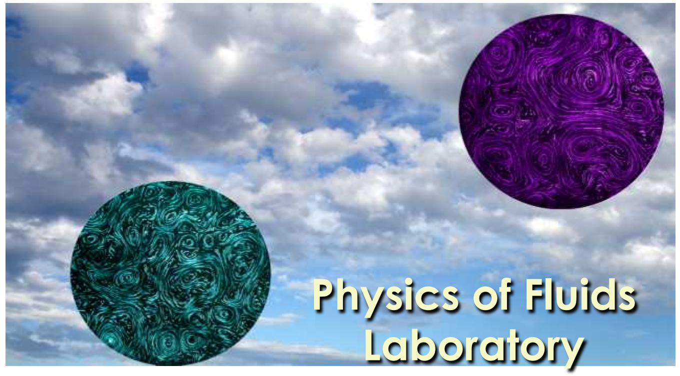

Turbulence on the water surface and vorticity generation by waves

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Canberra, Australia

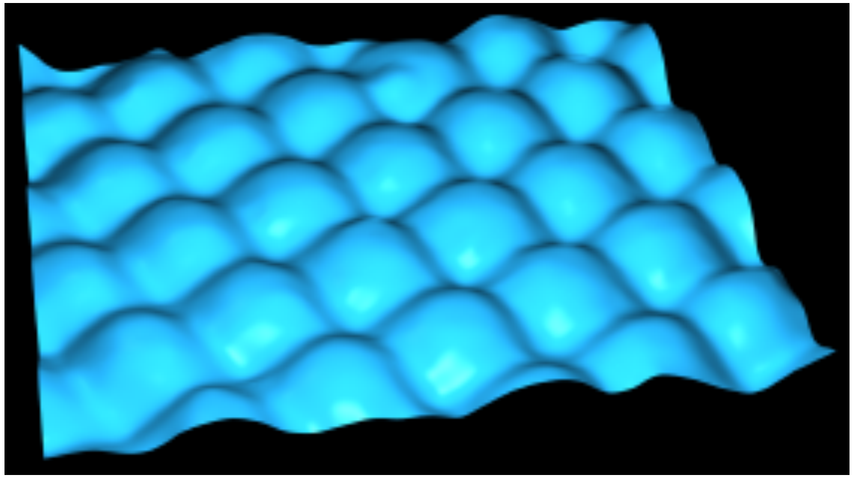
Collaborators: H. Xia, N. Francois, H. Punzmann, G. Falkovich

2D turbulence in Faraday waves: turbulent horizontal fluid motion

Faraday waves as a lattice of oscillons

Supercritical acceleration:

lattice of oscillons

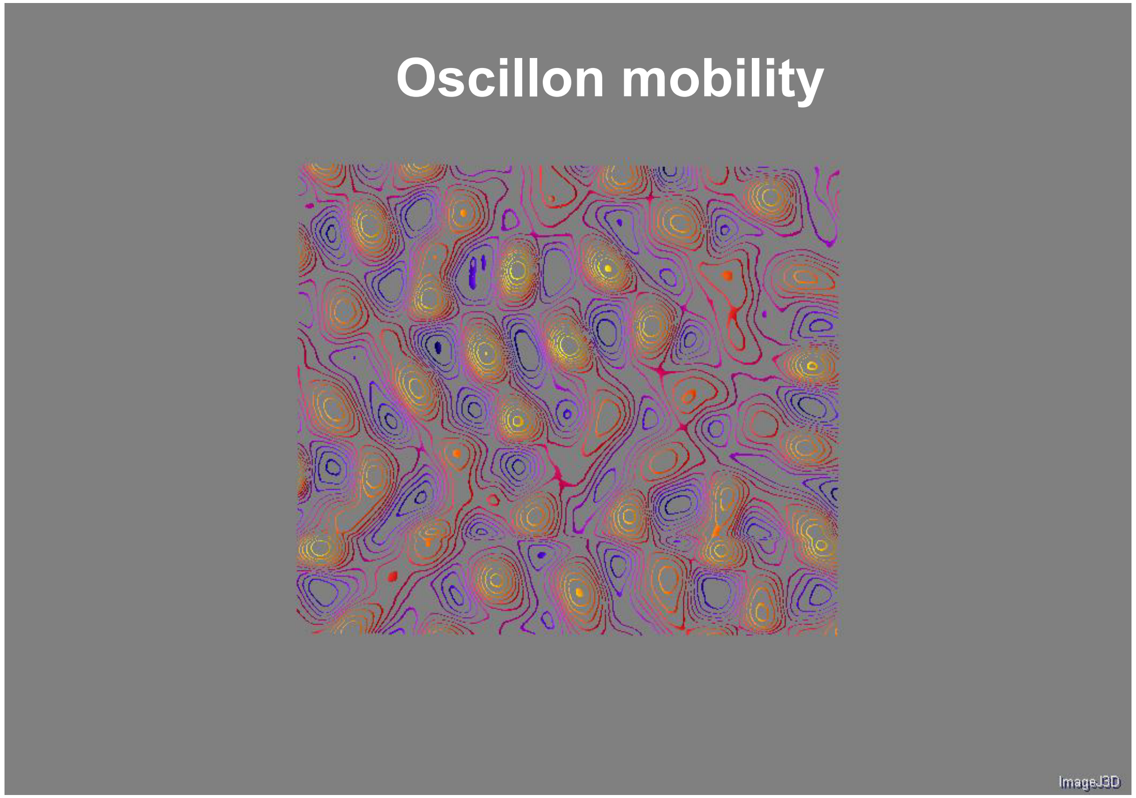


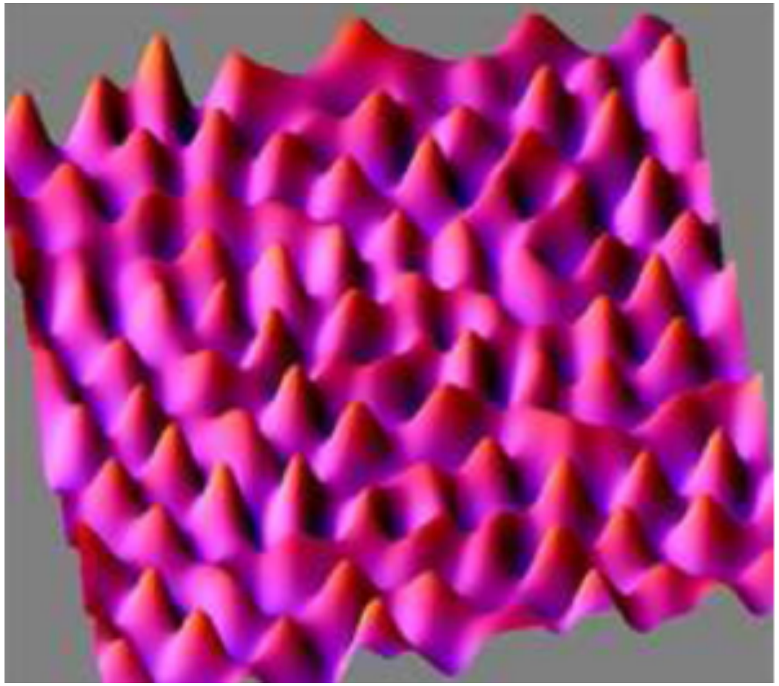
Subcritical acceleration: individual oscillon

Glycerol-water solution, high viscosity (190 mPa.s), acceleration 3.1g

Shats, Xia, Punzmann, *Phys. Rev. Lett.* **108**, 034502 (2012)

In water lattices become disordered





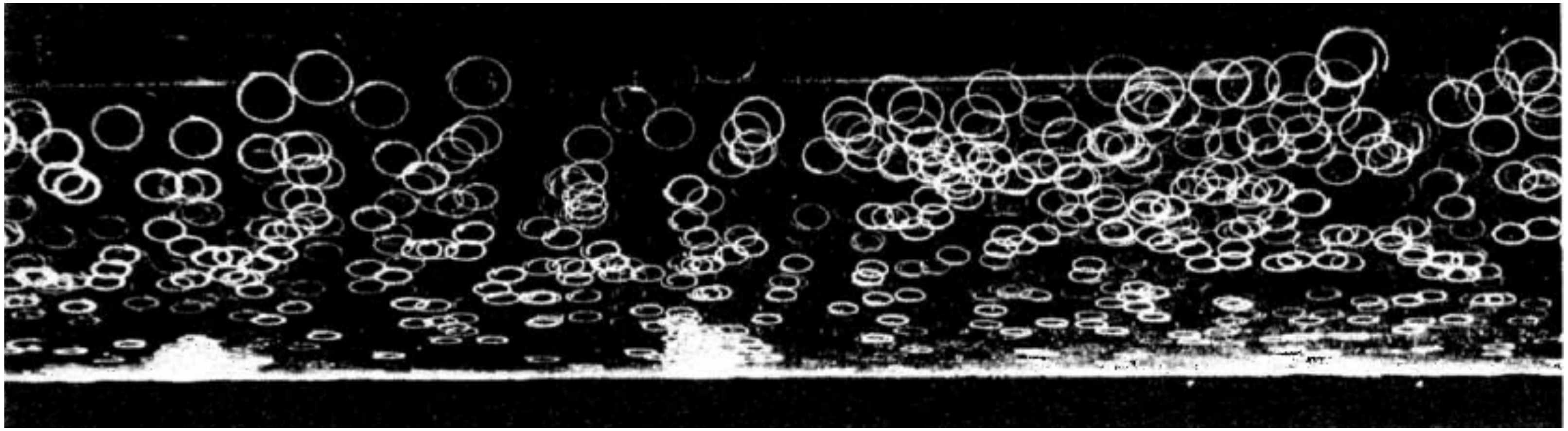
Shats M., Xia H., and Punzmann H.
Phys. Rev. Lett. 108, 034502 (2012)

