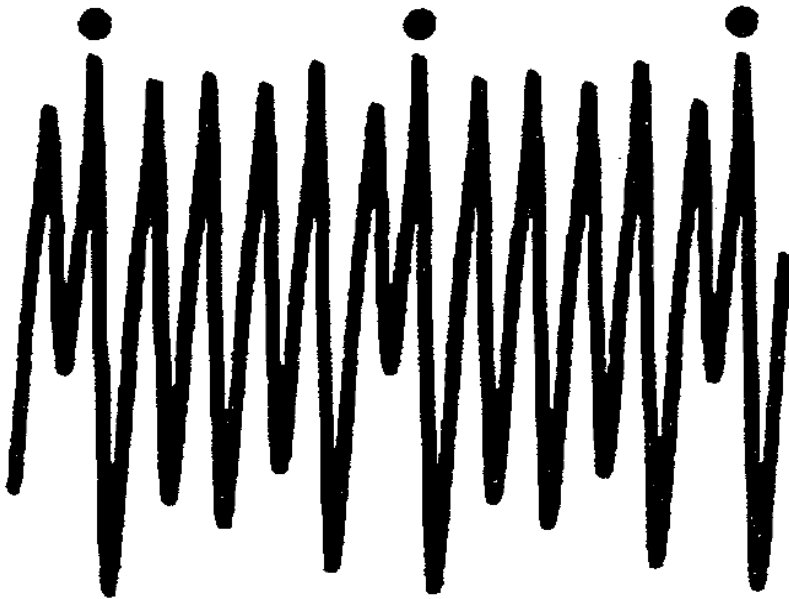
Roux,
Simoyi,
Swinney
Physica D
(1983)

Beyond the period doubling sequence: chaos and the “Universal Sequence” of periodic states for 1-dim. unimodal maps

Theory: Metropolis, Stein, & Stein (MSS), *J Combinatorial Theory, Ser. A* **15** (1973)

Experiment: Simoyi, Wolf, & Swinney, *Phys. Rev. Lett.* **49** (1982)

Bromide ion potential in the Belousov-Zhabotinski reaction:
one of many observed MSS states, a 6-cycle, period 690 seconds



Determining Lyapunov Exponents from a time series

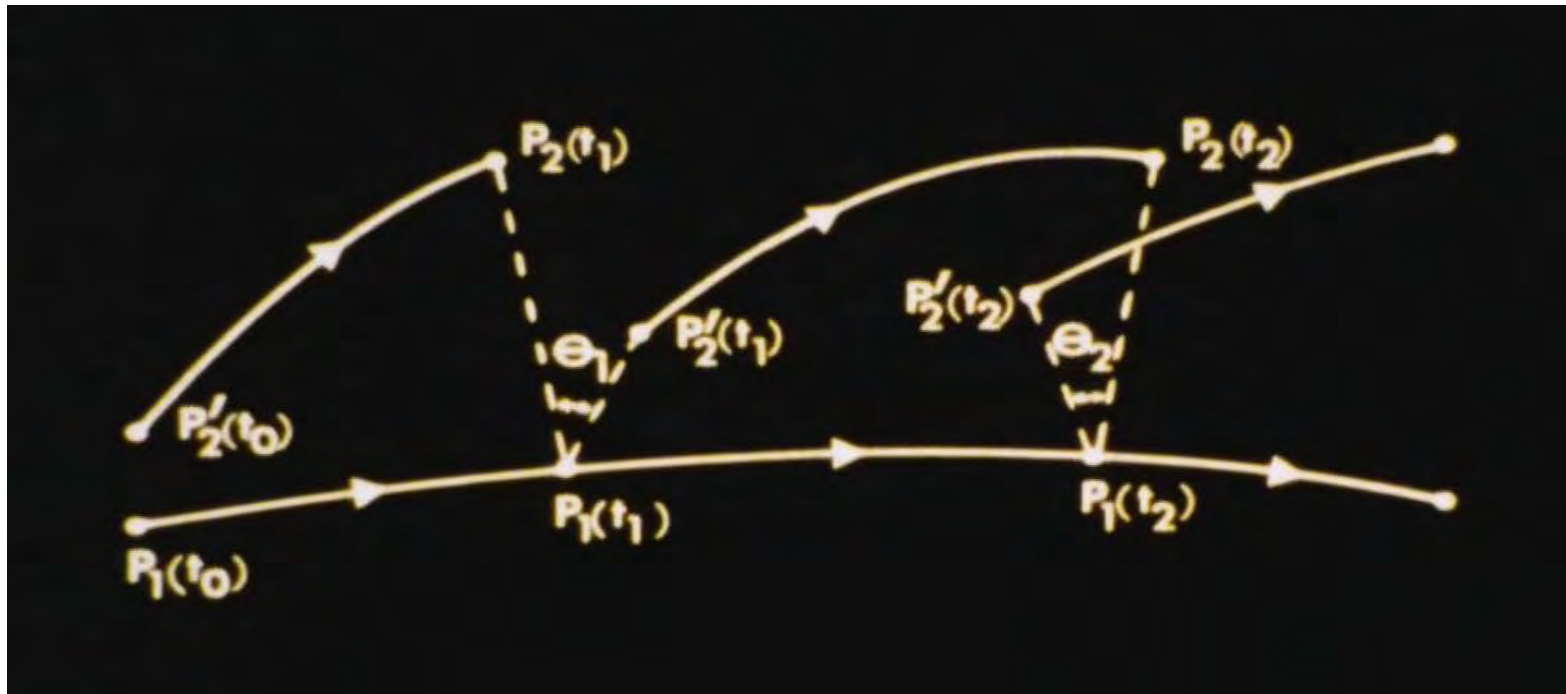
Wolf, Swift, Swinney, Vastano, *Physica D* (1985)

Repeated application of the **Gram-Schmidt reorthonormalization** process.

The analysis also includes

- ◆ data uncertainty
- ◆ number of data points
- ◆ attractor dimension

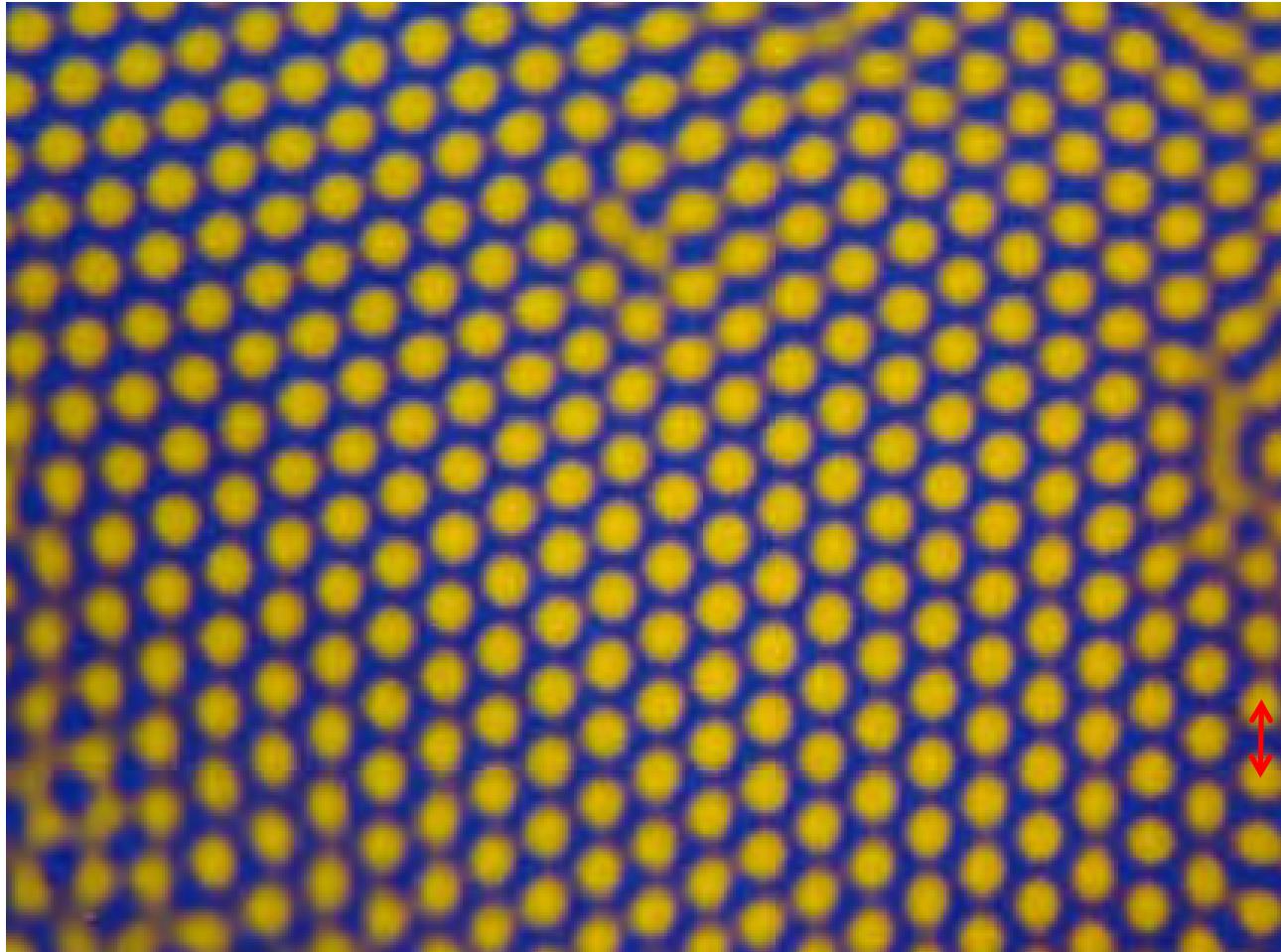
Alan Wolf
16 mm
movie
(1985)



