Universal mechanisms in non-equilibrium flows

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Three confined flows

- Gas ~ 10^{-6} m
- Molecular monolayers ~ 10^{-9} m
- Bubble rafts ~ 10^{-2} m

Mechanisms of stress relaxation due to dimensional confinement

VOLUME 81, NUMBER 8 PHYSICAL REVIEW LETTERS 24 AUGUST 1998

Coexistence of Buckled and Flat Monolayers

M. M. Lipp,[1] K. Y. C. Lee,[1] D. Y. Takamoto,[1] J. A. Zasadzinski,[1,*] and A. J. Waring[2]
[1]*Department of Chemical Engineering, University of California, Santa Barbara, California 93106*
[2]*MLK/Drew University Medical Center and Perinatal Labs, Harbor-UCLA, California 90059*
(Received 20 February 1998)

The minimum surface tension and respreadability of a surfactant monolayer is limited by a two to three dimensional instability called collapse. Liquid-condensed or solid phase monolayers collapse via
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islands
nplitude
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VOLUME 90, NUMBER 25 PHYSICAL REVIEW LETTERS week ending 27 JUNE 2003

Local Stress Relaxation and Shear Banding in a Dry Foam under Shear

Alexandre Kabla and Georges Debrégeas*
LFO–Collège de France, CNRS UMR 7125, Paris, France
(Received 27 November 2002; published 27 June 2003)

We have developed a realistic
transient, a shear-banding instab
obtained on real 2D (confined) f
response of the material to a singl
propose a scenario for the onset a
remain valid for most athermal a

DOI: 10.1103/PhysRevLett.90.258303

VOLUME 79, NUMBER 10 PHYSICAL REVIEW LETTERS 8 SEPTEMBER 1997

Bistability and Competition of Spatiotemporal Chaotic and Fixed Point Attractors in Rayleigh-Bénard Convection

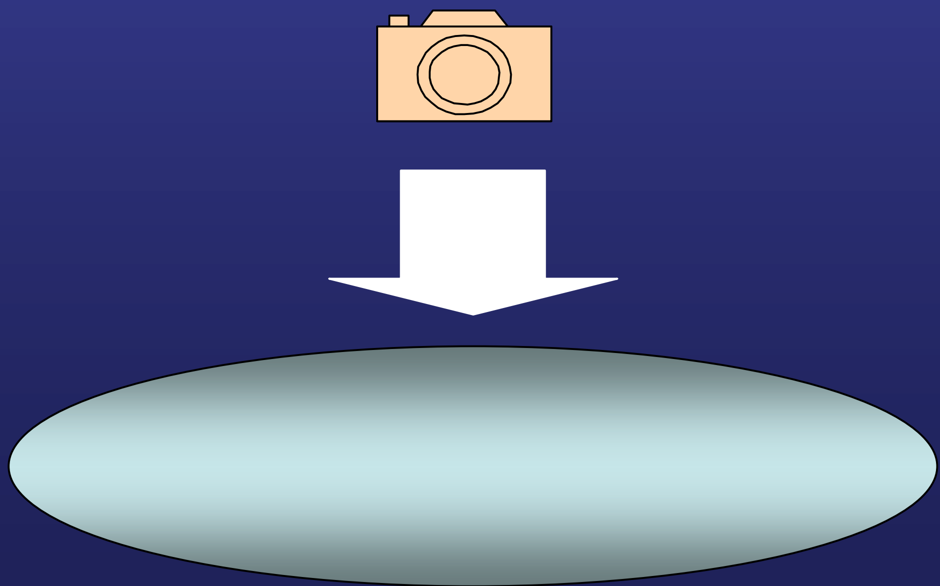
Reha V. Cakmur,* David A. Egolf,† Brendan B. Plapp, and Eberhard Bodenschatz‡
Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, New York 14853-2501
(Received 21 February 1997; revised manuscript received 28 May 1997)

For Rayleigh-Bénard convection in a square cell with a fluid of Prandtl number $\sigma \approx 1$, we report experimental results on the bistability of the spatiotemporal chaotic state of spiral defect chaos (SDC) and a stationary state of ideal straight rolls (ISR). We present the first large aspect ratio experimental confirmation of the theoretical prediction of stable ISR in the parameter regime where typical initial conditions lead to SDC. As a function of the control parameter and for typical experimental initial conditions, we also find a transition in the selection between SDC and ISR which is mediated by front propagation. We characterize the transition with two measures, the spatial correlation length and the spectral pattern entropy, and find that the transition shows similarities to equilibrium phase transitions. [S0031-9007(97)04007-6]

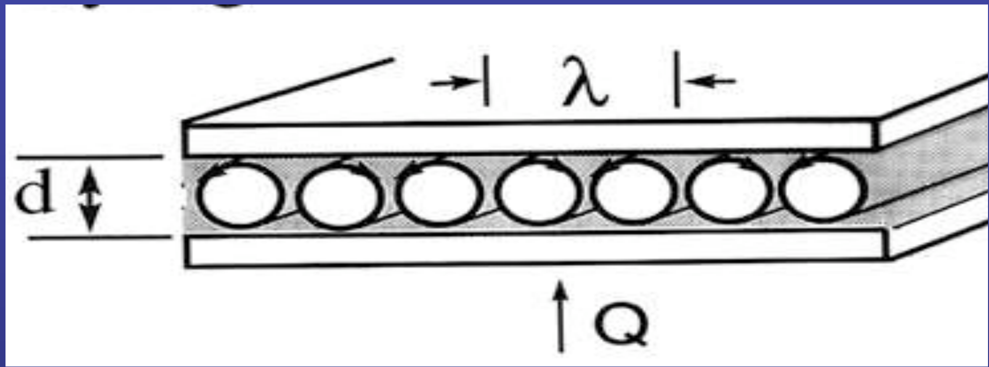
PACS numbers: 47.54.+r, 47.20.Lz, 47.27.Te, 47.52.+j

Experimental geometry

- Primarily dynamics confined to a narrow gap (2-dimensional surface)
- Experimental observation from a point looking down perpendicular to this surface