Xia, Maimbourg, Punzmann, and Shats
Phys. Rev. Lett.109, 114502 (2012)

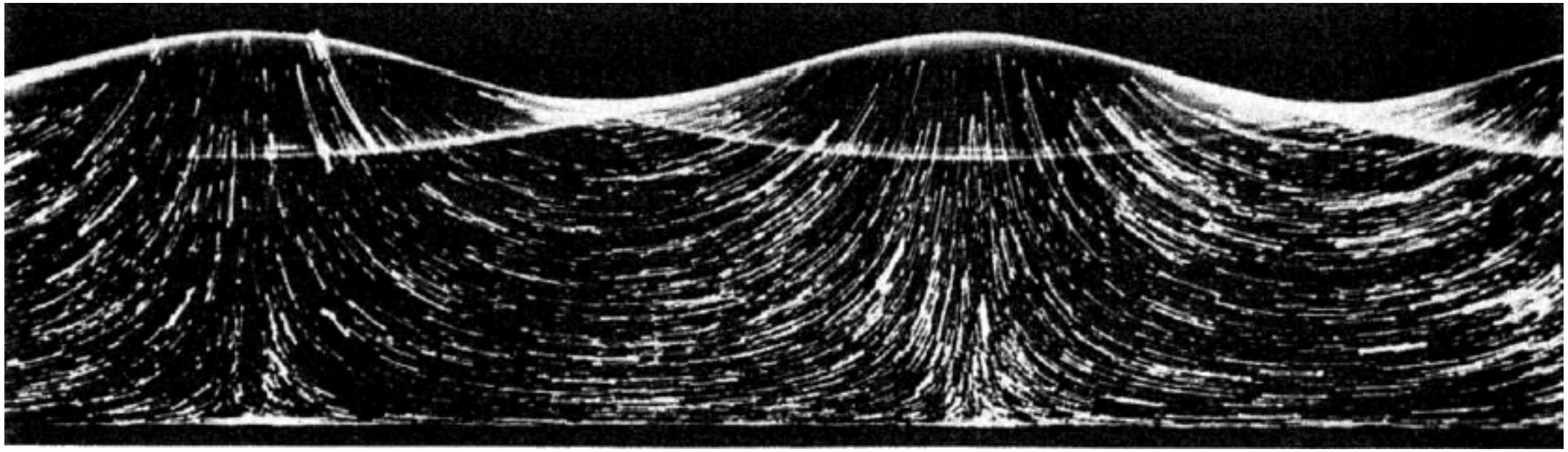
Particle trajectories in plane periodic 2D waves

Propagating wave

Long narrow wave flume



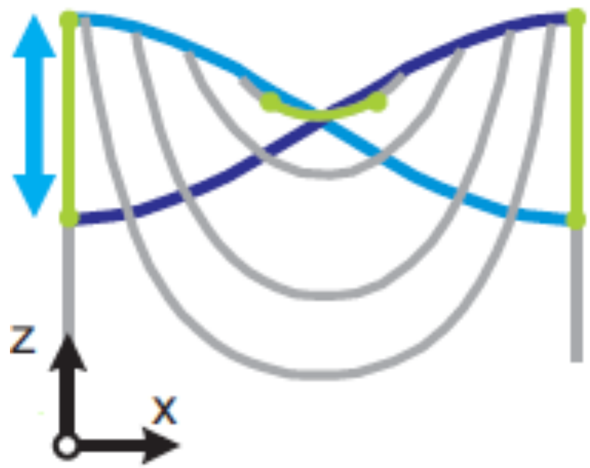
Standing wave

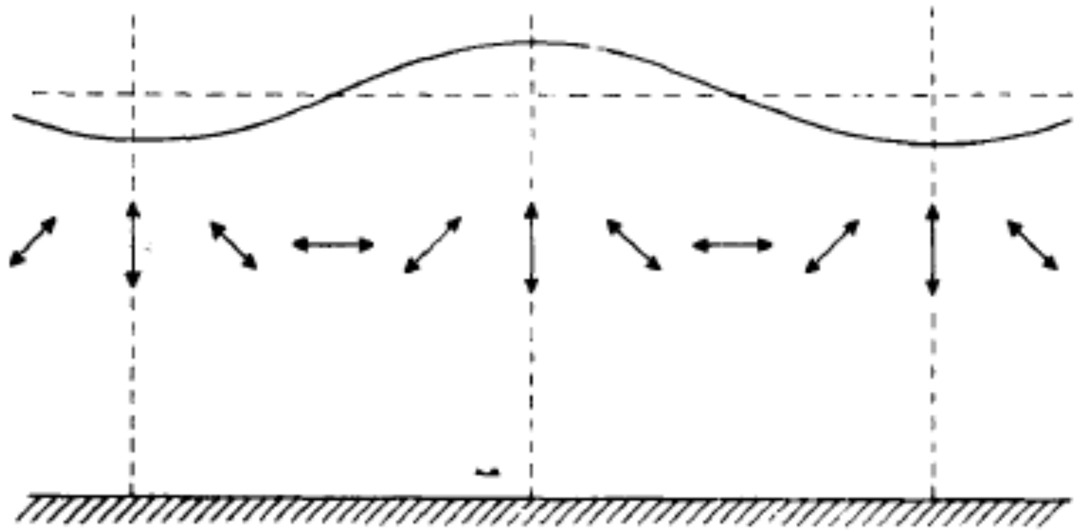


A.Wallet, and F. Ruellan, La Houille Blanche 5, 483-489 (1950).