Pattern formation by a reaction-diffusion system

Theory: Alan Turing, *Phil. Trans. Roy. Soc. London* (1952)

Experiment: Ouyang and Swinney, *Nature* (1991)



Measure:

λ = wavelength,

D = diffusion coefficient,

τ = reaction time

Results agree with

Turing relation:

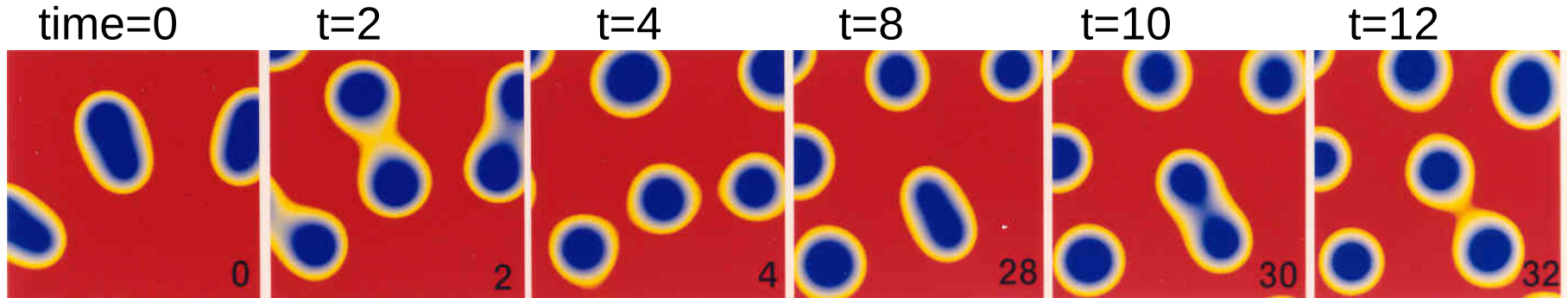
$$\lambda = 2\pi\sqrt{D\tau}$$

$\lambda = 0.2 \text{ mm}$

chlorite-iodide-malonic acid reaction

Replicating spots in reaction-diffusion system

Simulation with simple kinetics, $A + 2B \rightarrow 3B$: Pearson, *Science* 261 (1993)