Rayleigh Benard Convection

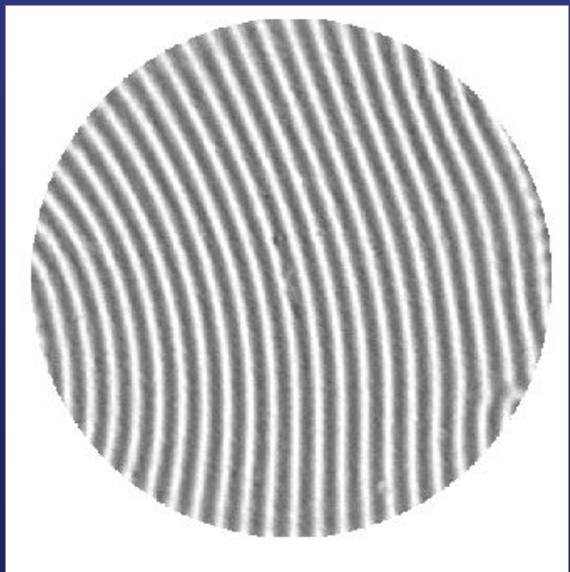


$\lambda = 2d$

Convection occurs when

$\Delta T > \Delta T_c$

$\varepsilon = \Delta T / \Delta T_c - 1$



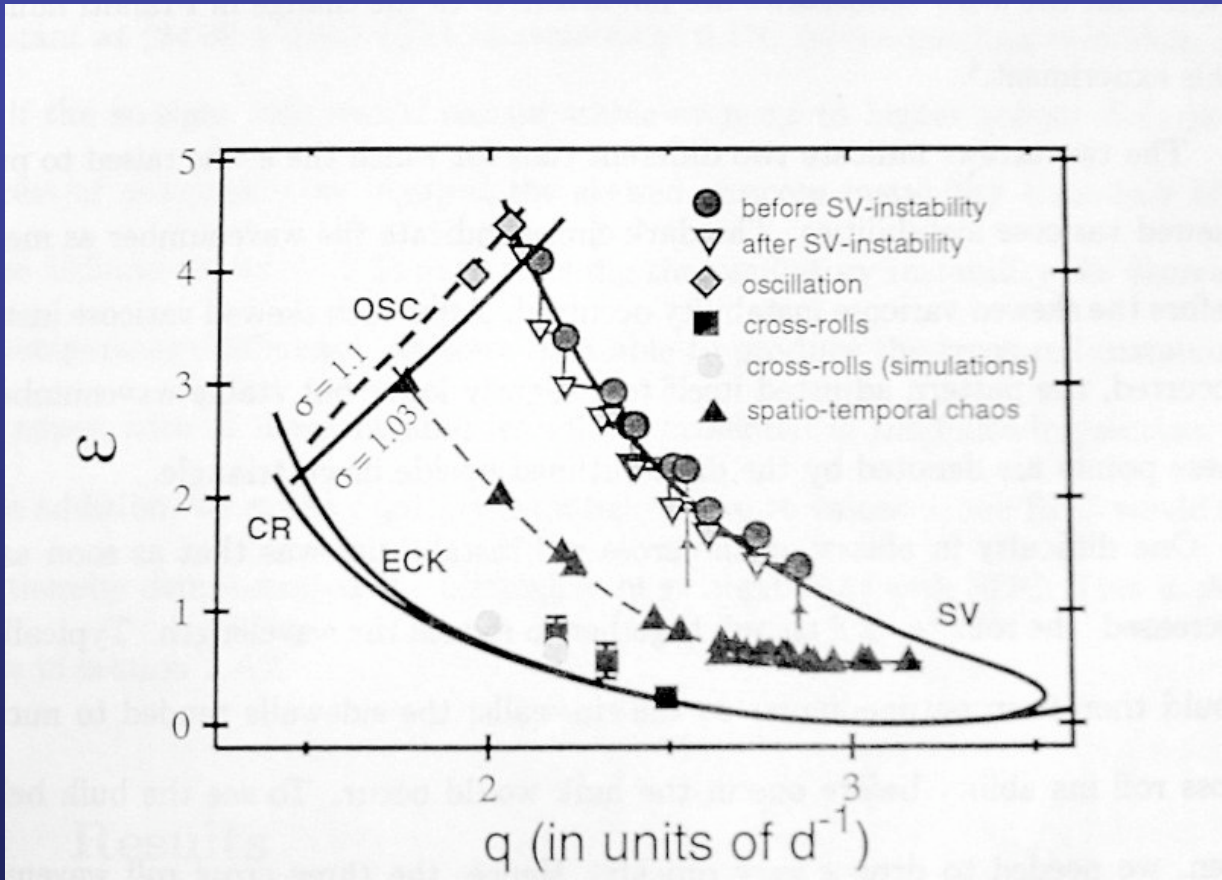
$R = \alpha g d^3 \Delta T / \nu\kappa$

α Thermal expansion

ν, κ Viscous, thermal dissipation

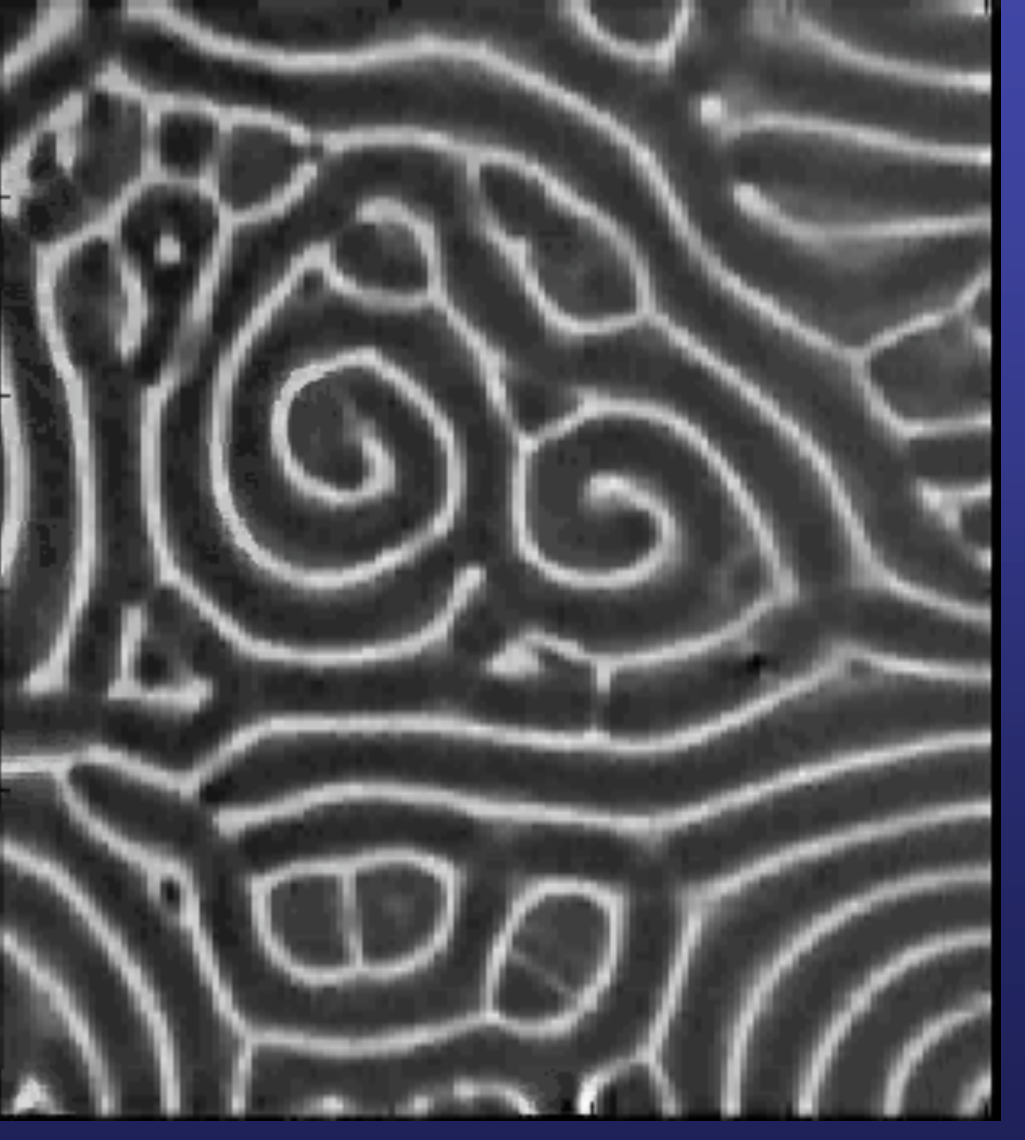
d Depth of fluid layer

Stability regime

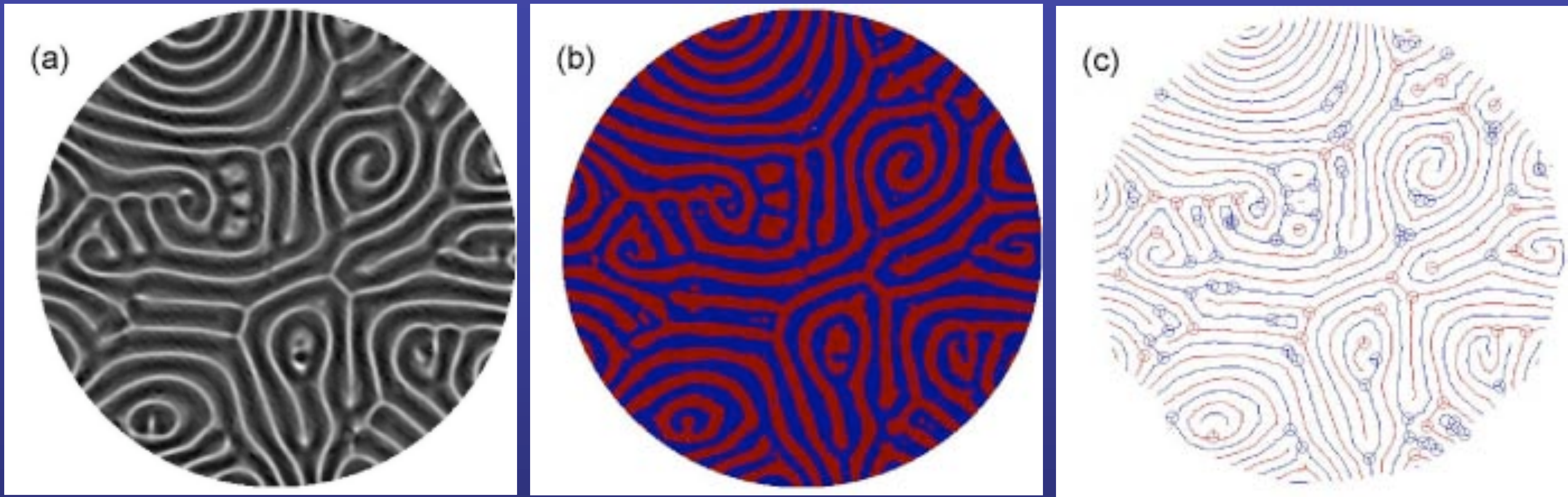


PhD Thesis of Brendon B. Plapp 1997

Spiral Defect Chaos



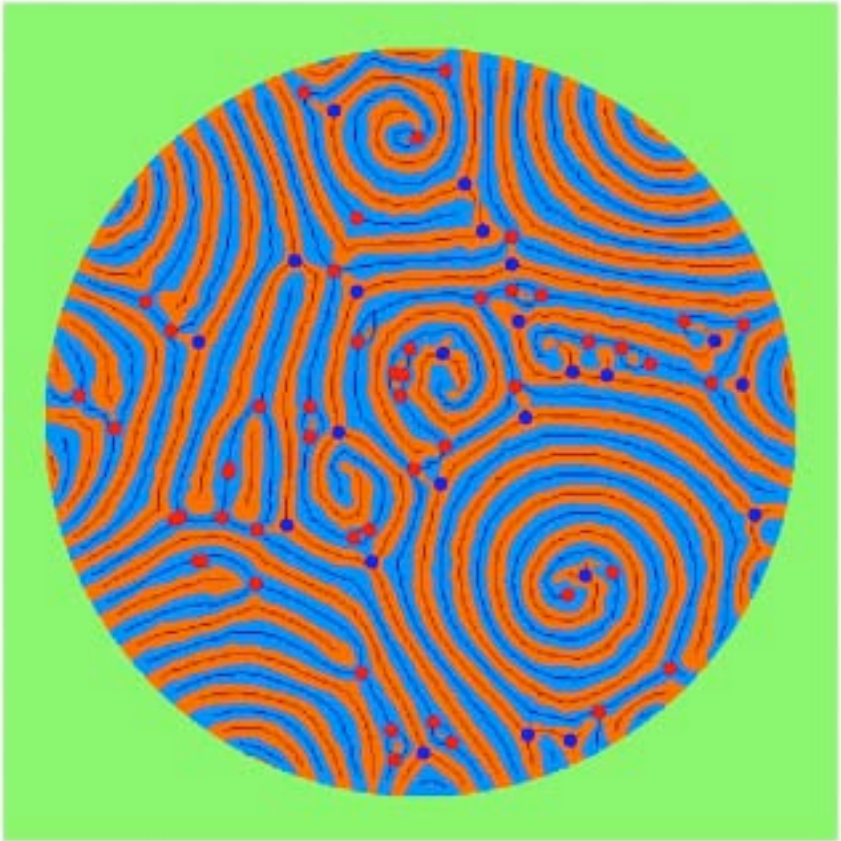
Coarse grained dynamics



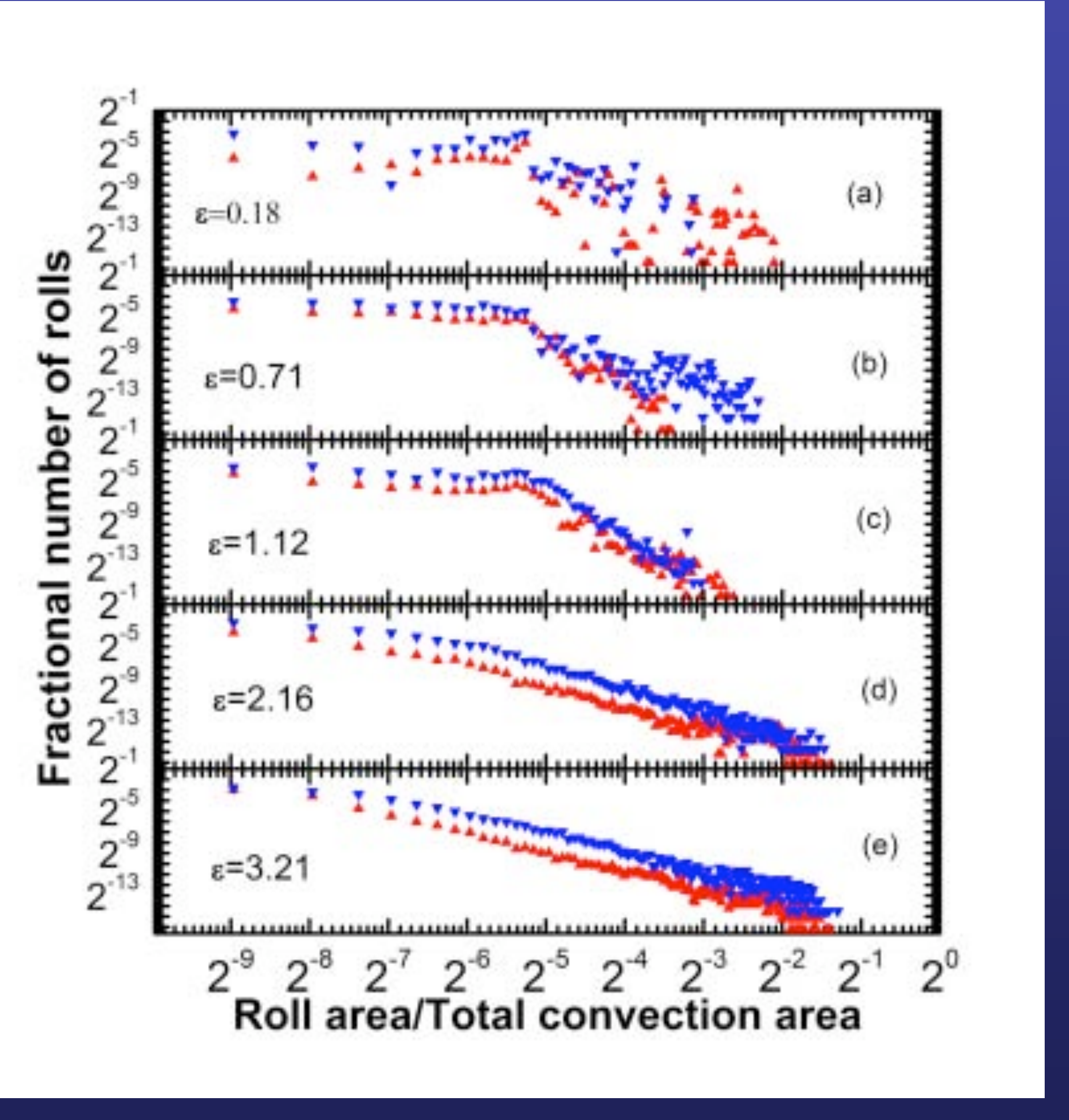
- Hierarchies of defect interaction in network structure
- Packing of multi-scale structure

K.Krishan, *Network structure of chaotic patterns (arXiv:0705.1993)*
K.Krishan, et. al., *Homology and symmetry breaking in Rayleigh Benard Convection, Phys. of Fluids **19**,117105, 2007*

Topological structure



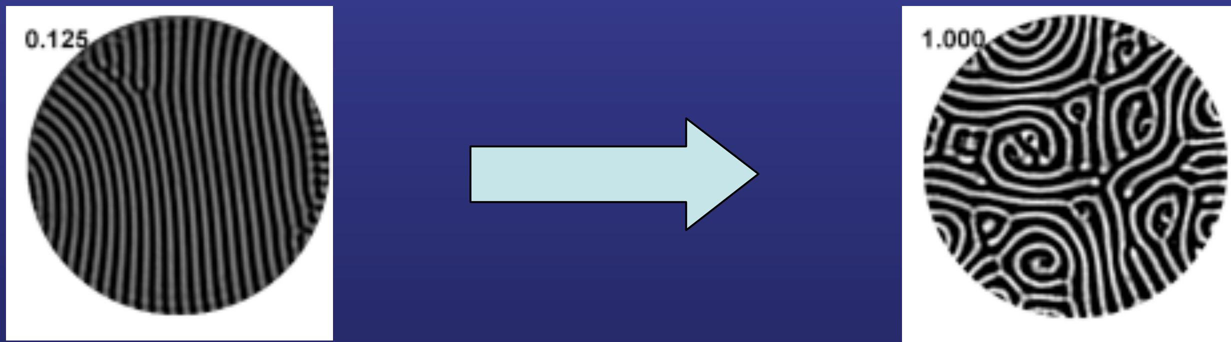
Scaling behavior in roll sizes



K.Krishan, *Importance of packing in spiral defect chaos (Pramana Vol 70, No 4, 669-678(2008))*