Particle trajectories in standing 2D waves

Standing wave

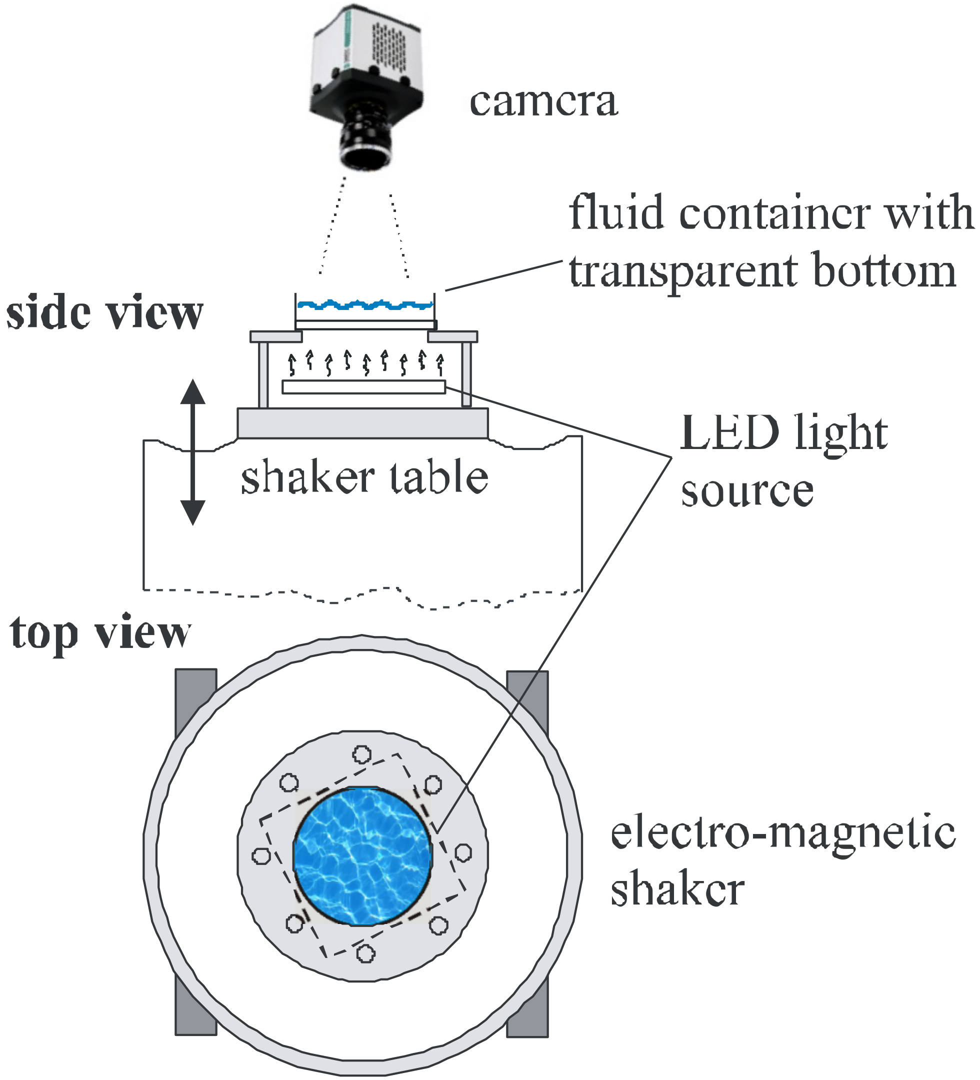




Longuet-Higgins, Stewart, Deep-Sea Research, 1964, Vol. II, pp. 529

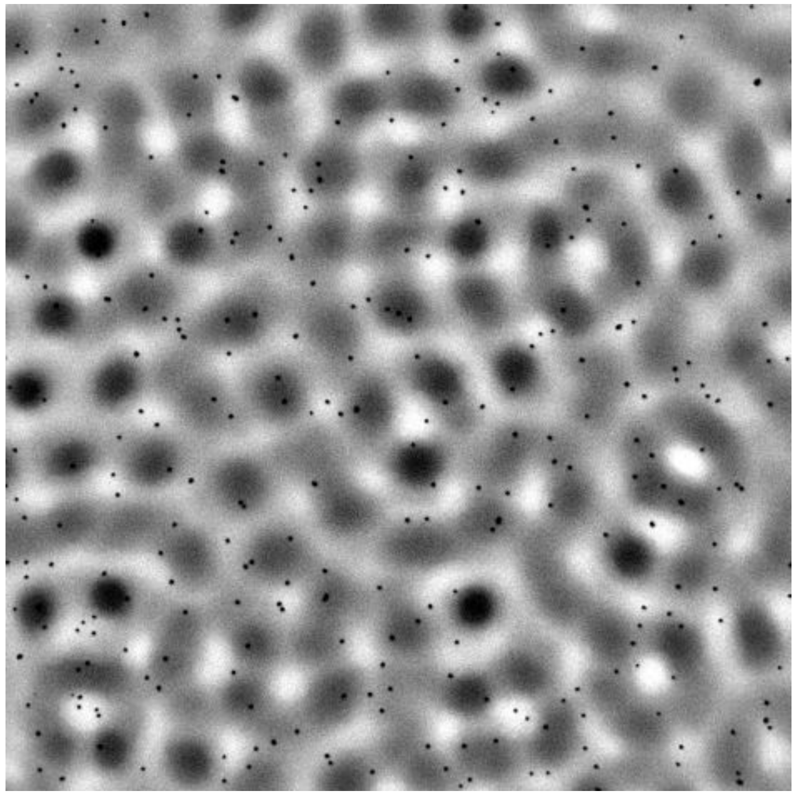
Particle trajectories correspond to vertical lines near the wave crest/trough, while particles perform the pendulum motion near the wave nodes

Experimental setup to visualize 3D trajectories



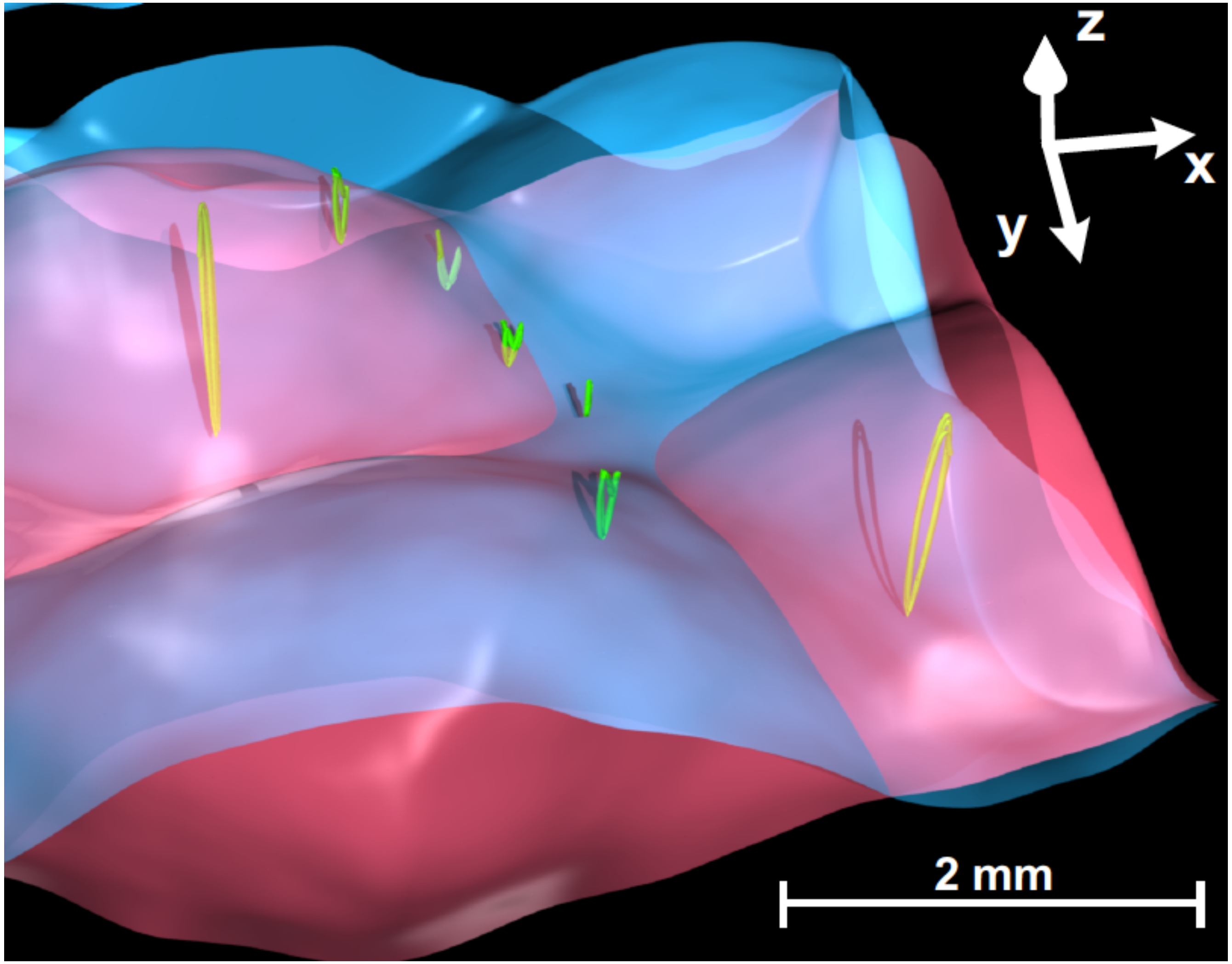
Diffusive light imaging

+ 2D PTV



Fluid particle orbits at high dissipation

solution of 73% glycerol + water



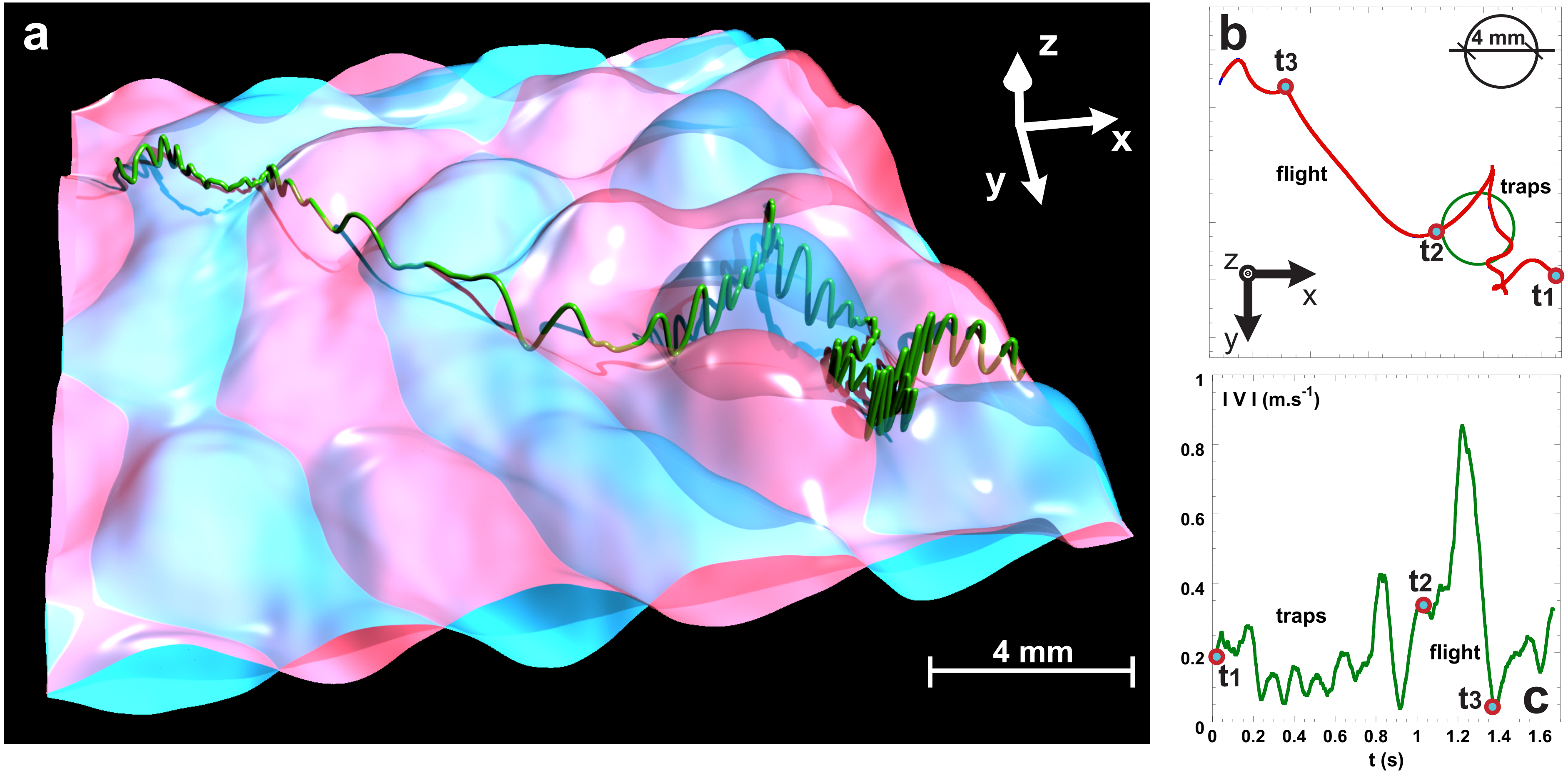
Dissipation reduces oscillon mobility, ordered lattice is formed

Particle trajectories are followed for 8 Faraday periods in a FW crystal

Closed orbits:

- Almost vertical motion near troughs/crests;
- Pendulum motion near wave nodes

3D trajectories in Faraday waves in water

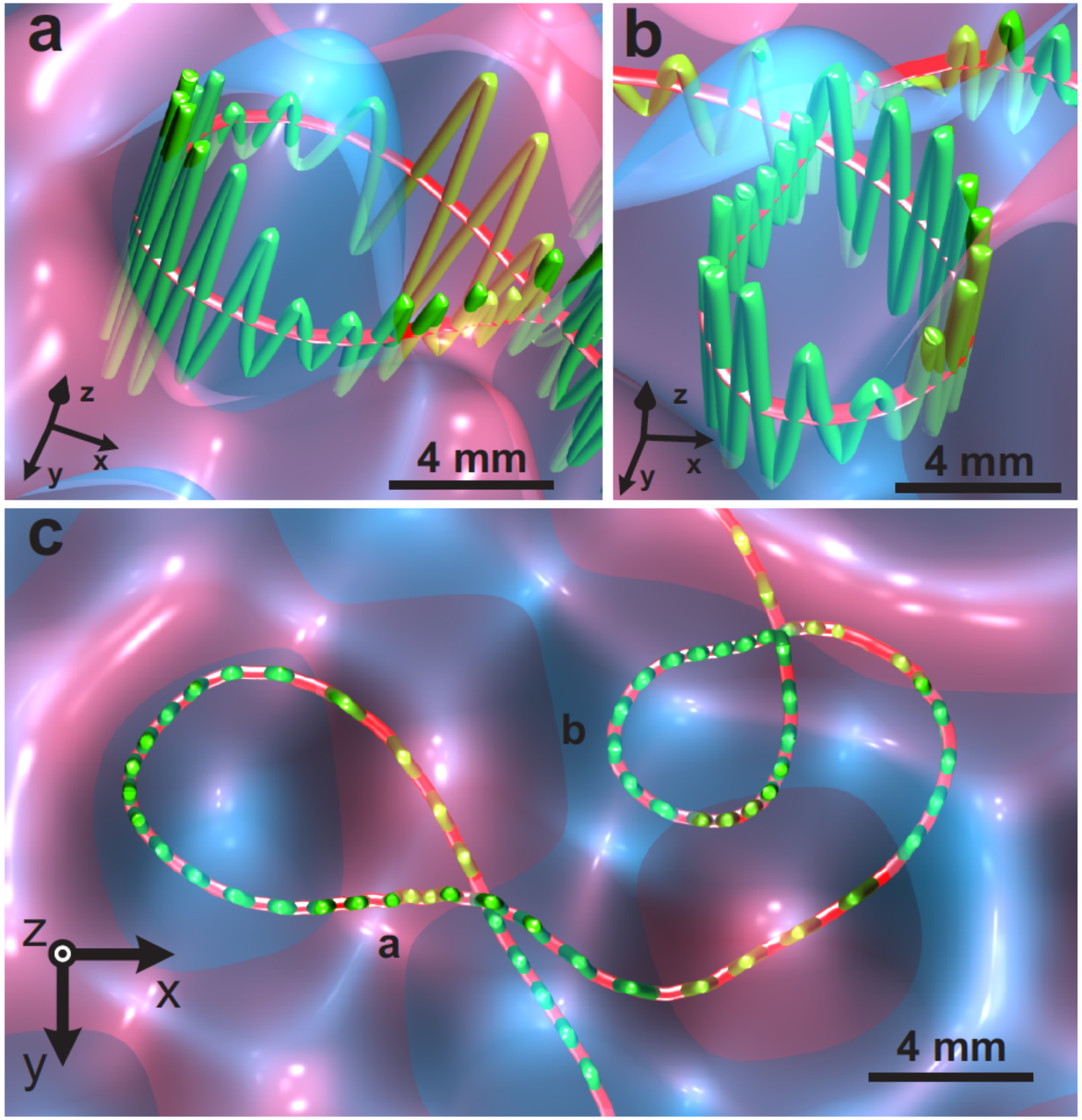


Particle trajectory followed for 1.6 s (a =1.6g f_0 = 60Hz)

Francois N., Xia H., Punzmann H., Ramsden S., and Shats M., *Phys. Rev. X* **4**, 021021 (2014).

3D particle trajectories in 2D Faraday turbulence

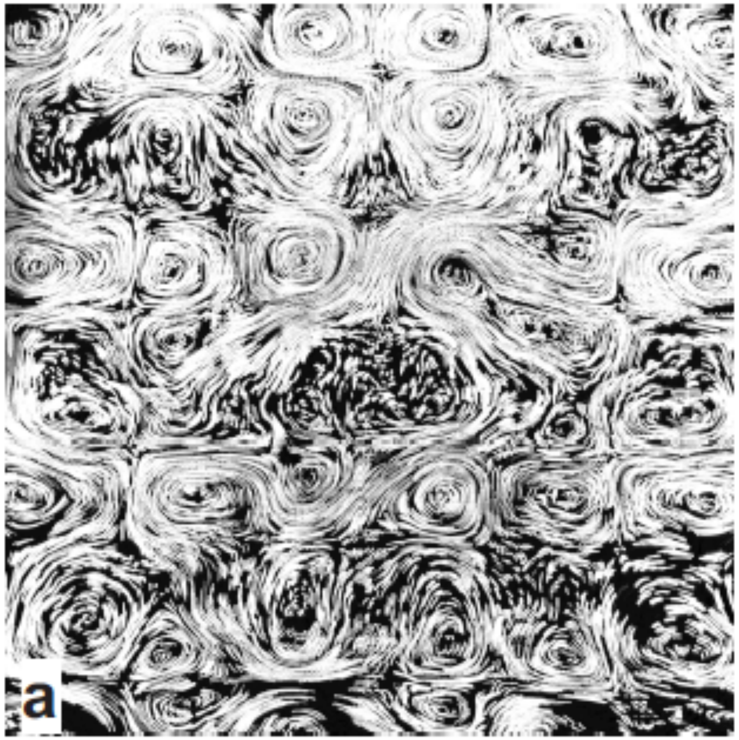
Particle trajectories are vertically polarized