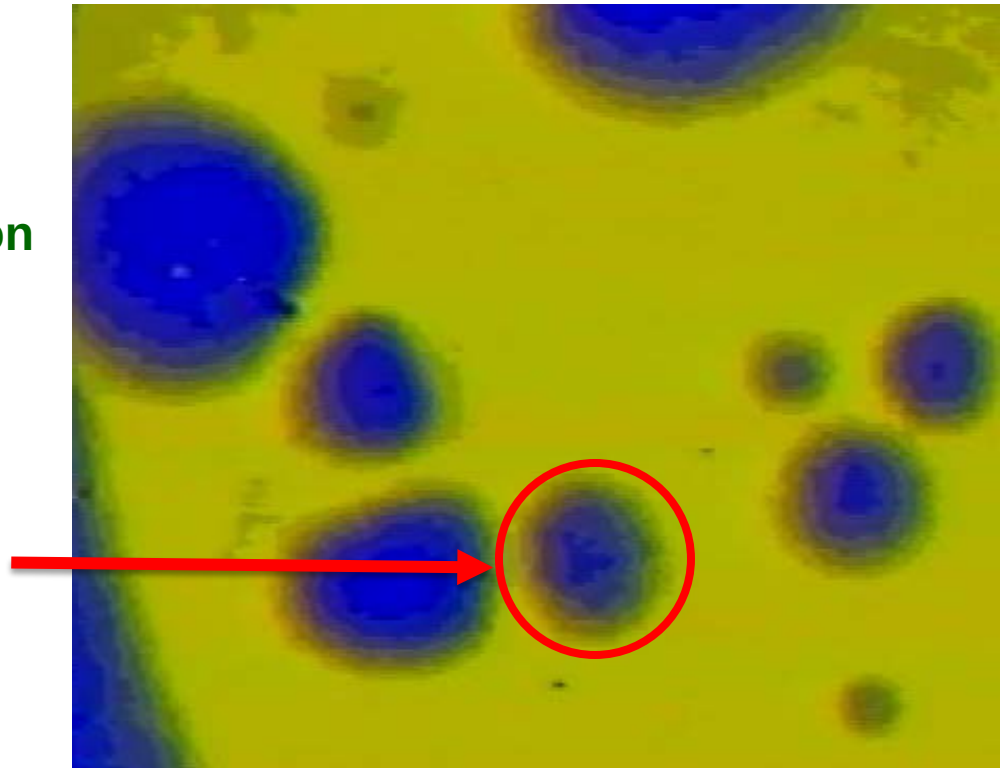
Experiment --

ferrocyanide-iodate-sulfite reaction

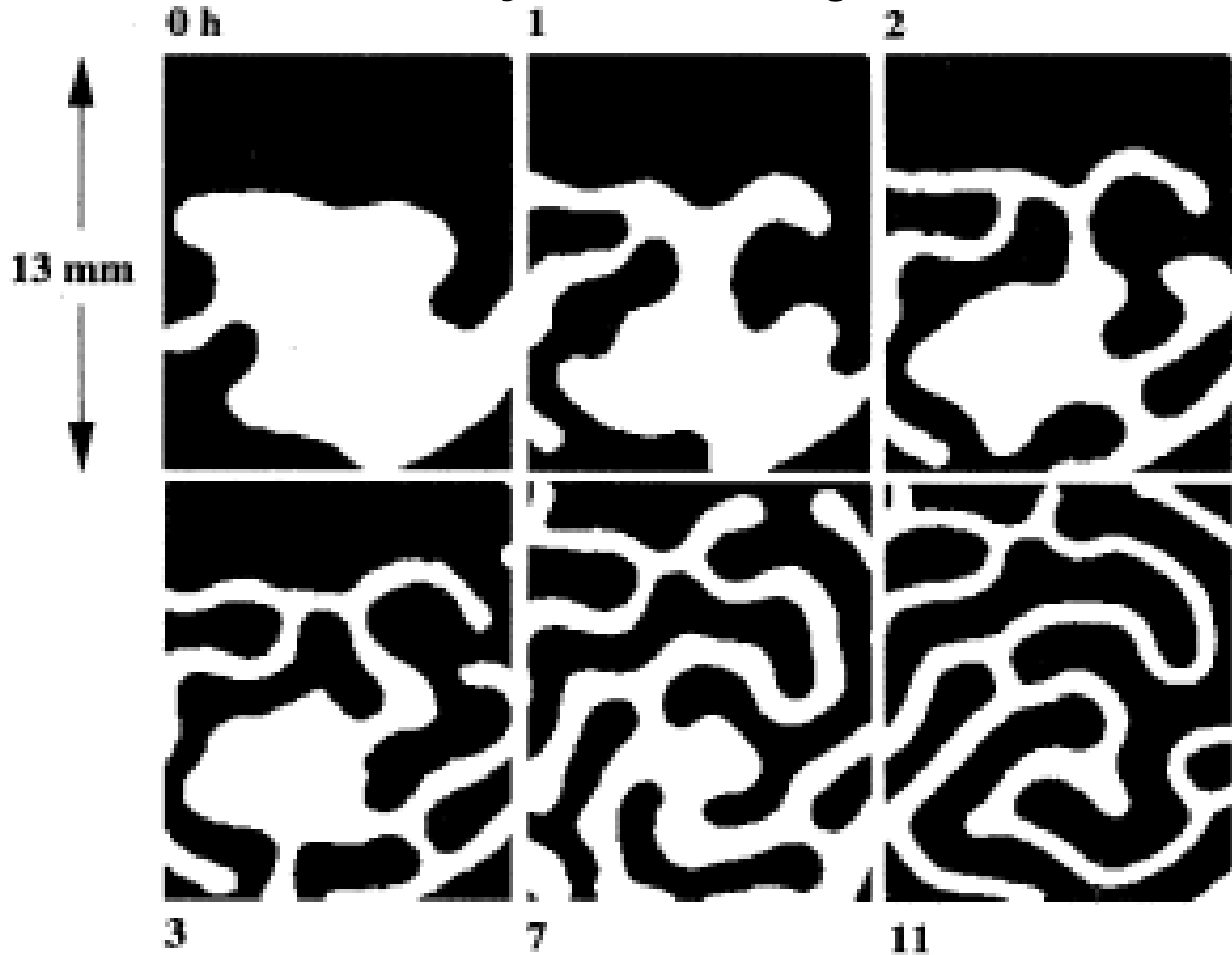
Lee, McCormick, Pearson, Swinney

Nature (1994)

watch this spot



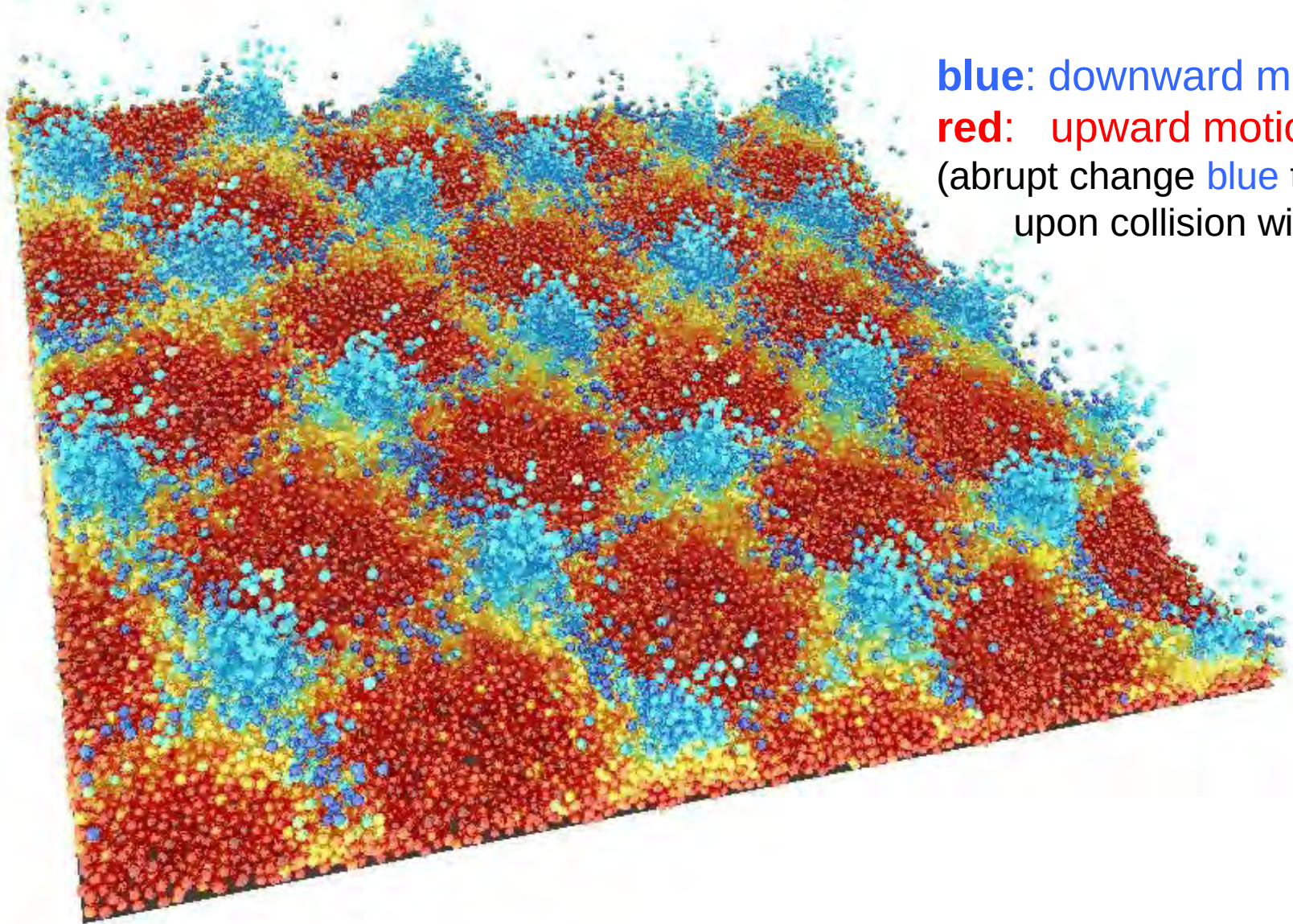
Pattern Formation by Interacting Chemical Fronts



Lee, McCormick, Ouyang, and Swinney, 1993 (CIMA)

Oscillate a container of particles vertically: **pattern emerges for acceleration $> 2.5g$**

Moon, Goldman, Shattuck, Swift, Swinney, *Phys. Rev. E* (2003); *Phys. Rev. Lett.* (2004)



blue: downward motion

red: upward motion

(abrupt change **blue** to **red**
upon collision with plate)

Granular patterns: experiment and MD simulation

snapshots of vertically oscillated layer

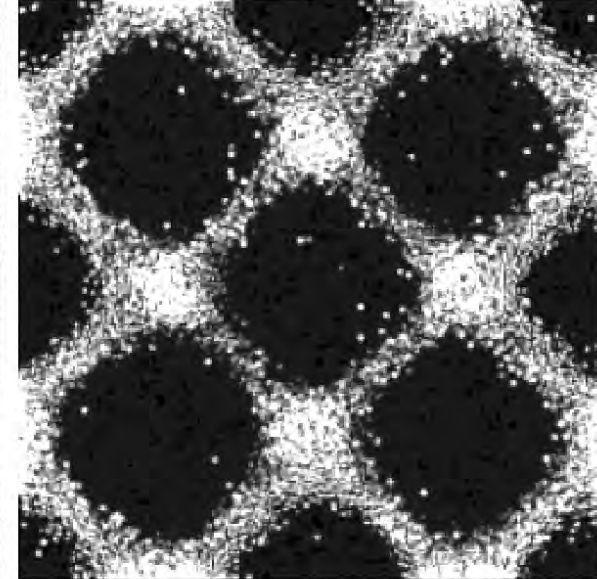
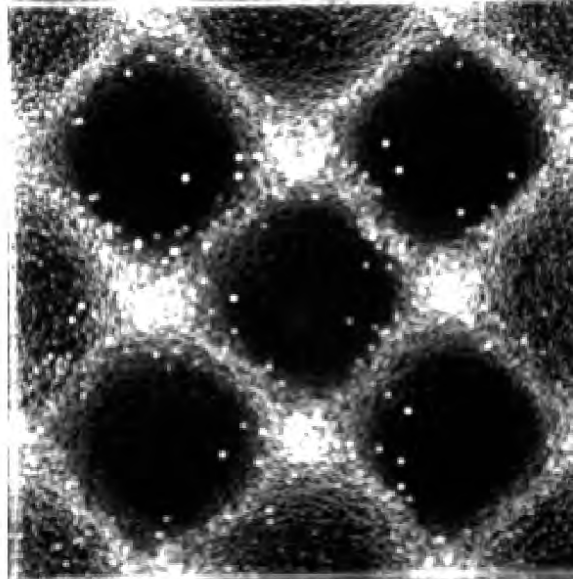
EXPERIMENT