Sequence of instabilities

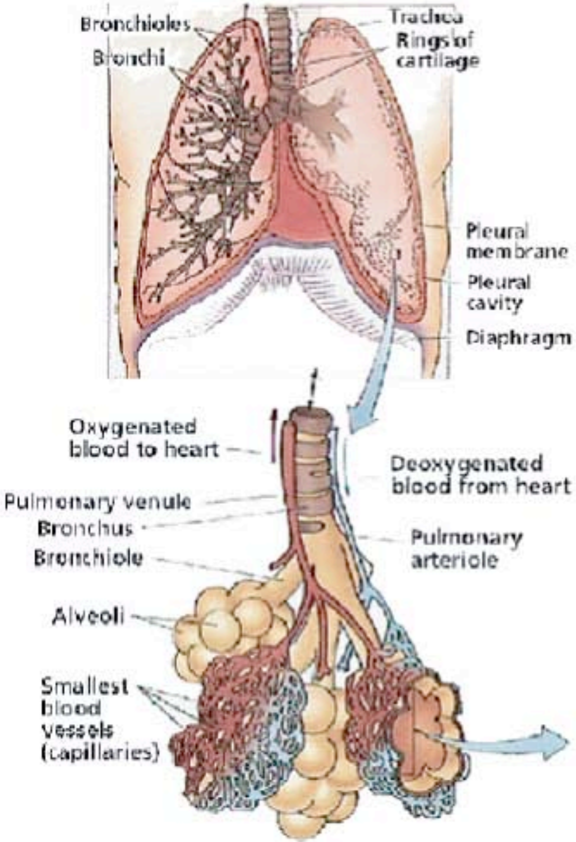
- Conduction to convective rolls
  --- Uniform stationary pattern
- Convection to weakly turbulent pattern
  --- Time dependent pattern



Local instabilities break the symmetries of the previous uniform stationary state.

Lung surfactants

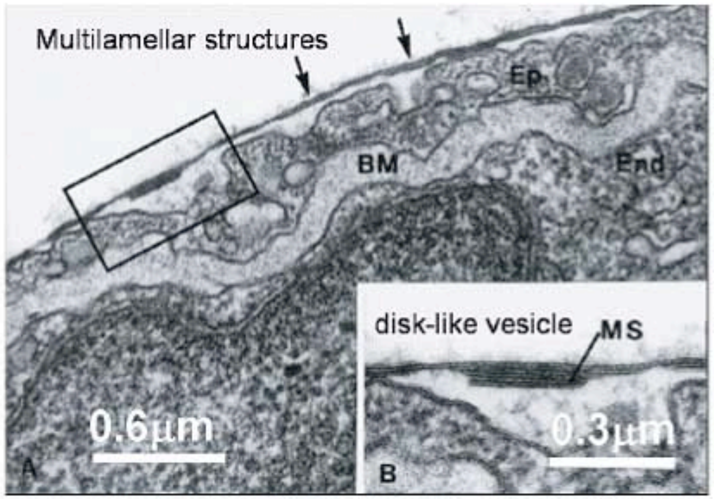
Lung Surfactant - The Air/Fluid Interface



http://gened.emc.maricopa.edu/bio/bio181/BIOBK/BioBookRESPSYS.html

Alveolar surface films containing lipids and proteins operate at nearly zero surface tension to facilitate the dynamic process of breathing.

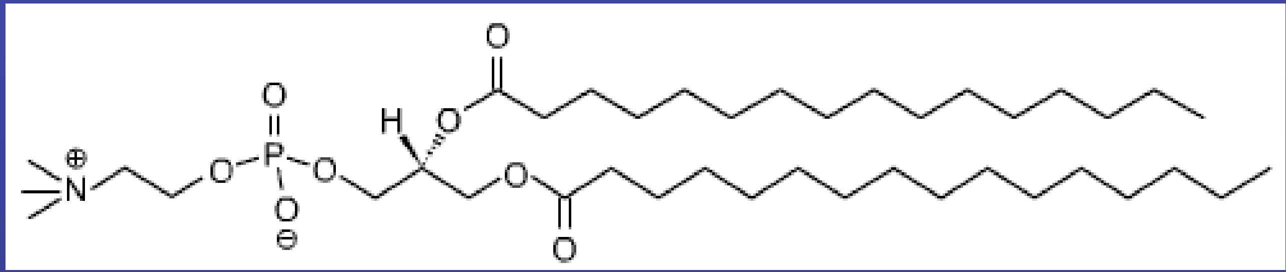
The formation of reversible 3d reservoirs from the interfacial film during the breathing cycle is thought to economize the loss of material from the surface during this dynamic process.



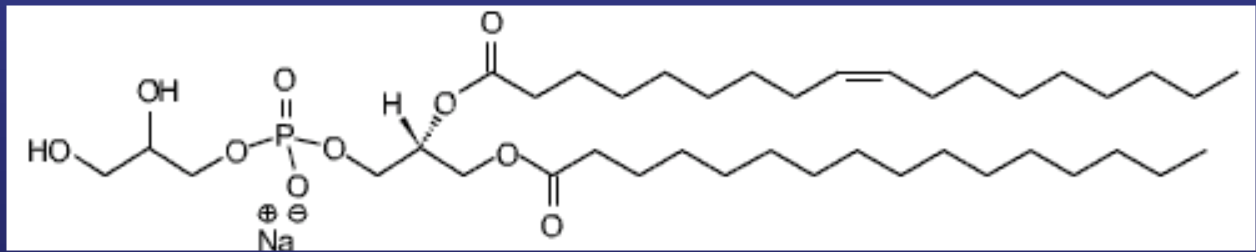
Alveolar fluid-air interface of a guinea pig lung showing coexistence of monolayers with multilamellar 3d structures

(Schürch, Green and Bachofen, BBA, 1408, 2-3, pp180-202, 1998)