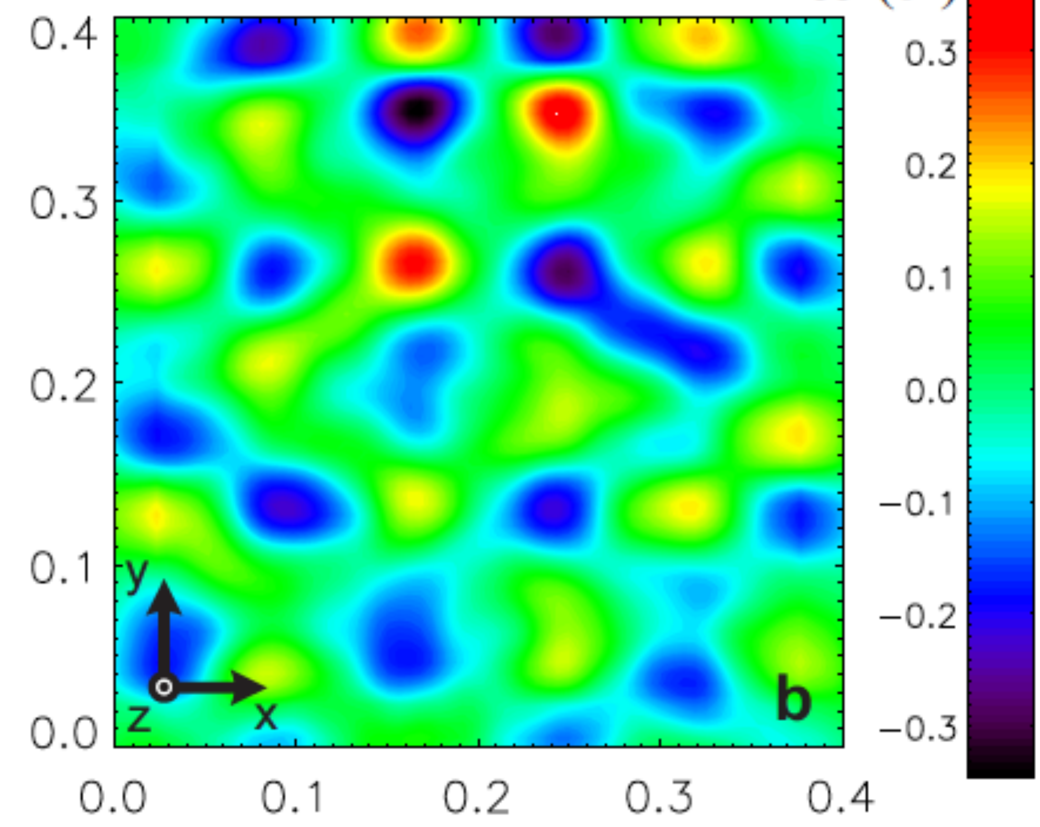
Wave induced vorticity

Early stage of turbulence development

Particle trajectories



Vorticity



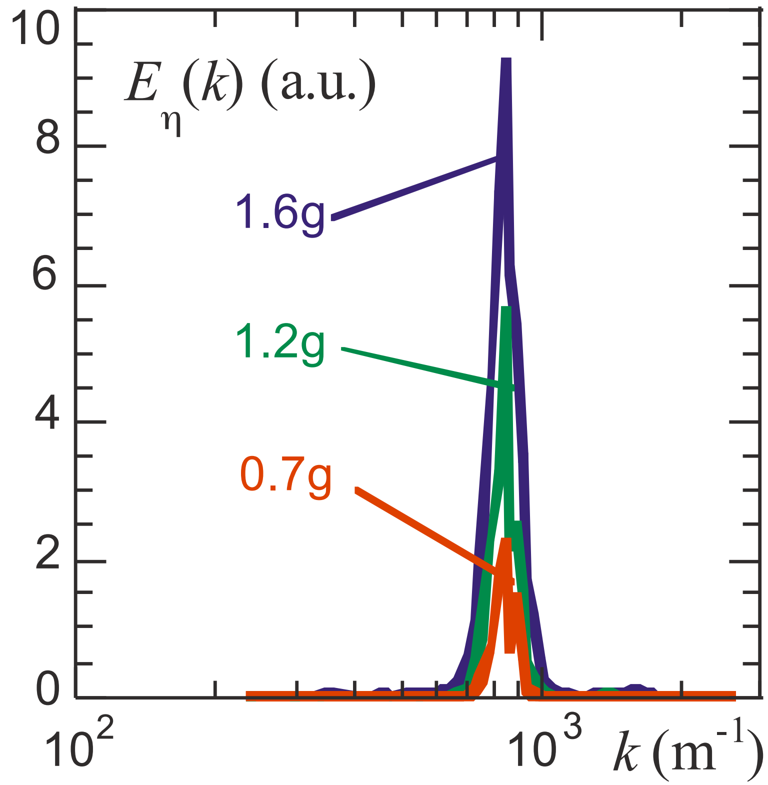
$f_0 = 10$ Hz and $a = 0.04$g

Summary 1

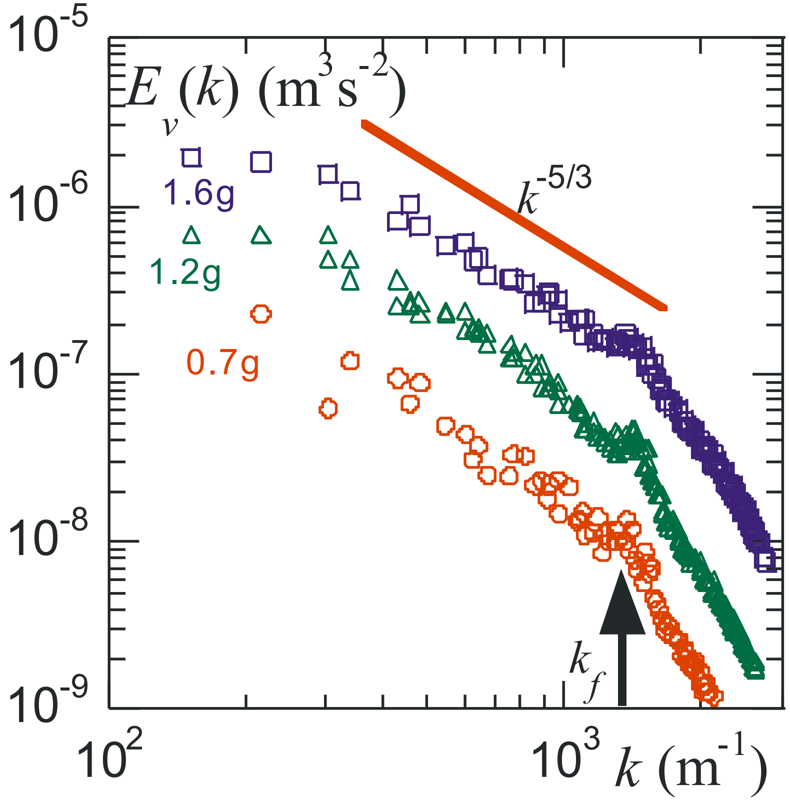
- **Faraday waves generate horizontal vortices on the water surface**
- **Those vortices interact inducing complex horizontal motion**

Wave spectra and horizontal kinetic energy spectra

Surface elevation spectra



Horizontal KE spectra



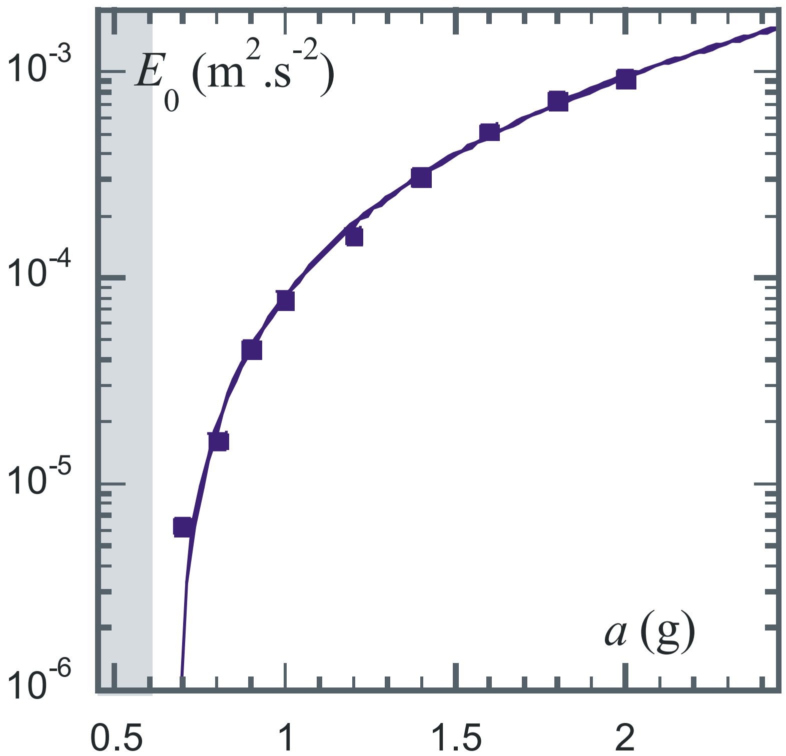
$$E(k) = C\,\varepsilon^{2/3} k^{-5/3}$$

A. von Kameke et al., *Phys. Rev. Lett.* **107**, 074502 (2011) – *shallow water*

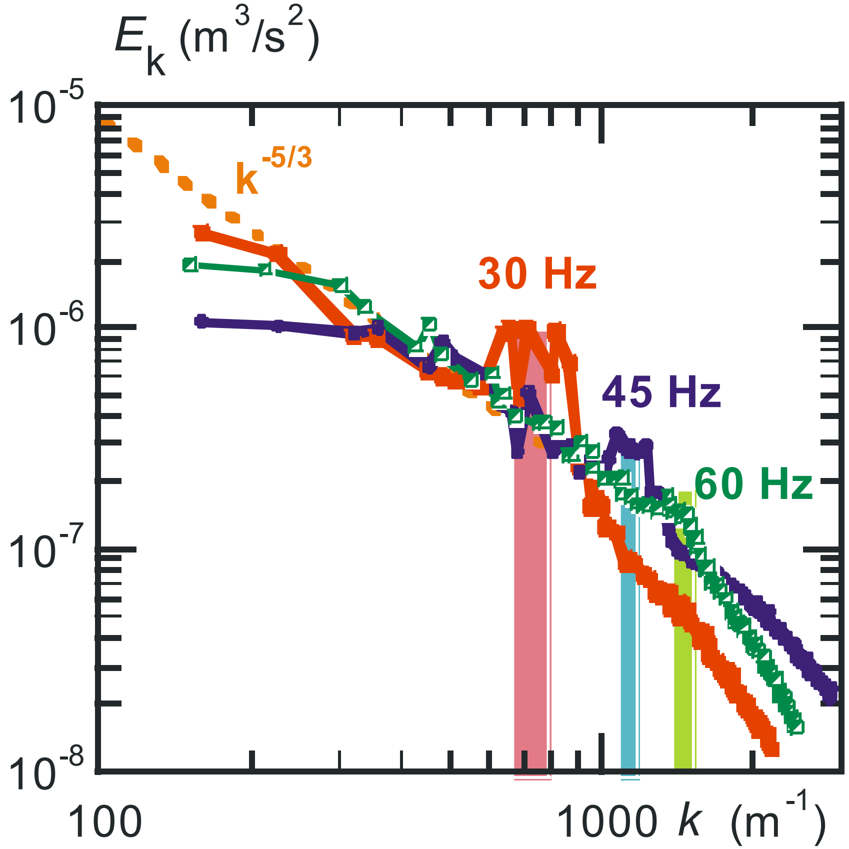
N. Francois, H. Xia, H. Punzmann, & M. Shats, *Phys. Rev. Lett.* **110**, 194501 (2013)

Turbulence control: acceleration and frequency

Turbulence KE vs vertical acceleration



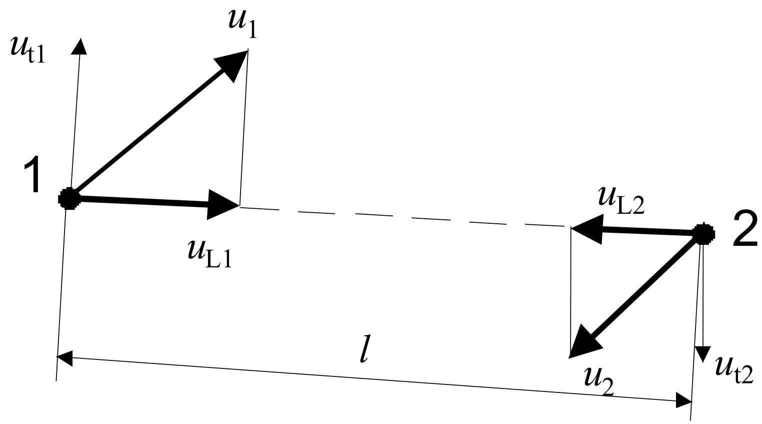
Faraday wave frequency controls turbulence forcing scale