TOP VIEW

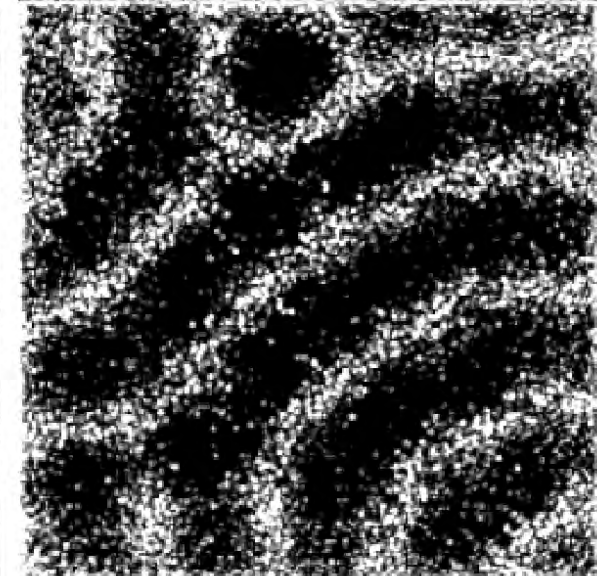
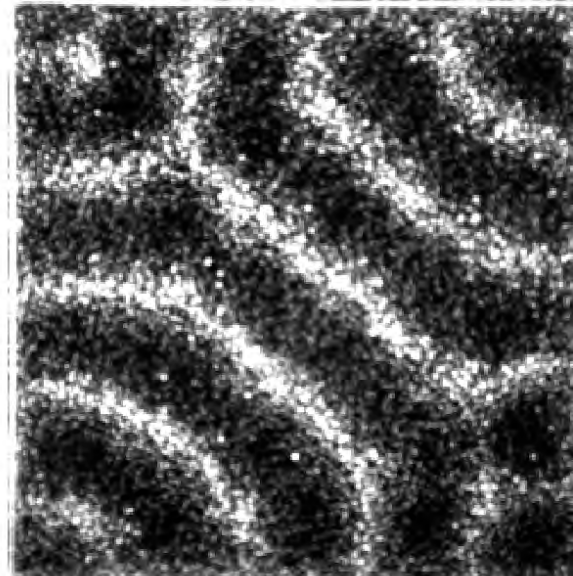
MD SIMULATION

- 60 000 spheres
- $d = 0.55$ mm diameter
- layer: $100d \times 100d \times 6d$
- acceleration = $3g$

$f = 15$ Hz



$f = 25$ Hz



Melo, Umbanhowar, Swinney
Phys. Rev. Lett. (1995)

Bizon, Shattuck, Swift,
McCormick, Swinney,
Phys. Rev. Lett. 80 (1998)

Oscillon: localized oscillating nonpropagating structure

snapshot

365 μm
balls

Umbanhowar, Melo, Swinney
Nature (1996)

movie

movie by Mark Shattuck (CCNY);
Reis, Ingale, Shattuck,
Physical Review E (2007)

Laboratory model of Jupiter's Great Red Spot

(spot discovered by Robert Hooke, 1664)

Experiment: Sommeria, Meyers, Swinney, *Nature* (1988)

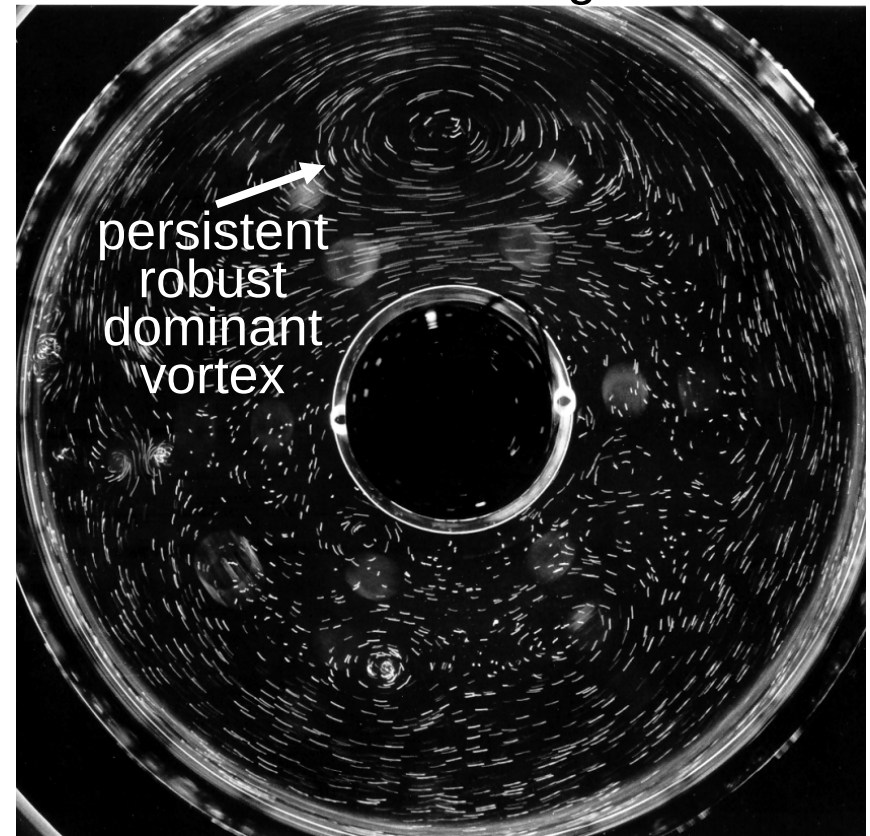
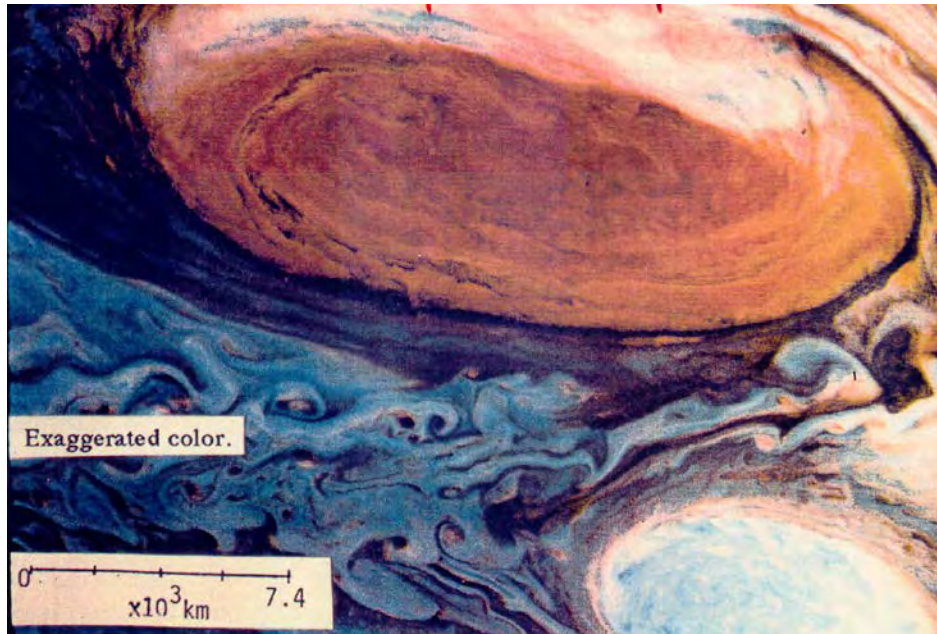
Theory: Marcus, *Nature* (1988)

System design mimics Jupiter's conditions:

♦turbulent flow ♦strong shear ♦strong Coriolis effect ♦Coriolis latitudinal gradient