System used

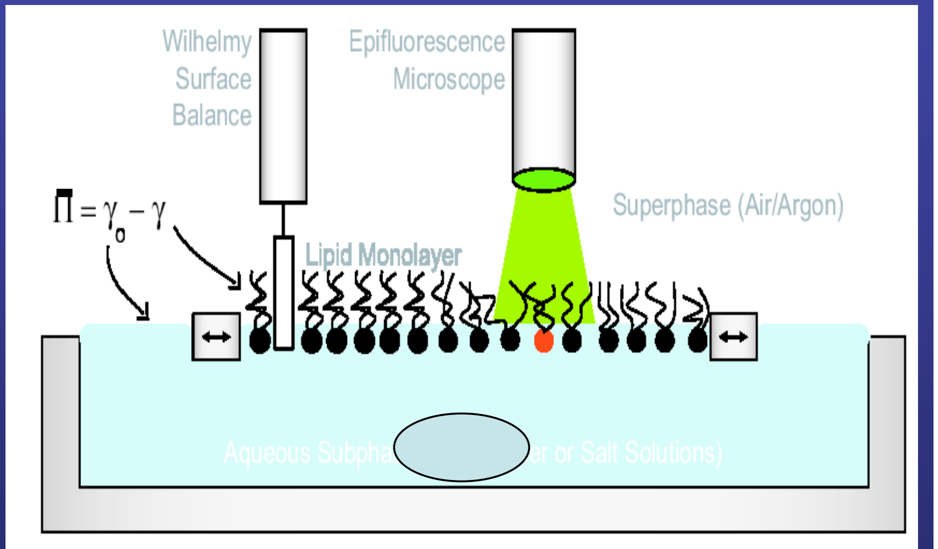


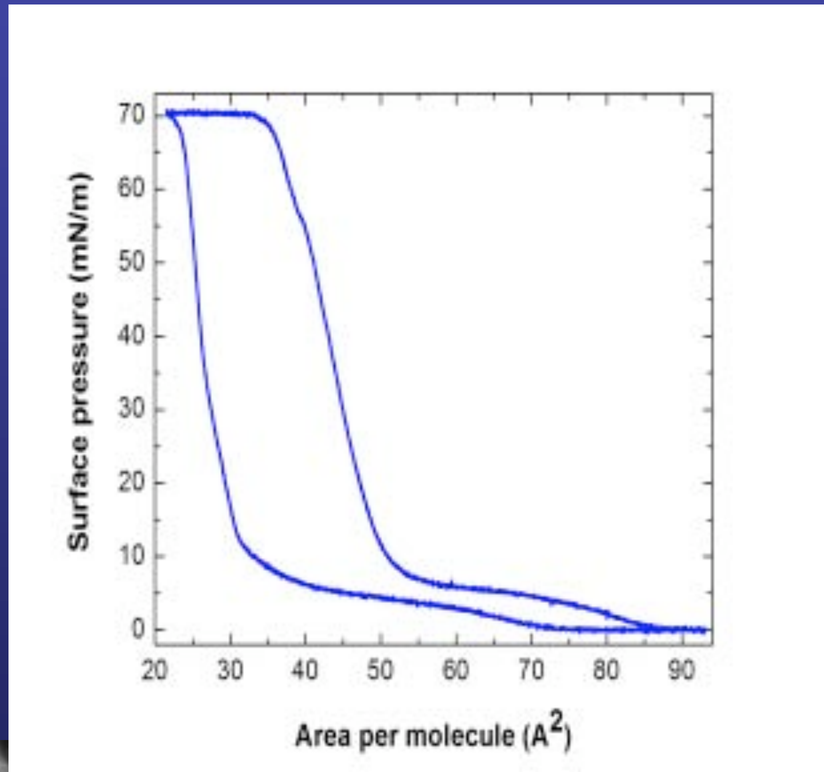
DPPC: $C_{40}H_{80}NO_8P$



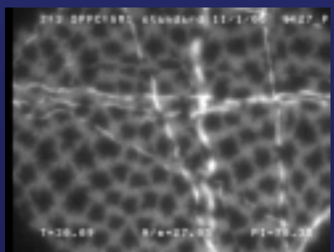
POPG: $C_{40}H_{76}O_{10}PNa$

Langmuir Monolayers

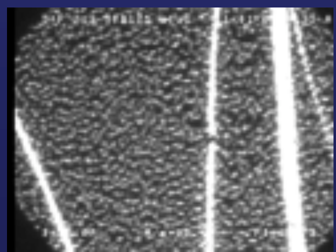




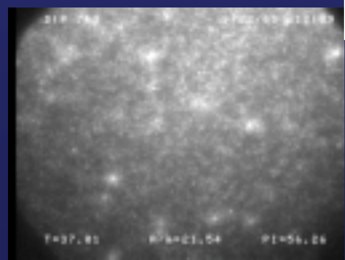
cracks
(irreversible)



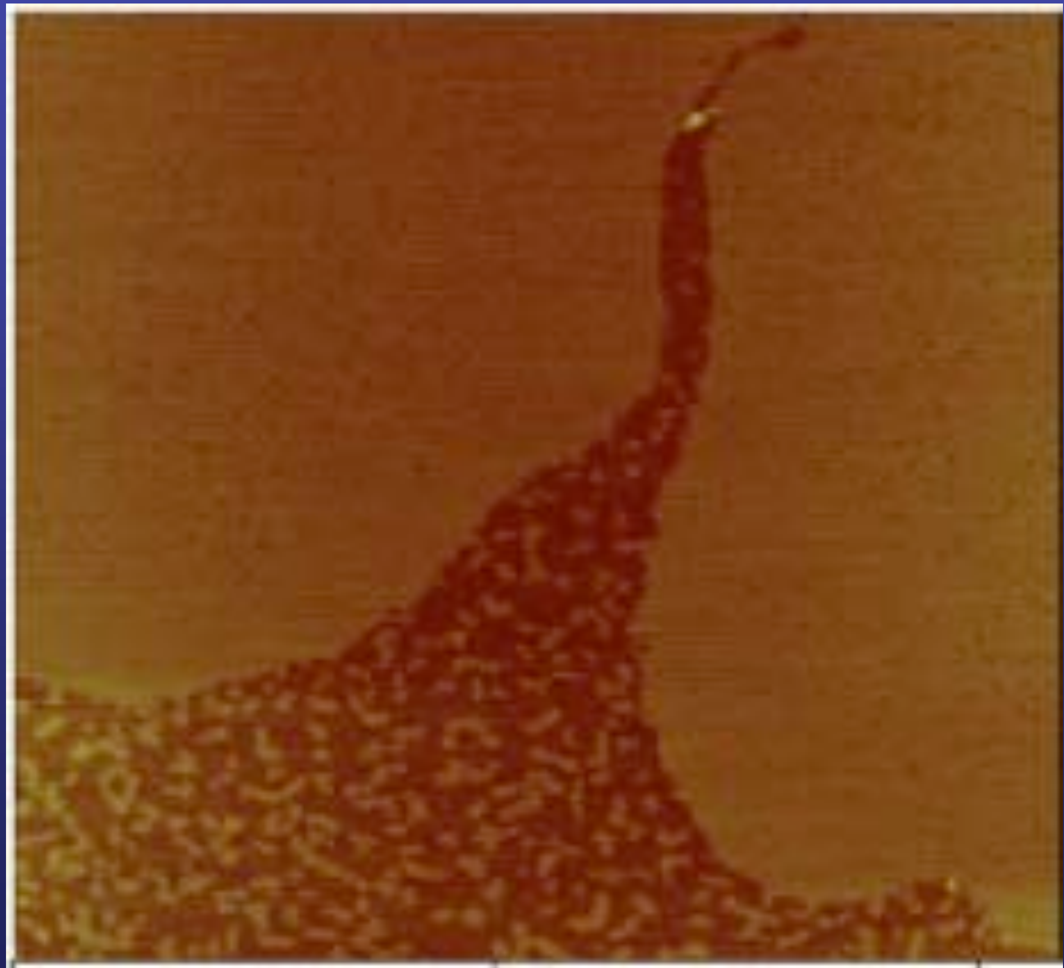
folds



vesicles
(irreversible)



Microstructure



L.Pocivavsek et. al, *Lateral stress relaxation and collapse in Lipid monolayers (Soft Matter 2008)*

Cascades of local instabilities lead to inherent “scaling” of dynamics

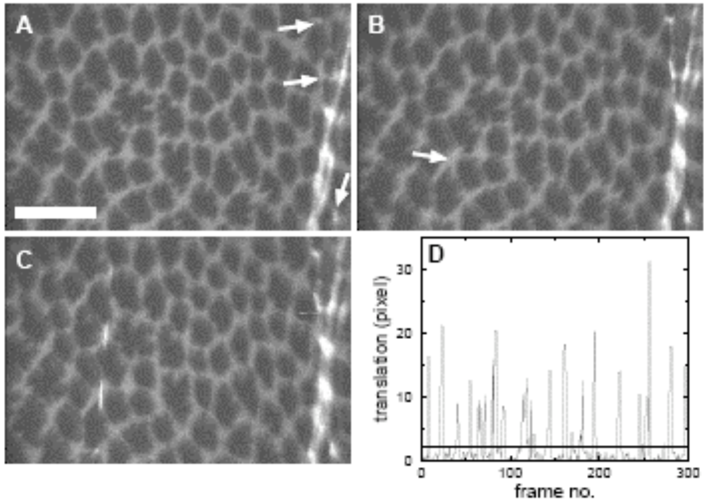


FIG. 1: (a)–(c) Fluorescence micrographs separated by 1/30 s intervals, showing the nearly-simultaneous formation of two folds. The images are blurred by monolayer motion. The scale bar length is 50 μm. (d) Typical output of the tracking program, showing the monolayer translation within the field of view in sequential video frames. The spikes correspond to folding events occurring out of view. The dotted line shows the threshold used for event identification.

Chain-reaction cascades in surfactant monolayer buckling

Ajaykumar Gopal,[1] Vladimir A. Belyi,[2] Haim Diamant,[3,*] Thomas A. Witten,[2] and Ka Yee C. Lee[1]

[1] *Department of Chemistry and James Franck Institute, University of Chicago, Chicago, Illinois 60637*
[2] *Department of Physics and James Franck Institute, University of Chicago, Chicago, Illinois 60637*
[3] *School of Chemistry, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel*

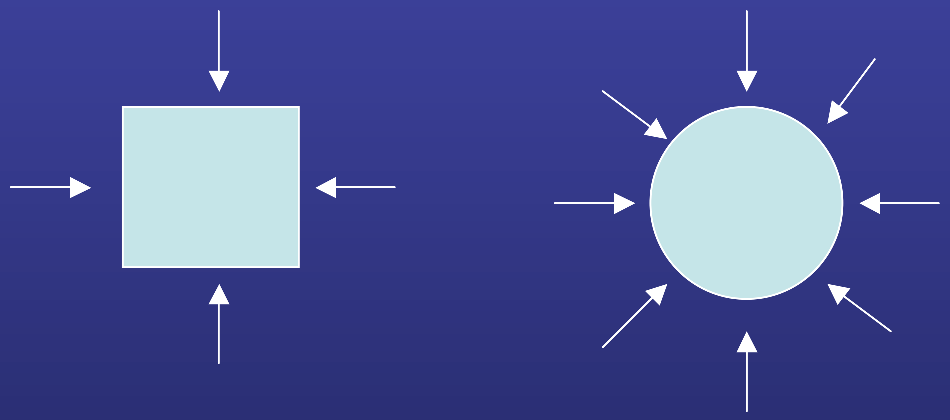
(Dated: September 6, 2004)

Certain surfactant monolayers at the water–air interface have been found to undergo, at a critical surface pressure, a dynamic instability involving multiple long folds of micron width. We exploit the sharp monolayer translations accompanying folding events to acquire, using a combination of fluorescence microscopy and digital image analysis, detailed statistics concerning the folding dynamics. The motions have a broad distribution of magnitudes and narrow, non-Gaussian distributions of angles and durations. The statistics are consistent with the occurrence of cooperative cascades of folds, implying an autocatalytic process uncommon in the context of mechanical instability.