Inverse energy cascade in wave-driven turbulence

Third-order velocity structure function

$$S_{3L}(r) = \left\langle \left[u_{L1}(x+r) - u_{L2}(x) \right]^3 \right\rangle$$

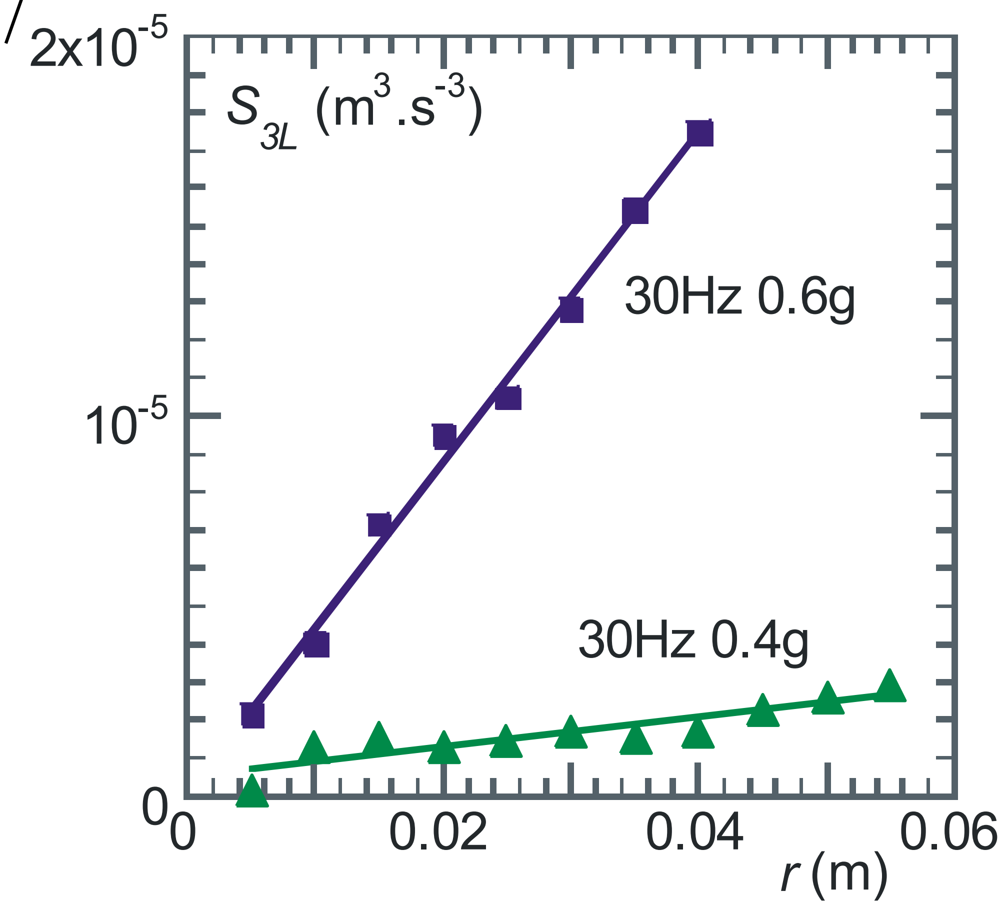


$$S_{3L}(l) = -\frac{3}{2}\varepsilon r$$

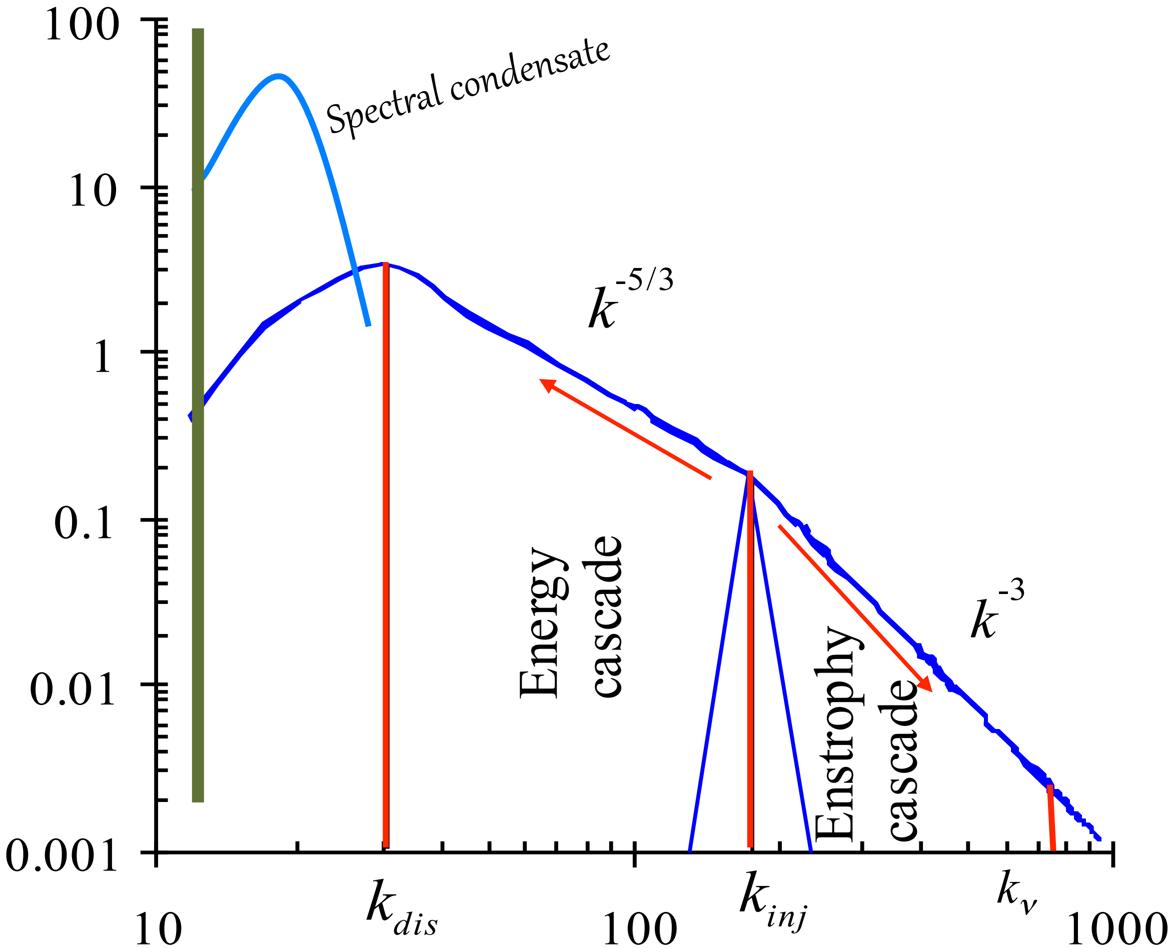
$S_3 > 0$ in 2D

$S_3 < 0$ in 3D

Faraday wave turbulence



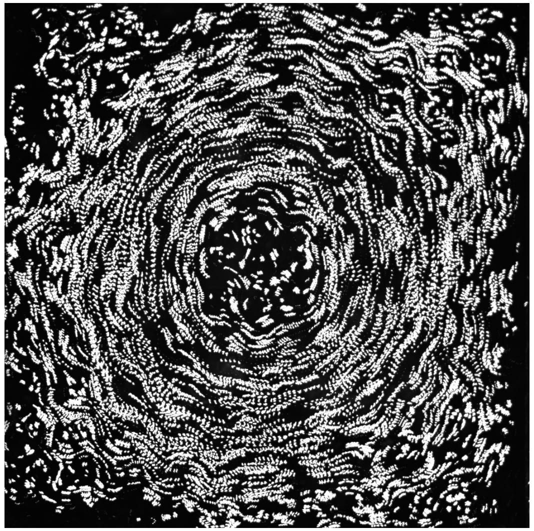
Spectral condensation of 2D turbulence



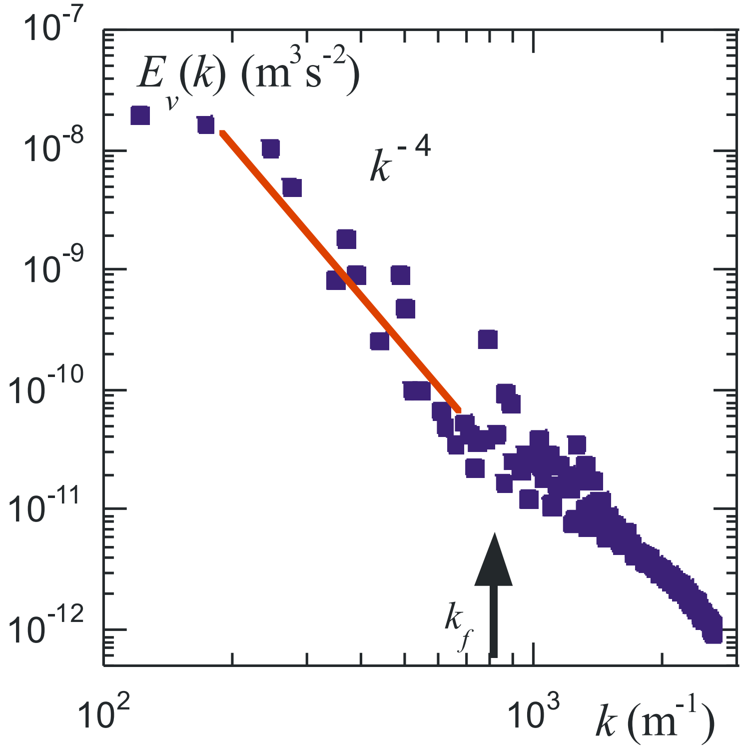
Kraichnan's inverse energy cascade (1967)