86 cm diameter rotating tank

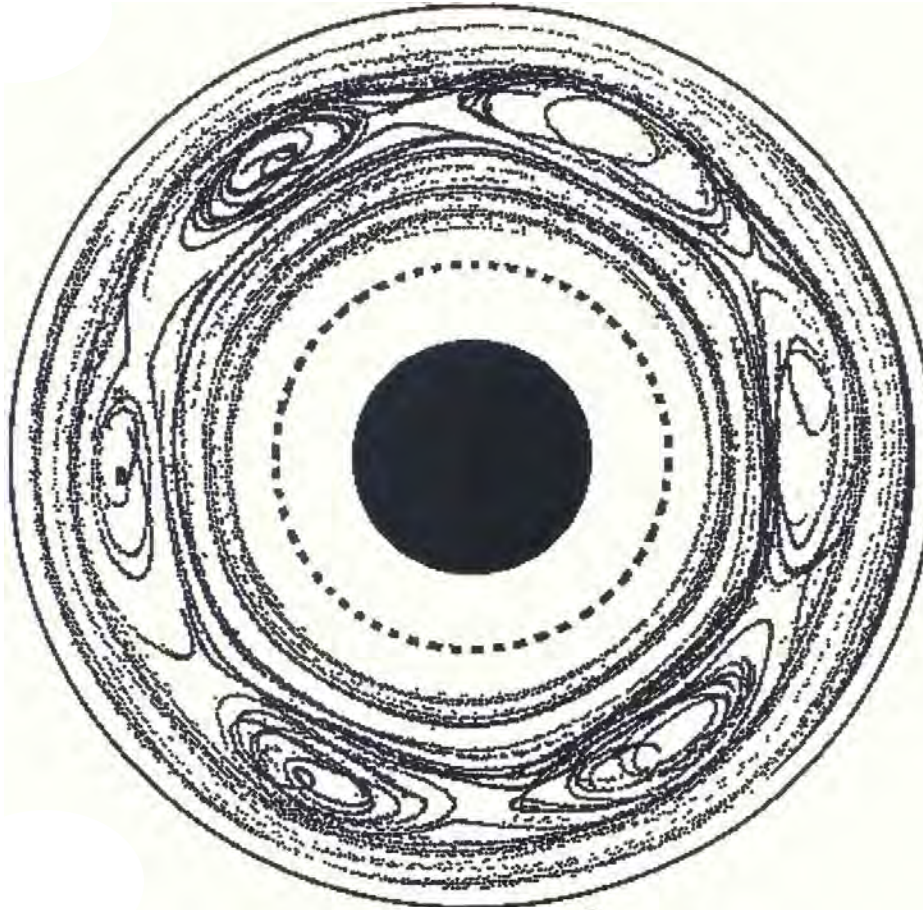
Voyager 2 (1979)



Anomalous diffusion: tracer particles alternate between ***Lévy walks*** in fluid jets and sticking in vortices

Solomon, Weeks, Swinney, *Phys. Rev. Lett.* (1993)

90 sec long trajectories of particles in
flow with 6 vortices between 2 jets



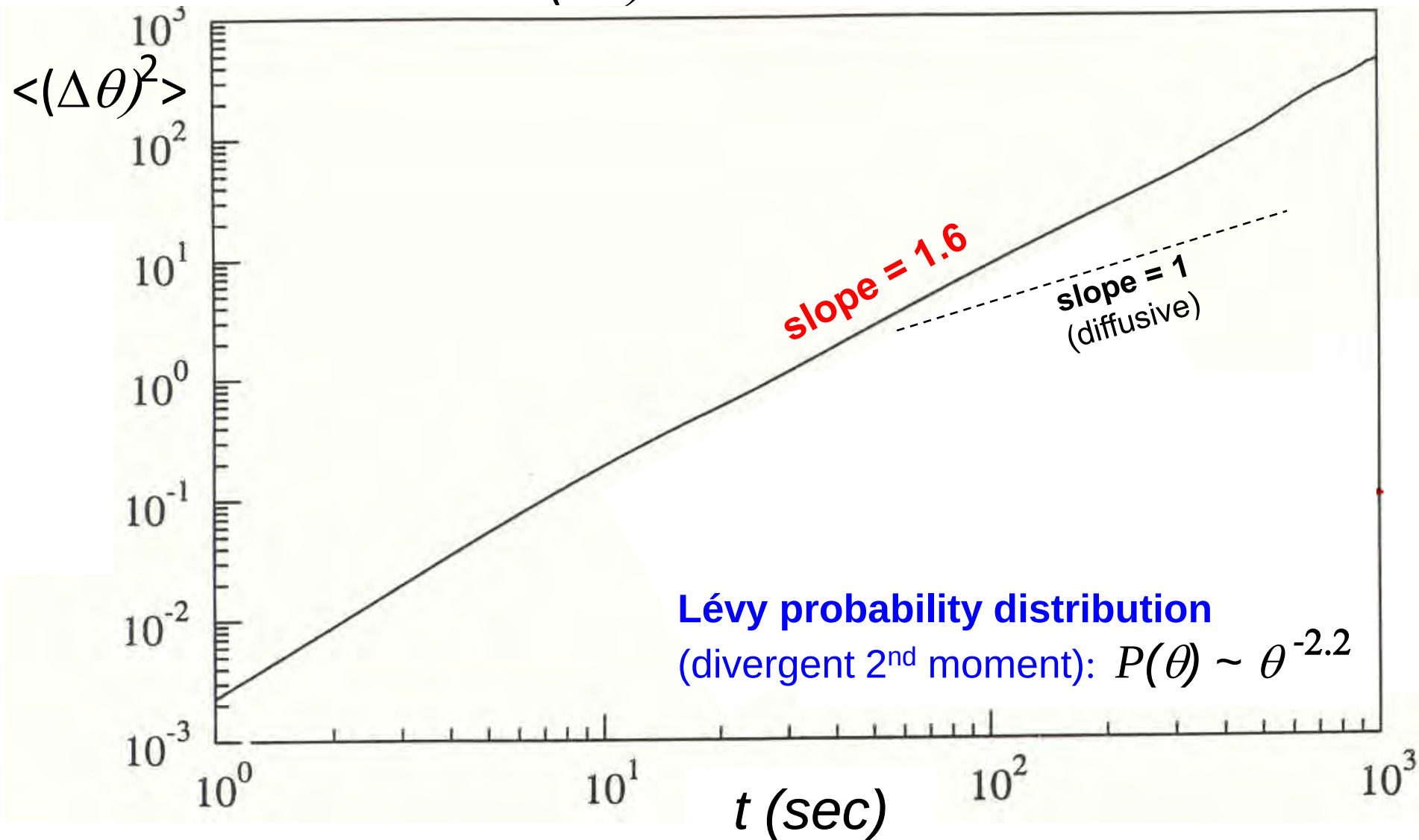
86 cm

Lévy walks and sticking in vortices



Anomalous diffusion in rotating flow

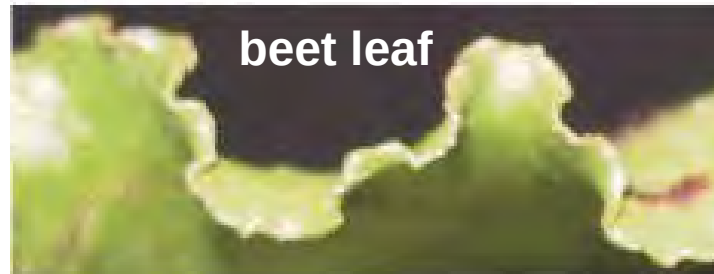
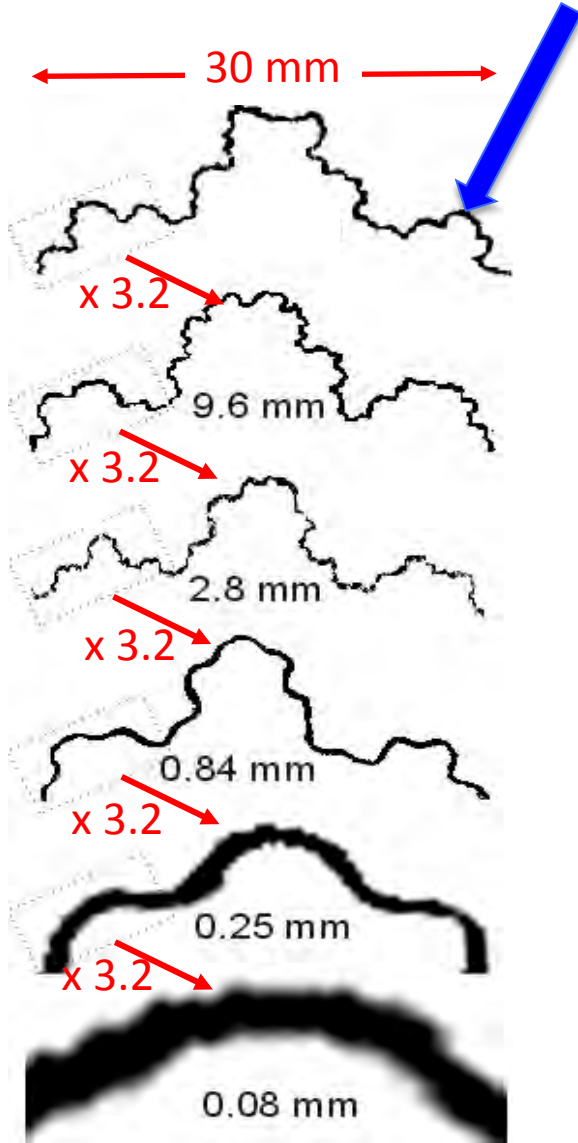
$$\langle (\Delta\theta)^2 \rangle \propto t^{1.6}$$