PACS numbers: 68.18.Jk, 64.60.Qb, 82.60.Nh, 87.68.+z

Influence of global compression

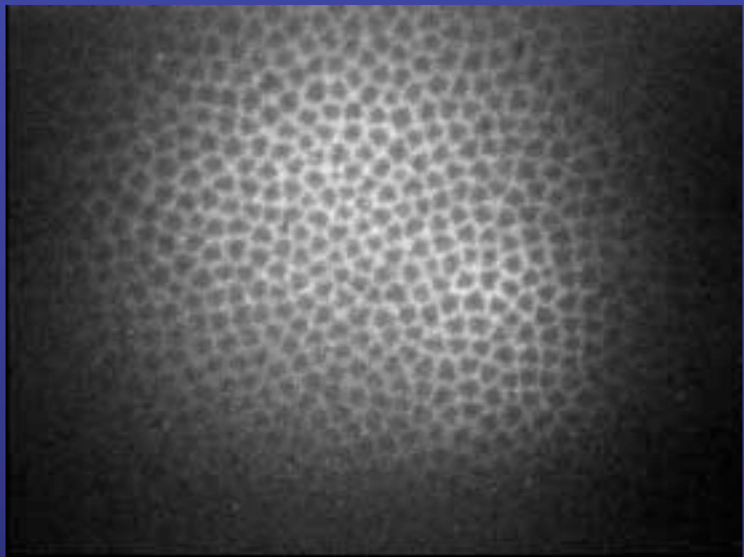
Compressive forces, F, needed are higher by about 50% for buckling of thin circular plates as compared to a square sheet.



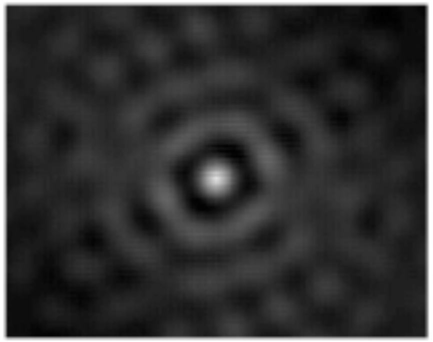
$F = \pi^2 D/a^2$ $\quad\quad$ $F = 14.7\ D/a^2$

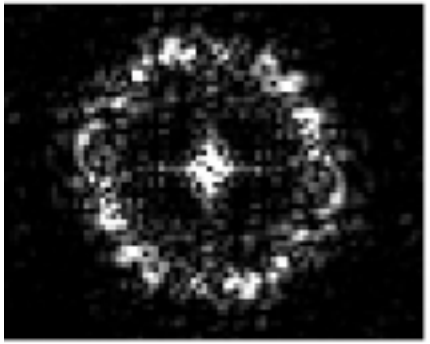
D : Flexural rigidity of the plate; includes material properties such as elasticity.
a : size of the plate, diameter in case of the circular geometry and the length of a side side for a square geometry.

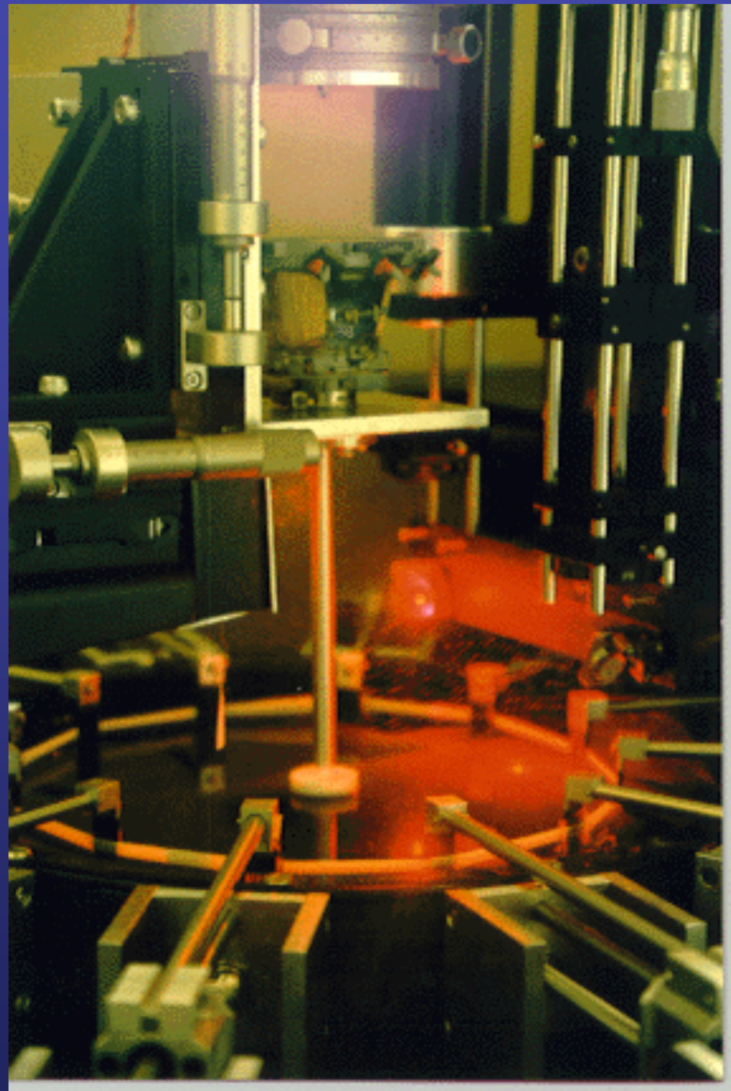
Microstructure



<ρ(x..)ρ(x..,+..,+..)> S(q)



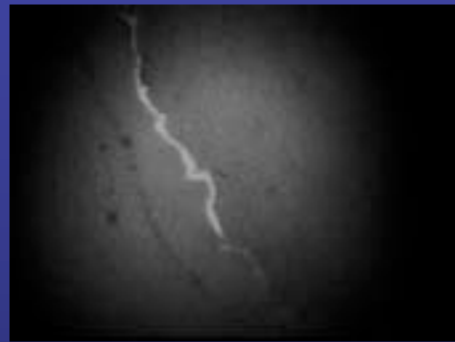




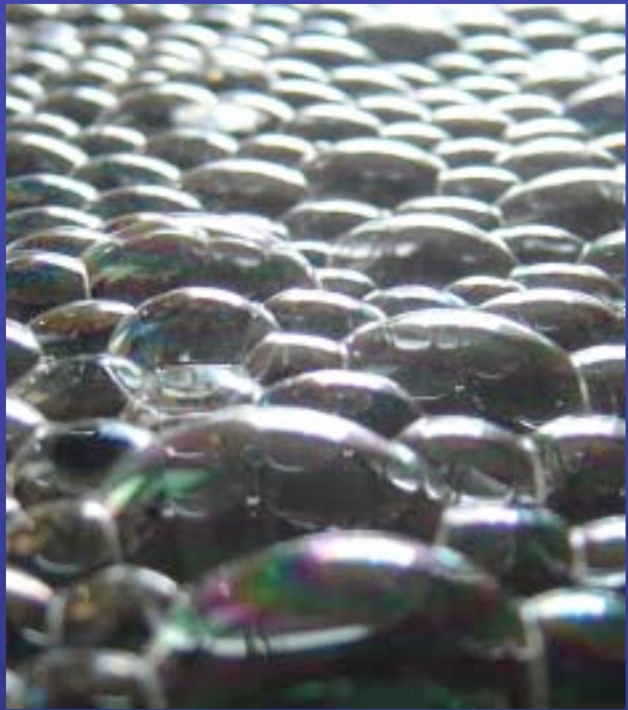
•Symmetry of domain packing changes even at low pressures.