Spectral condensation in Faraday turbulence

Square container



KE spectrum



Novel method of converting energy of the wave vertical energy into coherent horizontal motion

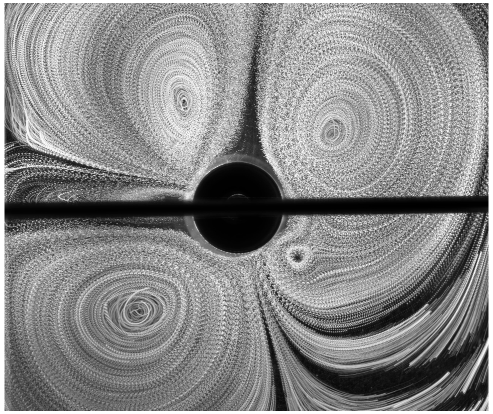
Summary 2

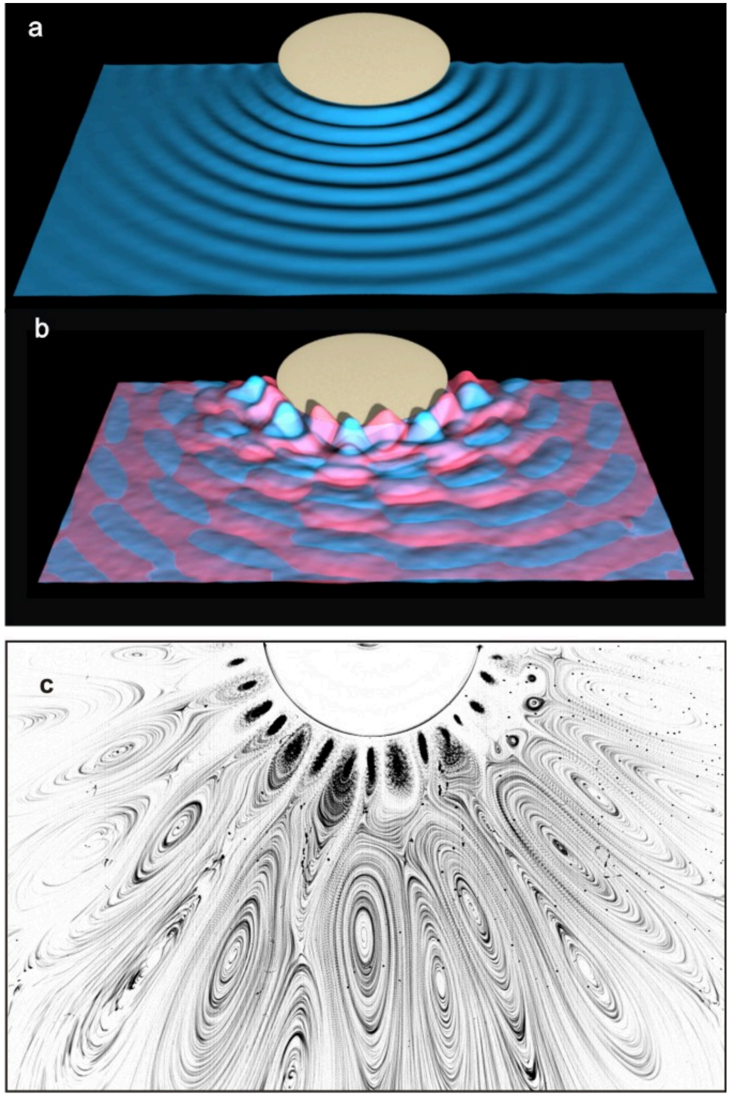
- **Faraday waves generate 2D turbulence on the water surface**
- **Wave-driven 2D turbulence can spectrally condense within a square boundary**

Propagating waves also can generate horizontal vortices on the water surface which drive surface flows

Punzmann, Francois, Xia, Falkovich & Shats, *Nature Physics* **10**, 658-663 (2014).