Edge of torn garbage bag



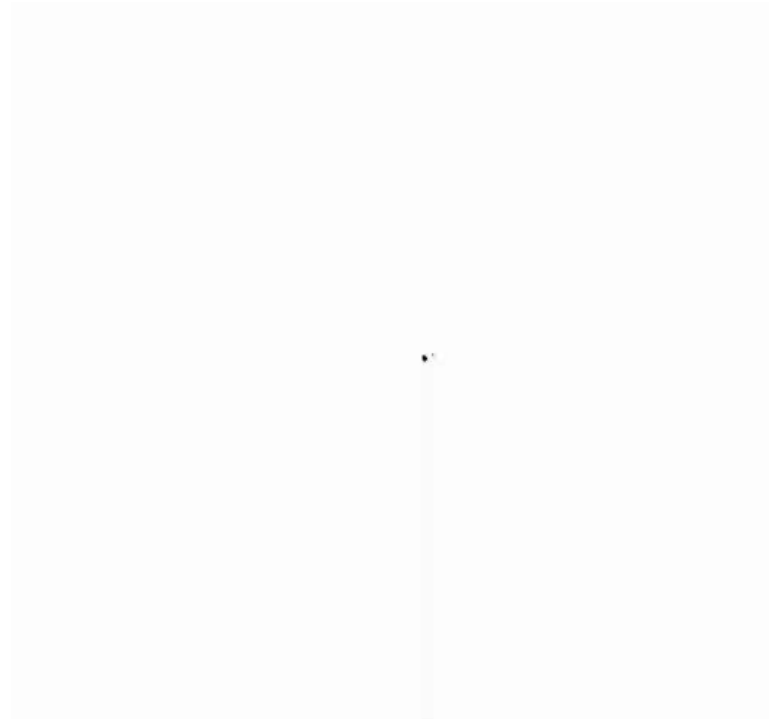
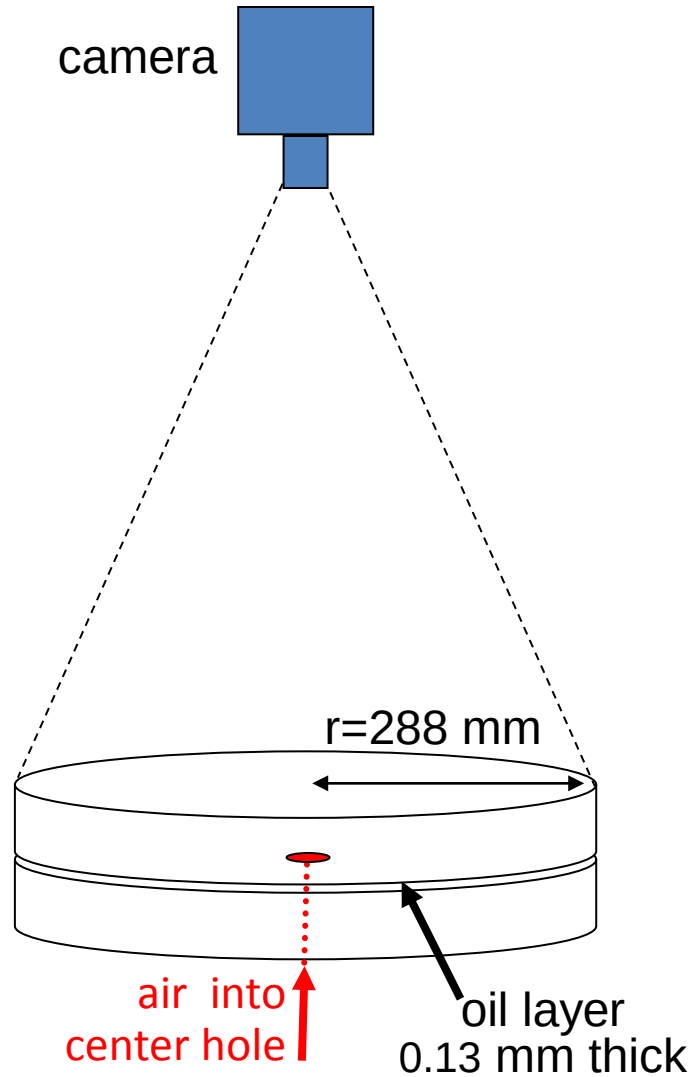
Experiment: Sharon et al., *Nature* (2002); *Phys. Rev. E* (2007)
Theory: Marder et al., *Europhys. Lett.* (2003)



**3-dim. fractal
structure forms
when the growth
imposes a metric
that cannot be
embedded in
2 dimensions.**

Fingering of air bubble growing in an oil layer

VISCOUS FINGERING APPARATUS



Same universality class as Diff. Limited Aggregation

Mathiesen, Procaccia, Swinney, Thrasher
Europhys. Lett. **76** (2006)

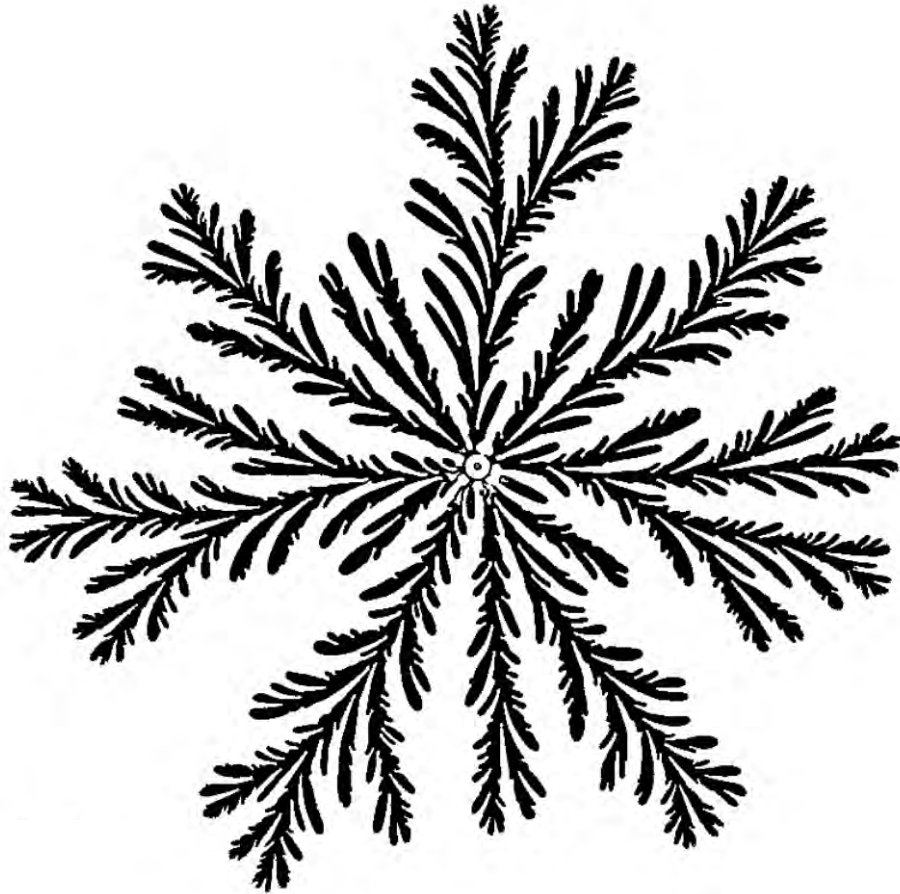
Harmonic moments are conserved

Leshchiner, Thrasher, Mineev, Swinney
Phys. Rev. E **81** (2010)

Fractal growth patterns

Viscous fingering

Be'er et al., *PNAS* 106 (2009)