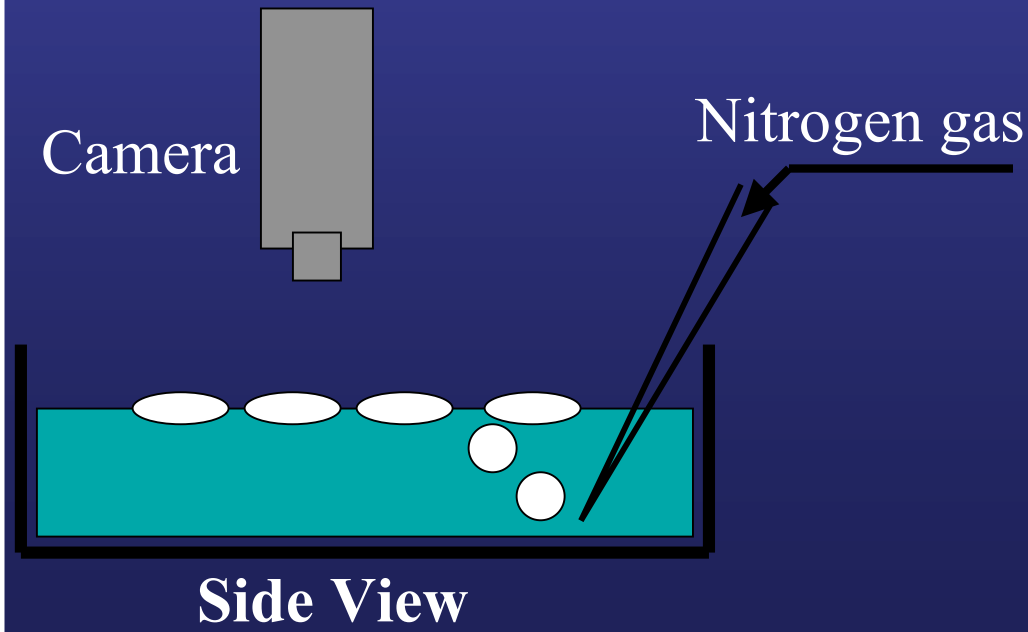
Infrequent structures

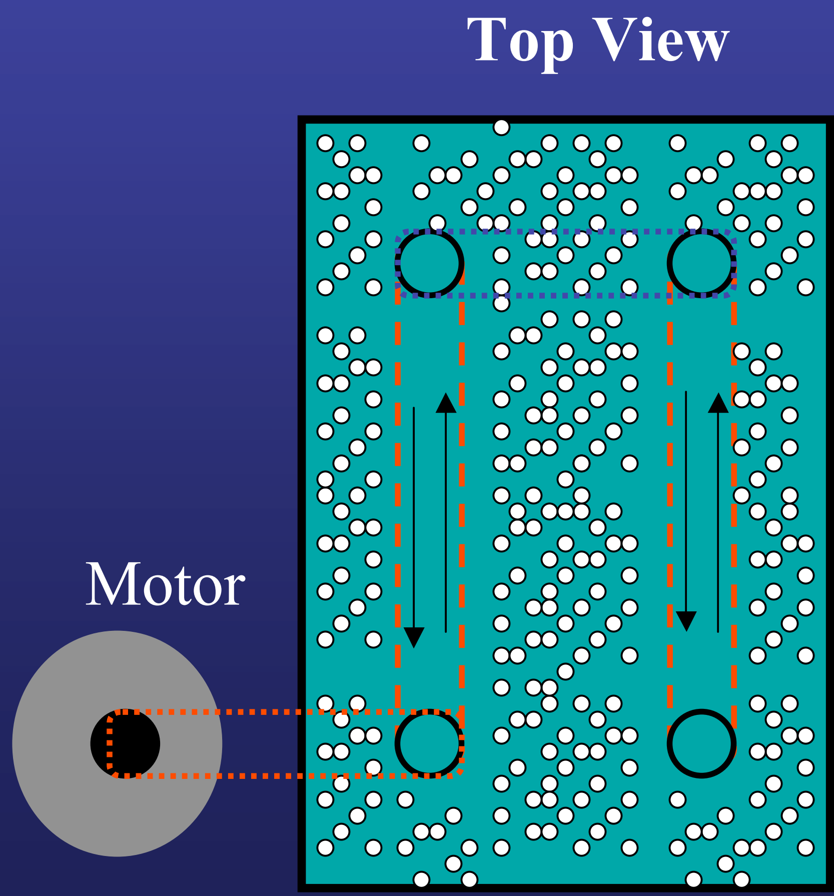




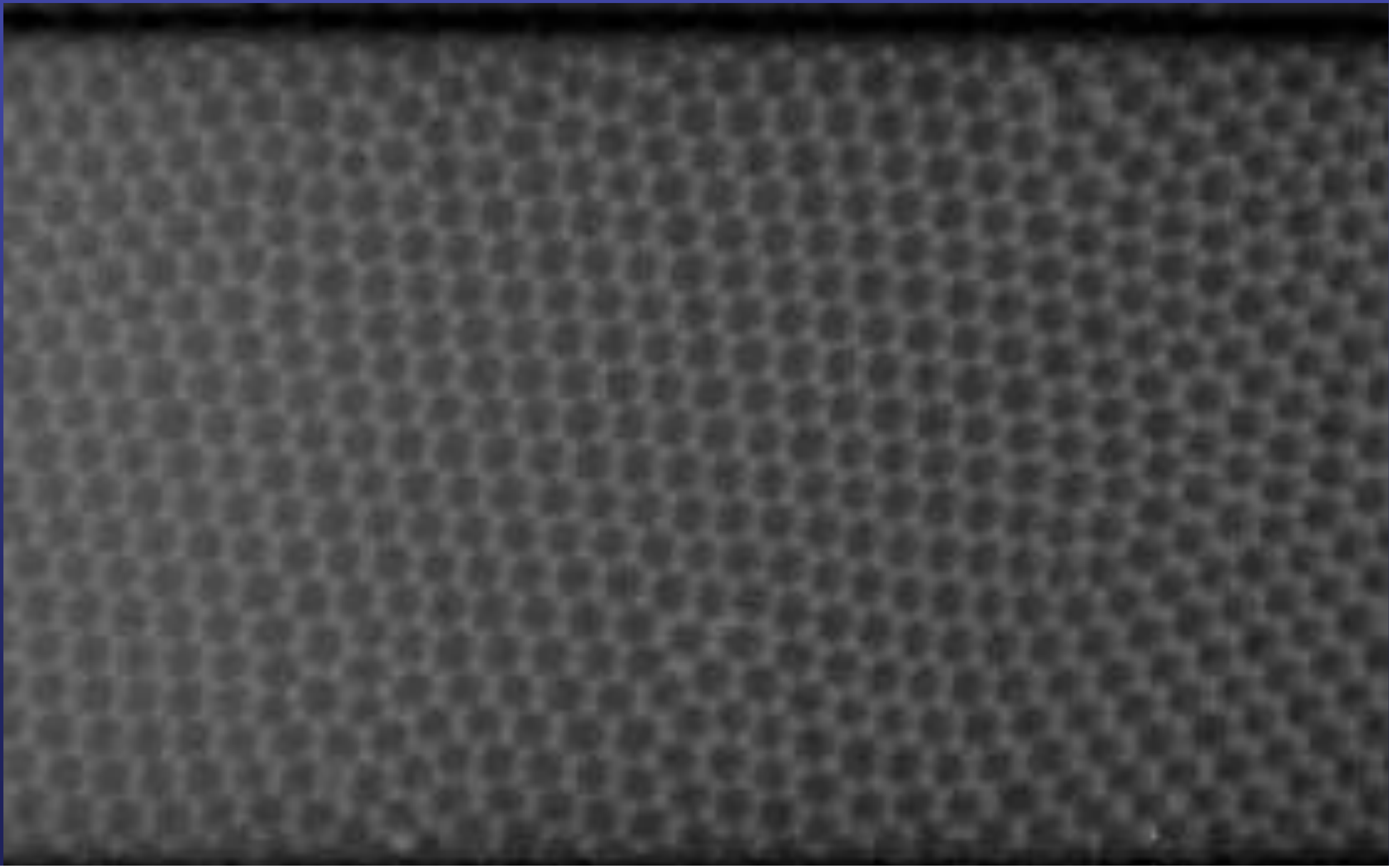

Sheared bubble rafts



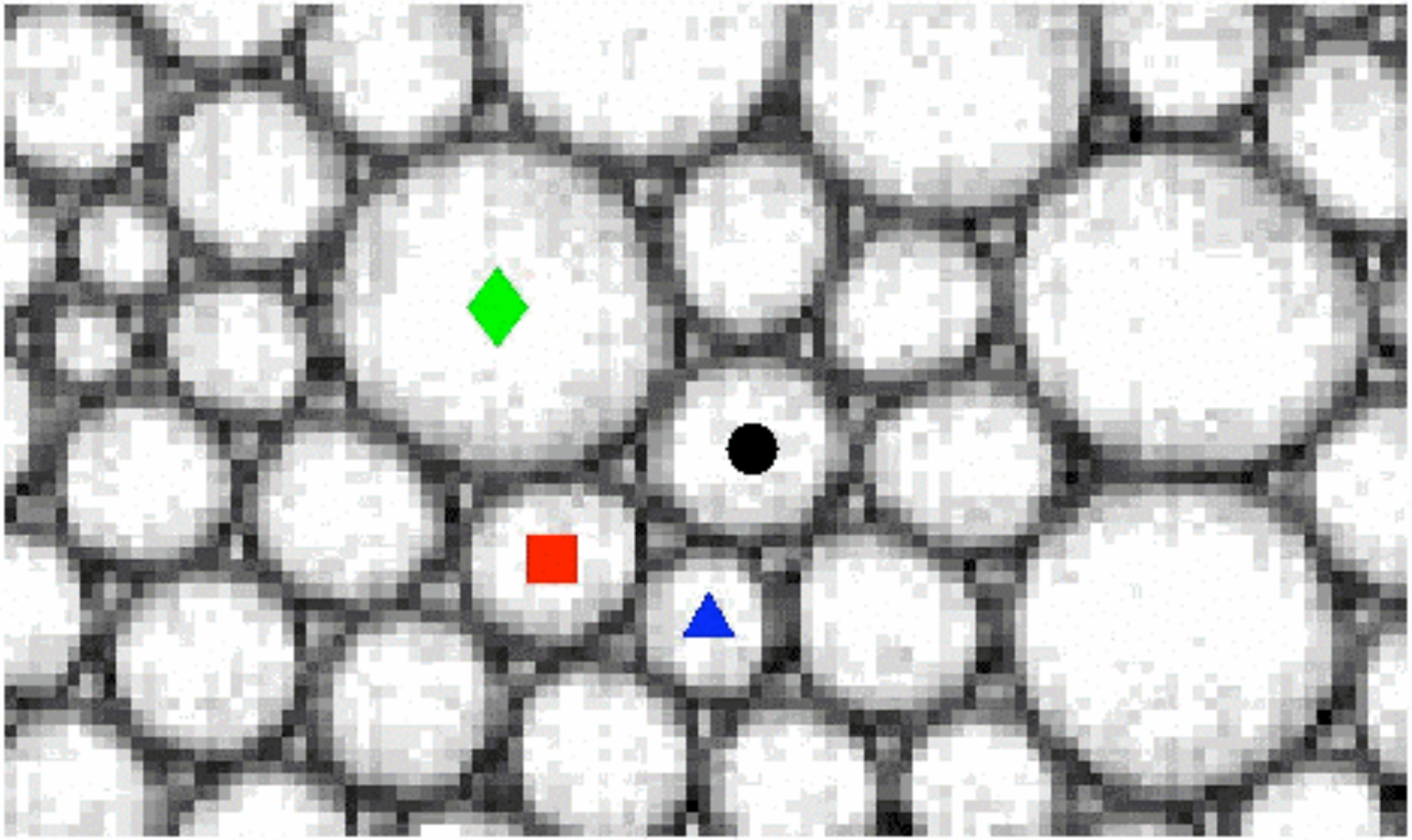




What we see…

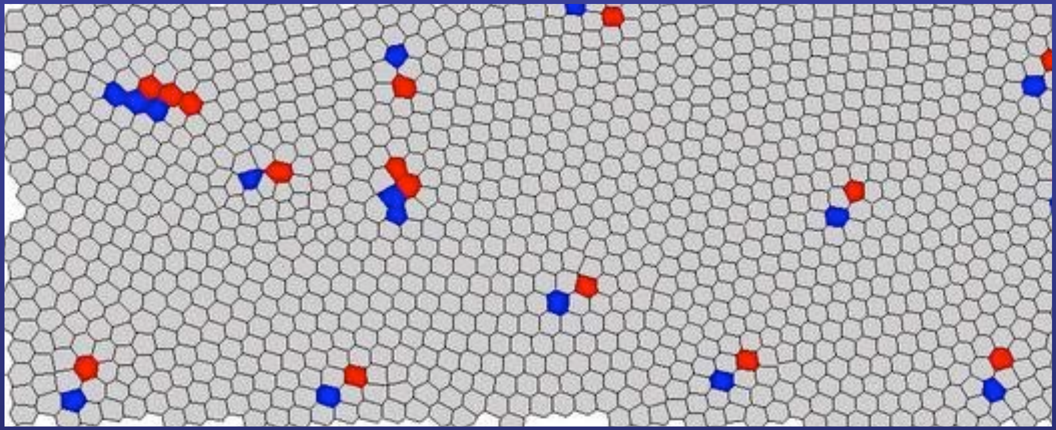


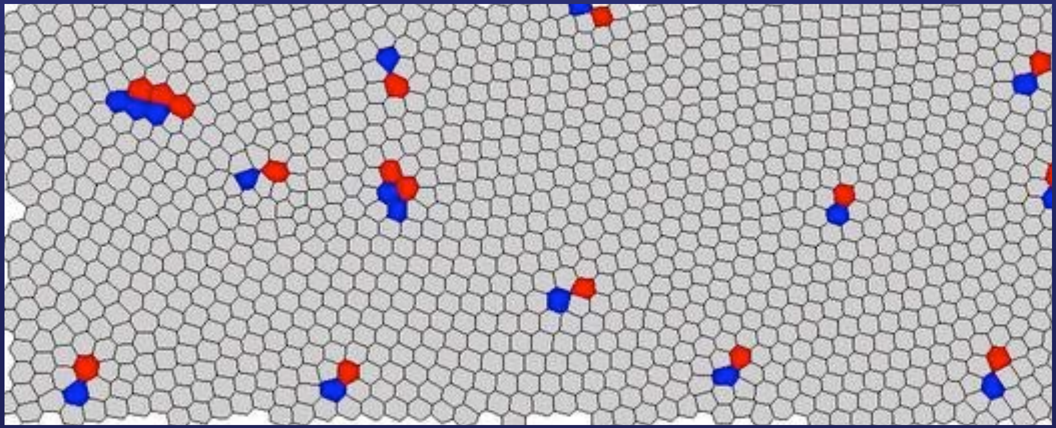
Response to local stress – T1 events = plasticity