Waves and vortices by conical wavemaker





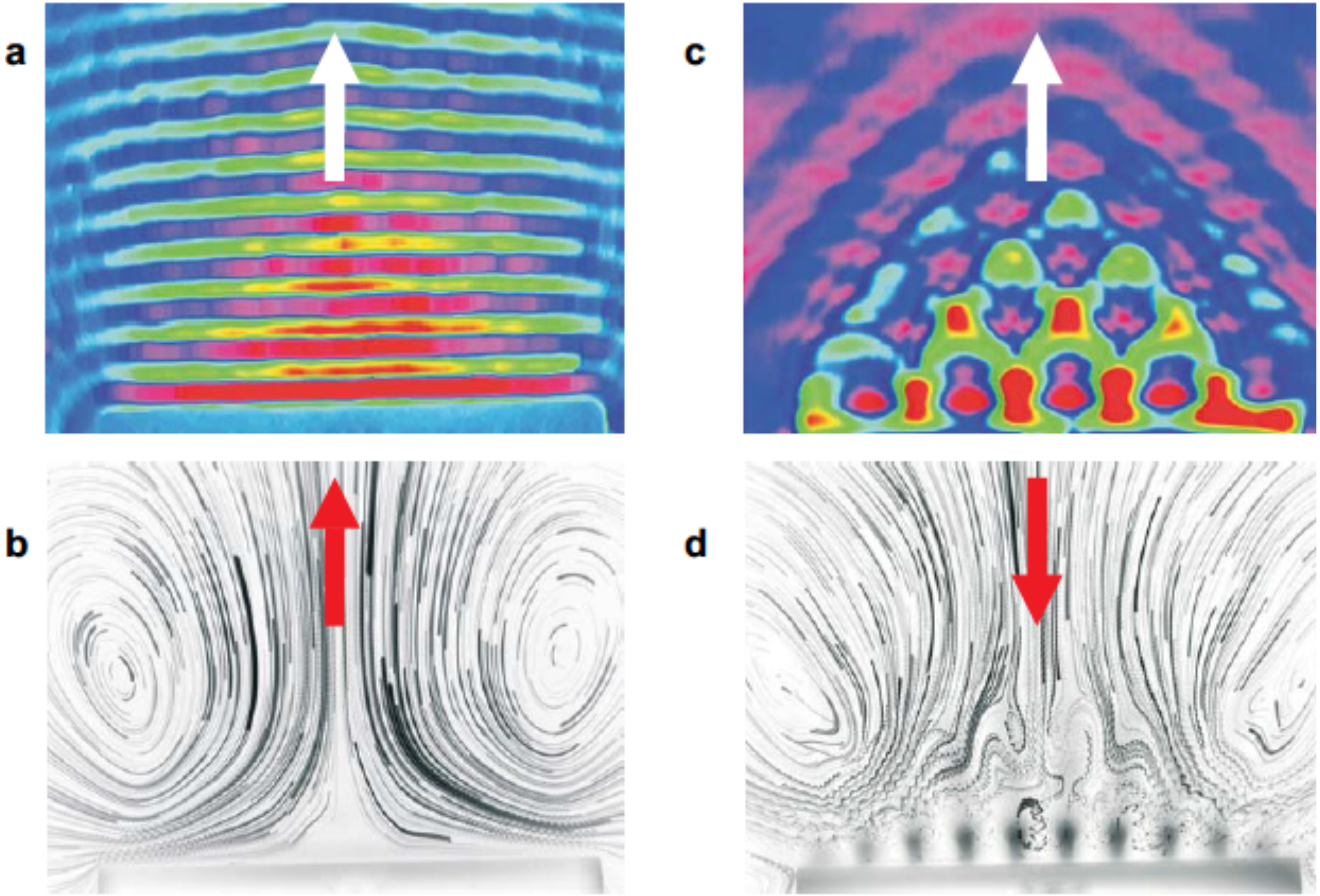
Below MI threshold

Above MI threshold

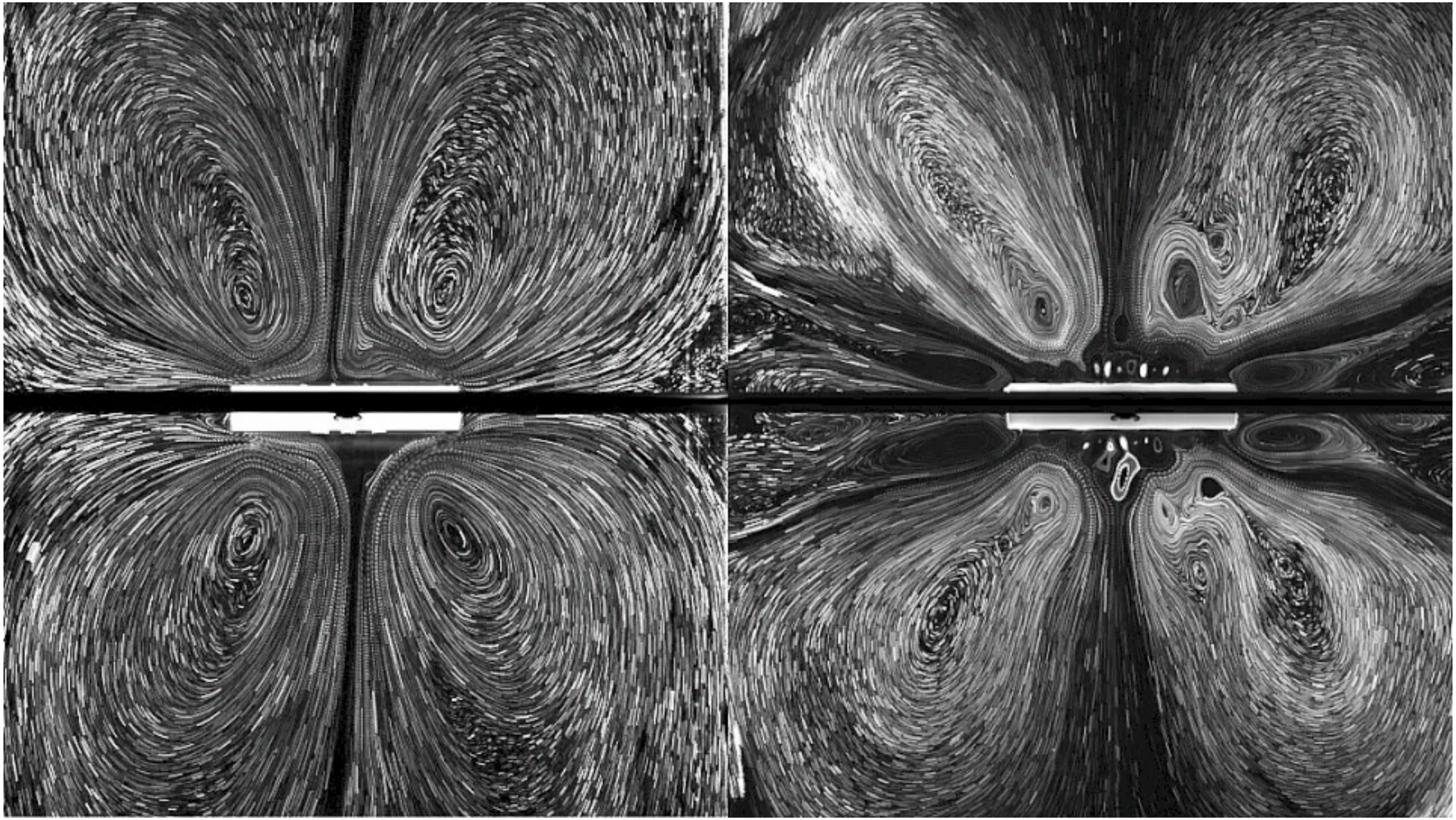
Surface flow

Water

Tractor beam by propagating waves

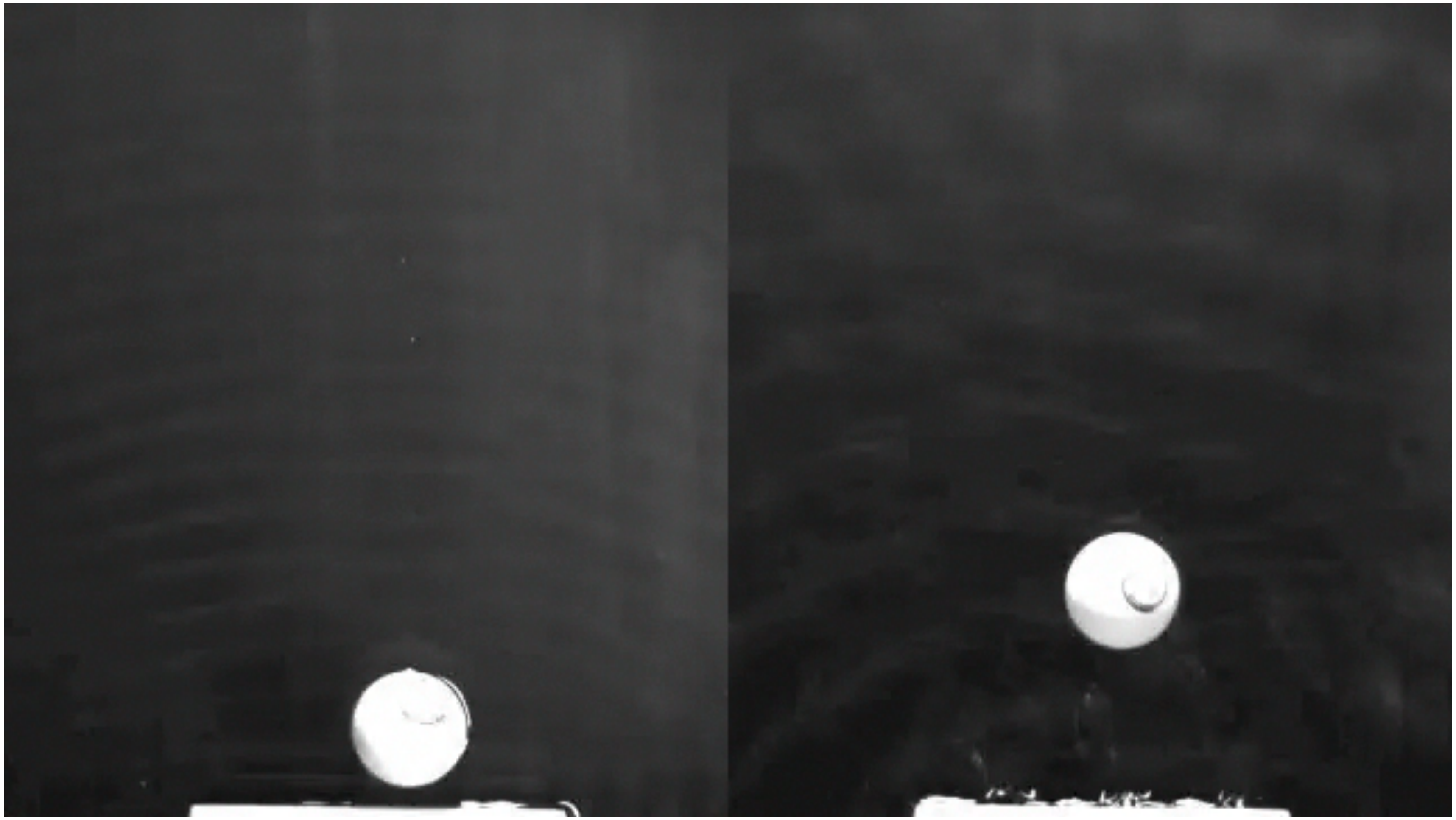


Water surface tractor beam

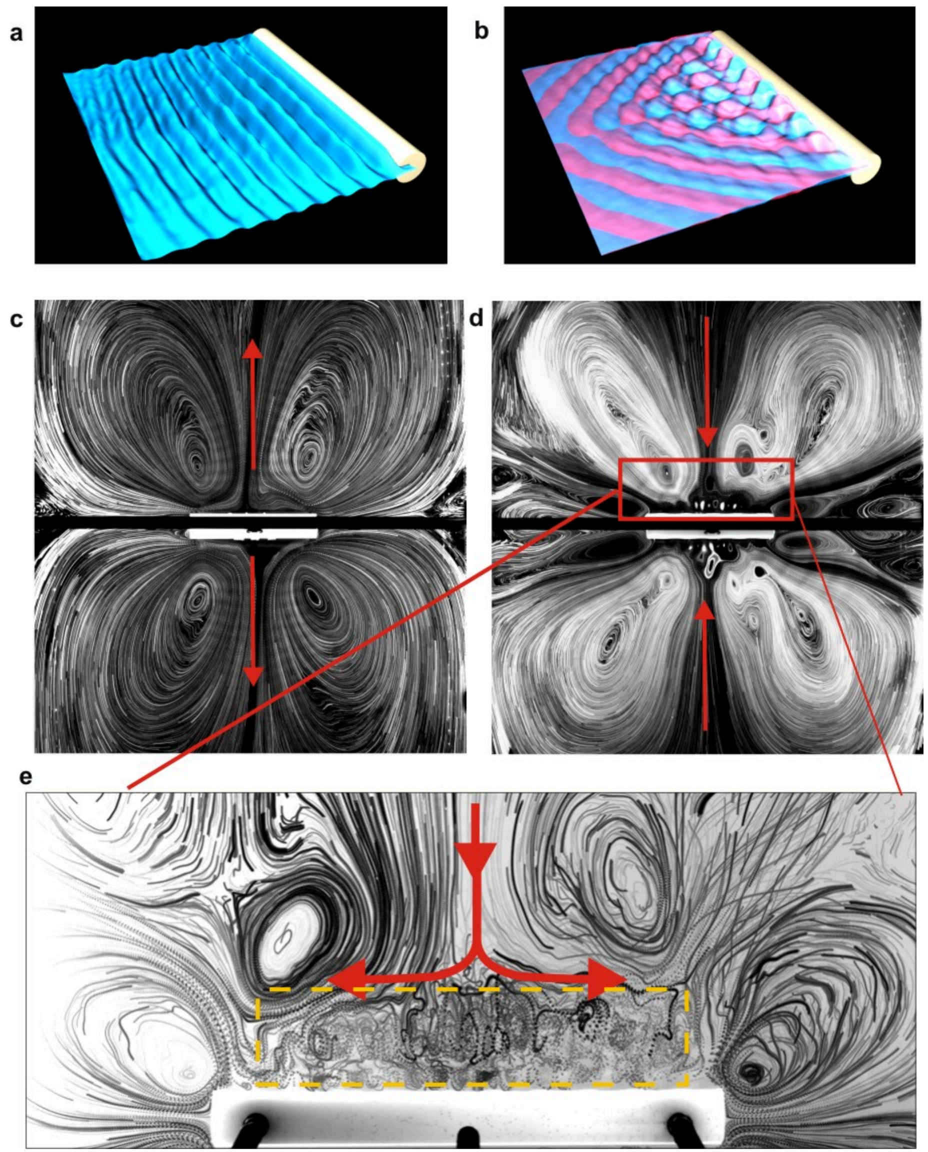


Object manipulation on the surface

Linear waves | **Nonlinear waves**



Stochastic pumping drives inward flow



Stochastic region

Summary 3

- **Propagating waves also generate horizontal vortices on the water surface**

- **Wave-driven vortices can generate strong stochastic transport of fluid particles on the surface**