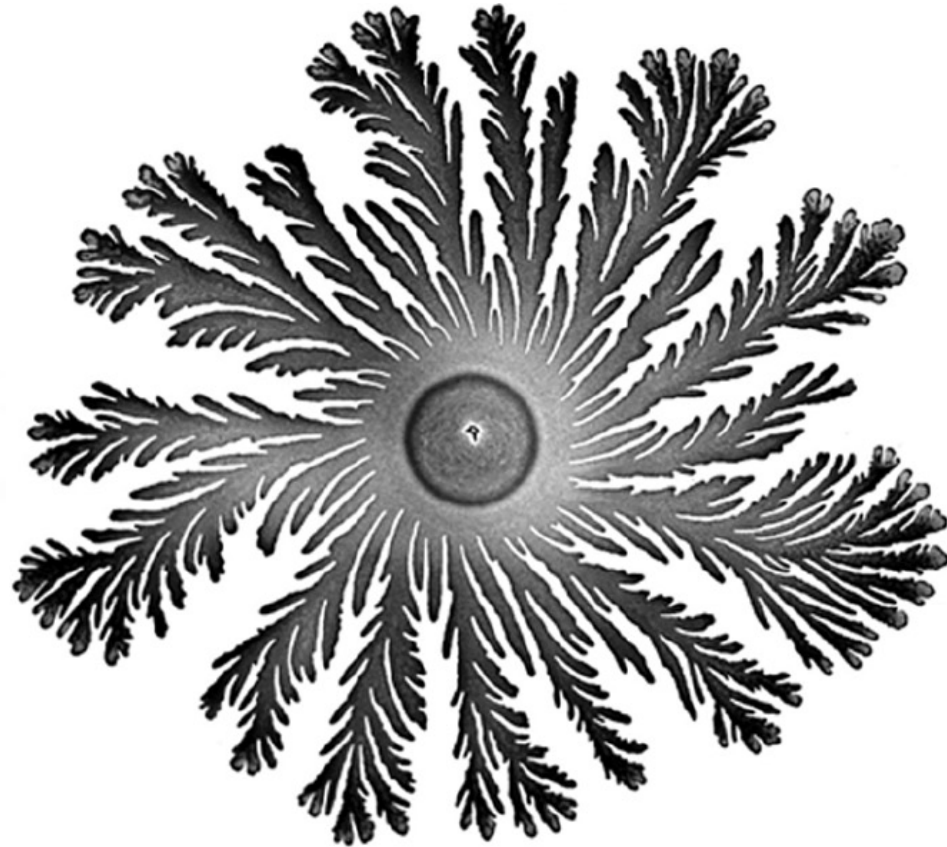


← 23 cm →

Bacterial colony

Paenibacillus subtilis

Praud & Swinney, *Phys. Rev. E* 72 (2005)



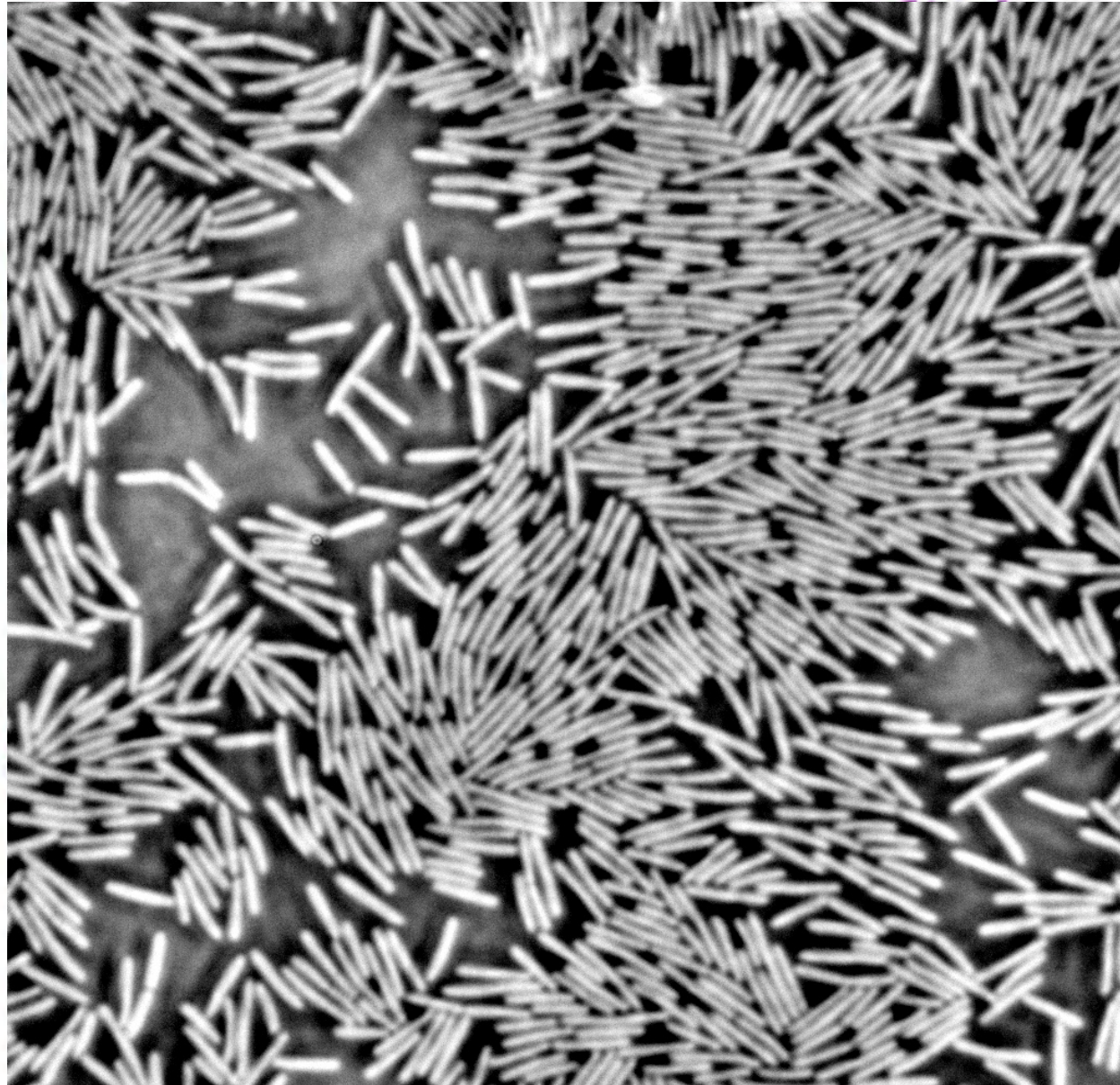
← 4 cm →

Collective dynamics of *Bacillus subtilis* bacteria (7 μm long rods) **swimming on an agar gel**

CLUSTERS:

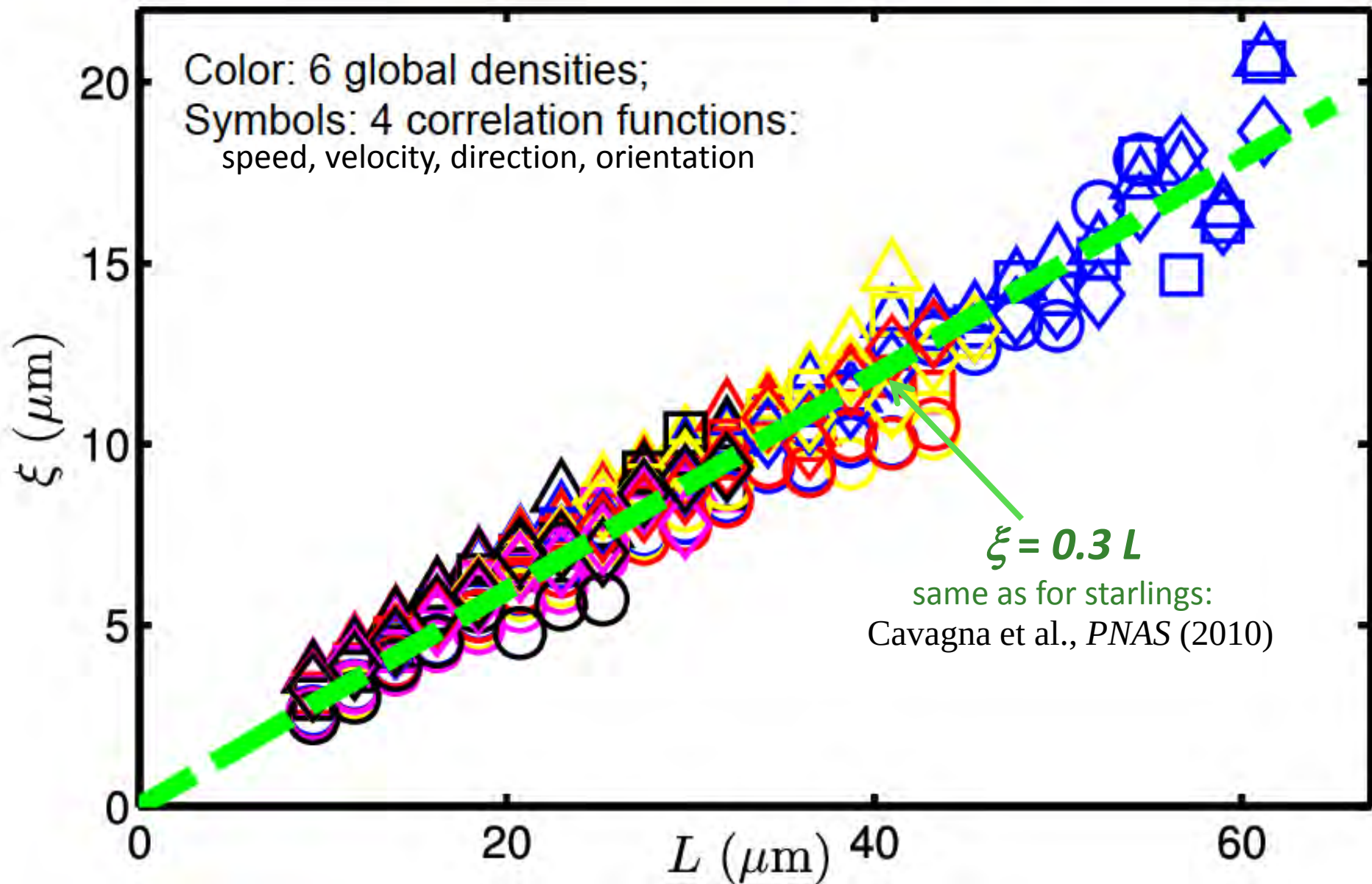
neighbors with
nearly the same
speed, velocity,
direction, orientation