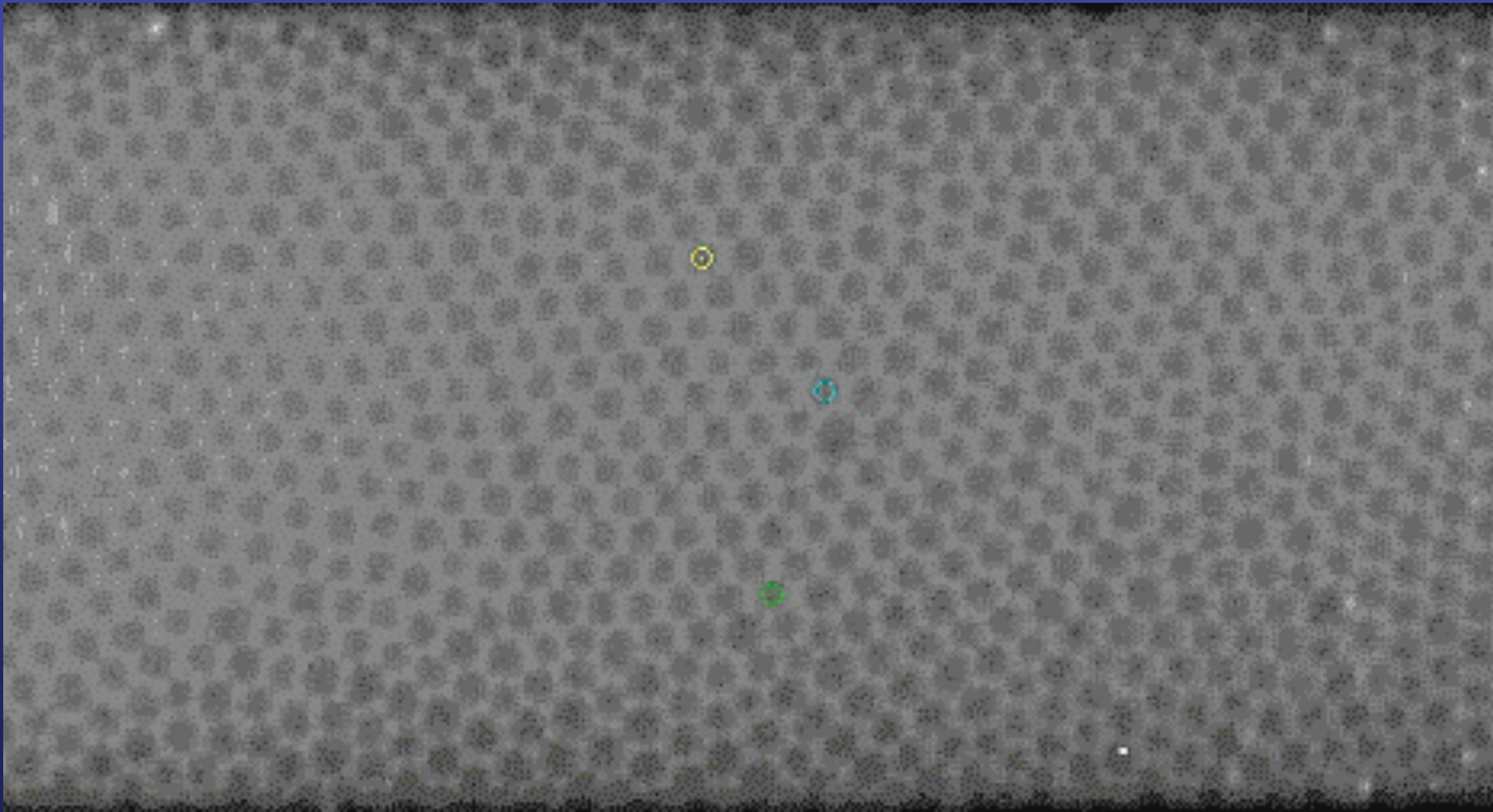
System-wide fluctuations

- Flow induced vs. thermal fluctuations

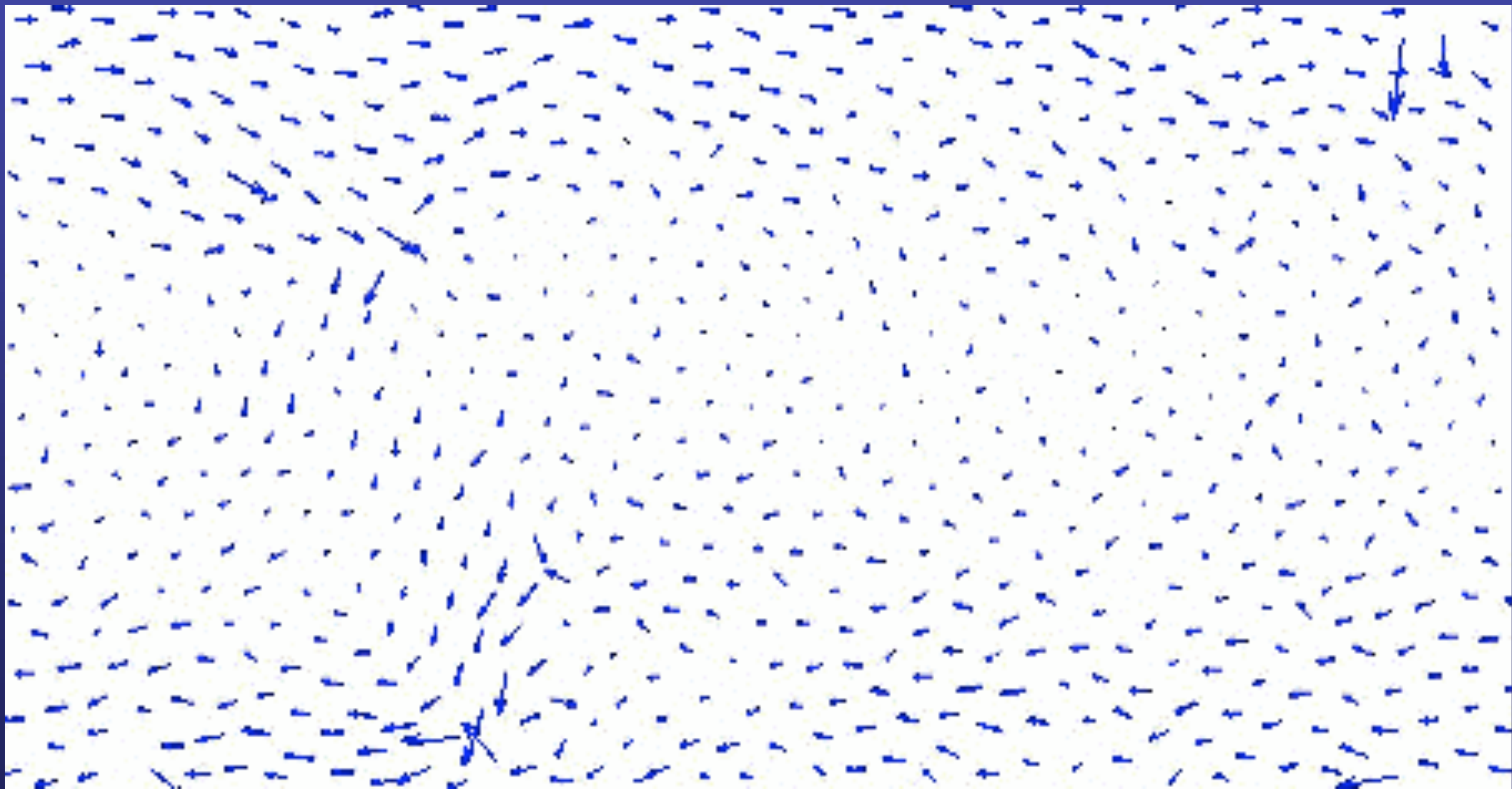




Bubble trajectories

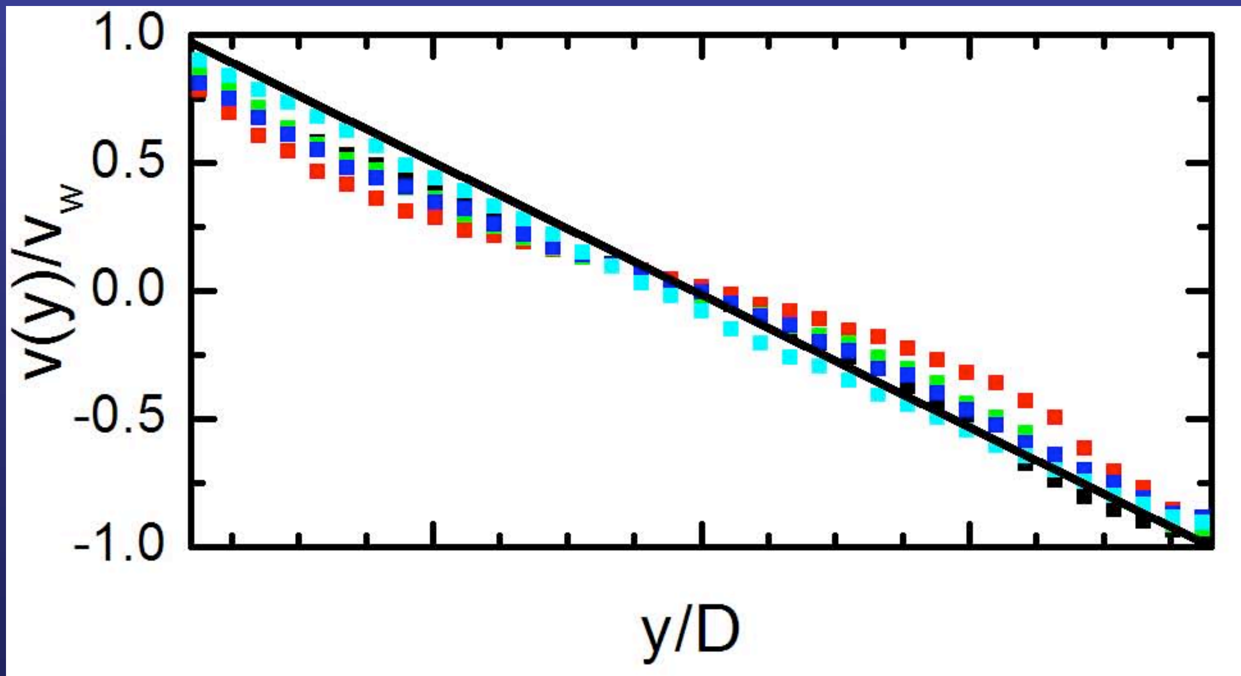


Velocity field

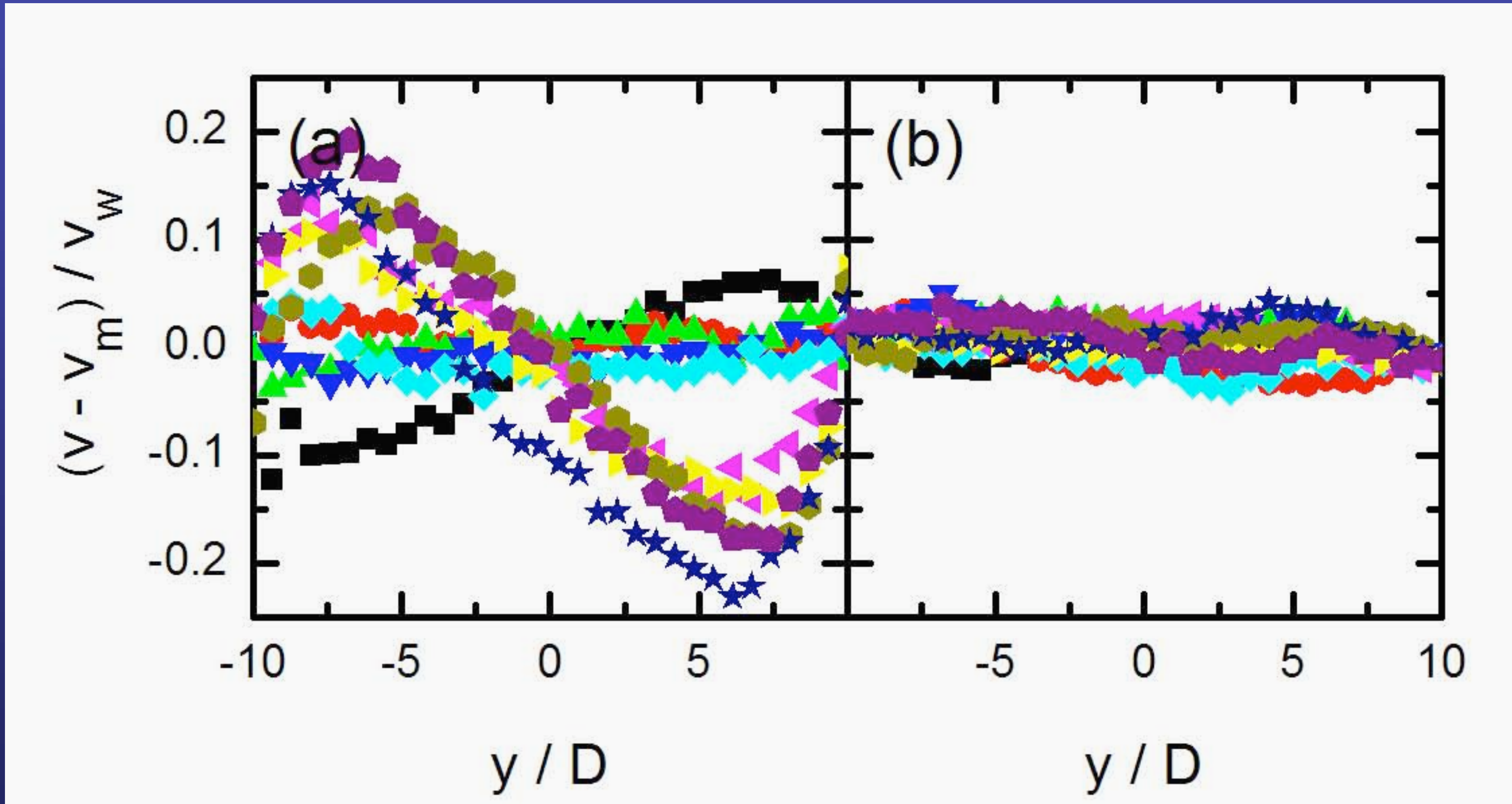


Velocity profile along shear

- Sampled across single realizations

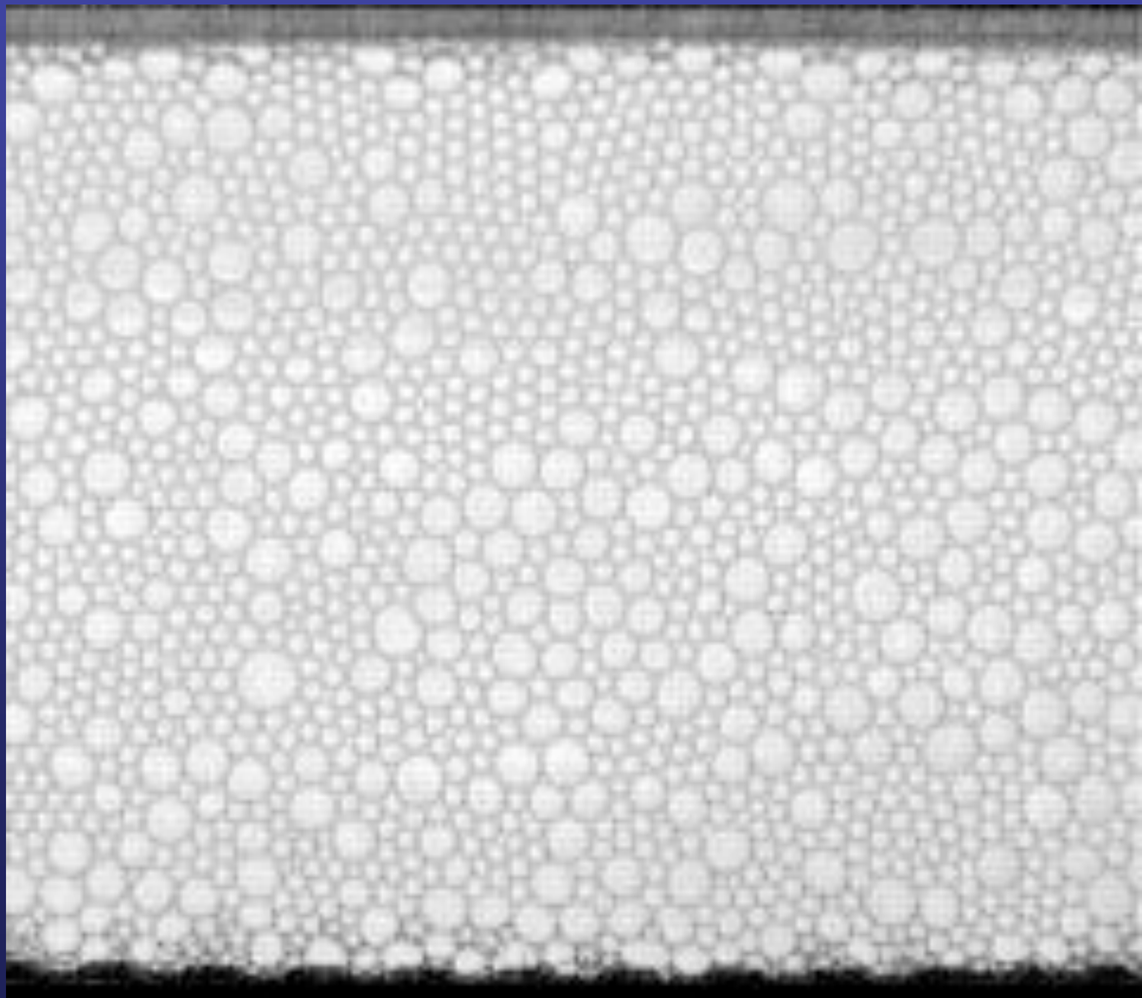


Velocity deviation from mean



Y.Wang et. al, *Limits of time and ensemble averages in shear flows,* Phys. Rev. Lett. ***98, 220602 (2007)***

Coexistance of elastic and plastic regions



Common themes

- Confinement causes focusing of stresses in the system.
- Local stress relaxation mechanism determines large scale structure of flow
- The relaxation often lead to breaking of base state symmetries
- In all three examples, there is coexistence of the state with broken symmetry and the base state
- Power law behavior – avalanche of folds in monolayers, power law fluid in foam, power law scaling in convection roll lengths.

Acknowledgements

- Spiral Defect Chaos

  Michael Schatz, Roman Grigoriev, Konstantin Mischaikow, Marcio Gameiro, Andreas Handel
- Langmuir Monolayers

  Luka Pocivavseck, Ka Yee Lee, Michael Dennin, Shelli Frey, Haim Diamant
- Bubble rafts

  Michael Dennin, Yuhong Wang, Micah Lundberg
- Funding

  Department of Energy, Institute for Complex Adaptive Matter, National Science Foundation