Chen, Dong, Be'er,
Swinney, Zhang,
Phys. Rev. Lett.
(2012)



Correlation length scales with cluster size

Chen, Dong, Be'er, Swinney, Zhang, *Phys. Rev. Letters* (2012)



Flocking (Starlings Above Rome)



Harry's Ph.D. Students

T. K. Lim, Johns Hopkins University, 1973 (now Professor emeritus, Korea University, Seoul)
“The Rayleigh Linewidth of Simple Fluids near the Critical Point”

Jay Newman, New York University, 1975 (now Professor at Union College)
“Dynamic Light Scattering and Birefringence Studies of fd Virus and Its DNA”

Dennis Wonica, City College of CUNY, 1979
“Brillouin Scattering in Xenon Near the Critical Point”

Randy Fenstermacher, City College of CUNY, 1979
“Laser Doppler Velocimetry Study of the Onset of Chaos in Taylor Vortex Flow”

Leslie Reith, The University of Texas, 1981
“Transition to Turbulence in a Circular Couette System”

Gregory P. King, The University of Texas, 1983 (now at the University of Lisbon, Portugal)
“Limits of Stability and Irregular Flow Patterns in Wavy Vortex Flow”

Anke Brandstater, Christian Albrechts Universität (Kiel), 1984
“Low Dimensional Chaos in a Hydrodynamic System”

Donald Allen Hirst, The University of Texas at Austin, 1987

“The Aspect Ratio Dependence of the Attractor Dimension in Taylor-Couette Flow”

Andrew McLeod Fraser, The University of Texas at Austin, 1988 (now at LANL)

“Information and Entropy in Strange Attractors”

John Vastano, The University of Texas at Austin, 1988

“Bifurcations in Spatiotemporal Systems”

Peter McCarty, University of Texas at Austin, 1989

Advisor: Werner Horthemke; co-advisor: Harry Swinney

(now at the Applied Research Laboratories, University of Texas at Austin)

“Modelling of spatially extended open chemical systems”

Steven D. Meyers, The University of Texas at Austin, 1990

(now Senior Scientist, University of South Florida)

“Laboratory Experiments on Coherent Structures in Quasi-geostrophic Flows”

W. Stuart Edwards, The University of Texas at Austin, 1991

“New Stability Analyses for the Couette-Taylor Problem”

Michael F. Schatz, The University of Texas at Austin, 1991

(now Professor, Georgia Institute of Technology)

“Transition in Plane Channel Flow with Spatially Periodic Perturbations”

Daniel P. Lathrop, The University of Texas at Austin, 1992

(now Professor, University of Maryland)

“Turbulent Drag and Transport in High Reynolds Number Couette-Taylor Flow”

Kyoung J. Lee, The University of Texas at Austin, 1994 (now Professor, Korea University)

“Nonequilibrium Chemical Patterns and their Bifurcations”

Steven P. Gross, The University of Texas at Austin, 1995

Co-advisors: Harry Swinney and Michael Marder

(now Professor at University of California, Irvine)

“Dynamics of Fast Fracture”

John M. Huth, The University of Texas at Austin, 1995

“Dynamics and Convective Transport in Electrochemical Deposition”

Gregory S. Lewis, The University of Texas at Austin, 1996

(now at Aerosol Dynamics, Inc., Berkeley)

“Velocity Fluctuations, Wall Shear Stress and the Transition in Torque Scaling at $R=13,000$ in Turbulent Couette-Taylor Flow”

Paul B. Umbanhowar, The University of Texas at Austin, 1996

“Pattern Formation in Vertically Vibrated Granular Materials”

Stephen Van Hook, The University of Texas at Austin, 1996 (now at Penn State University)
“Long-Wavelength Instability in Surface-Tension-Driven Benard Convection”

Eric R. Weeks, The University of Texas at Austin, 1997
(now Professor, Emory University)
“Experimental Studies of Anomalous Diffusion, Blocking Phenomena, and
Two-Dimensional Turbulence”

Jens Hauch, The University of Texas at Austin, 1999
Advisor: Michael Marder; co-advisor, Harry Swinney
“Dynamic Fracture in Brittle Materials”

John Burgess, The University of Texas at Austin, 1999
Advisor, Harry Swinney; Co-advisor: W. D. McCormick (now at Nvidia, Austin)
“Thin Film Instabilities: Rayleigh-Taylor with Thermocapillarities and
Kolmogorov Flow in a Soap Film”

Charles Baroud, The University of Texas at Austin, 2001
(now Professor at Ecole Polytechnique, Paris)
“Transitions from three-to two-dimensional turbulence in a rotating system”

Daniel I. Goldman, The University of Texas at Austin, 2002
(now Assistant Professor at Georgia Institute of Technology)
“Pattern formation and fluidization in vibrated granular layers, and grain dynamics and
jamming in a water fluidized bed”

Douglas S. Martin, The University of Texas at Austin, 2003

Advisor, Josef Käs), co-advisor, Harry Swinney

(now Assistant Professor at Carlton College)

“Speed and Propagation of Diffusive Signals in Spatially Inhomogeneous Membranes”

Martin B. Forstner, The University of Texas at Austin, 2003

Advisor: Josef Käs; co-advisor, Harry Swinney

(now Assistant Professor at Syracuse University)

“Motion of Nano-Objects in Langmuir Monolayers”

Mitchell G. Moore, The University of Texas at Austin, 2003

“Unsteady Growth and Relaxation of Viscous Fingers”

Erin C. Rericha, The University of Texas at Austin, 2004

(now Assistant Professor at Vanderbilt University)

“Shocks in Rapid Granular Flows”

Sunghwan Jung, The University of Texas at Austin, 2005

(now Assistant Professor at Virginia Tech University)

“Statistics of Turbulence in a Rapidly Rotating System”

Jori Elan Ruppert-Felsot, The University of Texas at Austin, 2005 (now at CitiBank, Tokyo)

“Coherent Structures and Two-Dimensionalization in Rotating Turbulent Flow”

Andrew T. Lee, The University of Texas at Austin, 2005
“Dynamics of a Single Sphere Sedimenting in a Fluid”

Matthew Thrasher, The University of Texas at Austin, 2007
(now at the Applied Research Laboratories, Austin)
“Geometry and Dynamics of Fluid-Fluid Interfaces”

Benjamin King, The University of Texas at Austin, 2010
“Laboratory and Numerical Studies of Internal Wave Generation and Propagation in the Ocean”

Bruce Rodenborn, The University of Texas at Austin, 2011
“The Fluid Dynamics of Flagellar Swimming by Microorganisms and Harmonic Generation by Reflecting Internal, Ocean-like Waves”