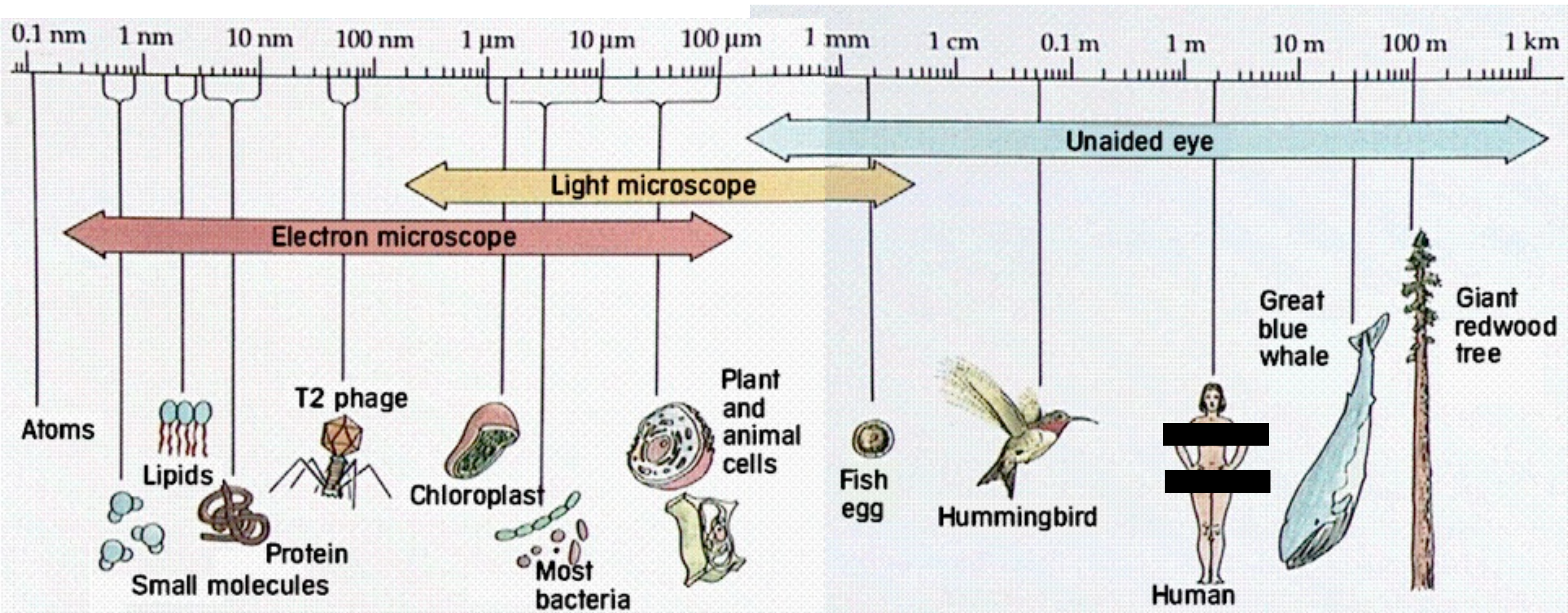
18.095 IAP Maths Lecture Series

Over-damped dynamics of small objects in fluids

Jörn Dunkel

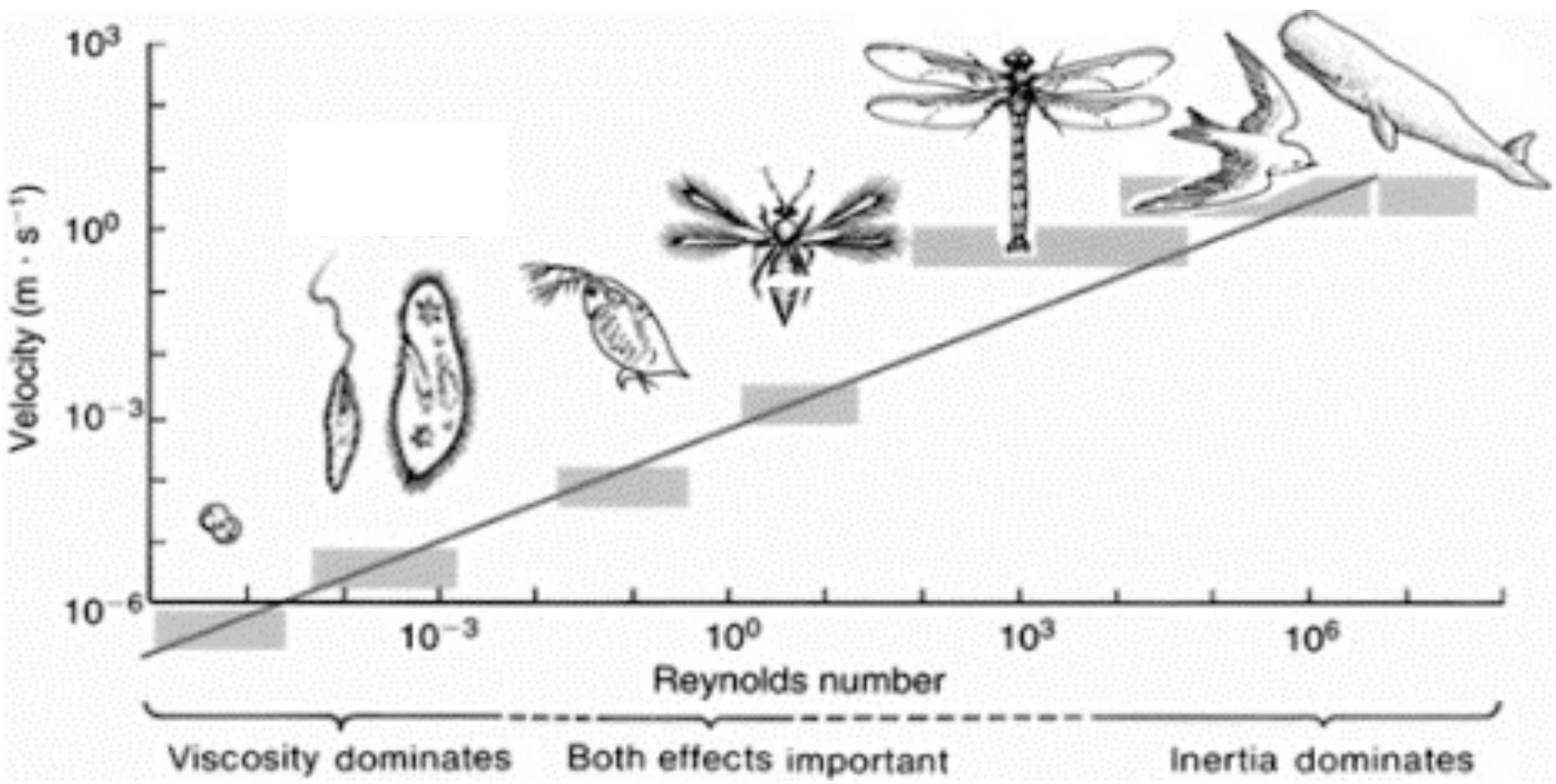
Typical length scales



http://www2.estrellamountain.edu/faculty/farabee/BIOBK/biobookcell2.html

Reynolds numbers

$$Re = \frac{\rho U L}{\mu} = \frac{U L}{\nu}$$



dunkel@math.mit.edu

Laminar (low-Re) flow

For Re$\rightarrow$0

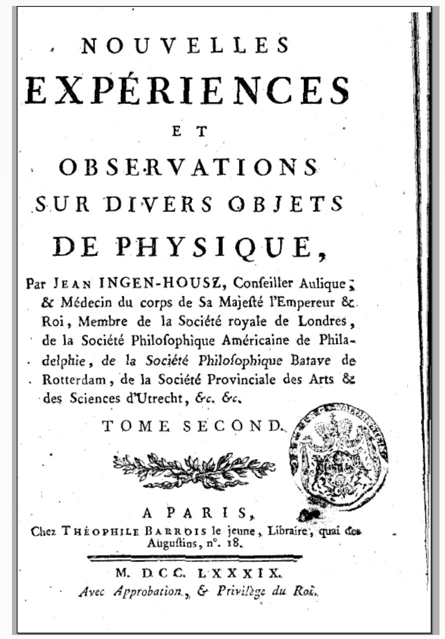
fluid flow becomes reversible !

... except for thermal fluctuations

Brownian motion

“Brownian” motion

Jan Ingen-Housz (1730-1799)



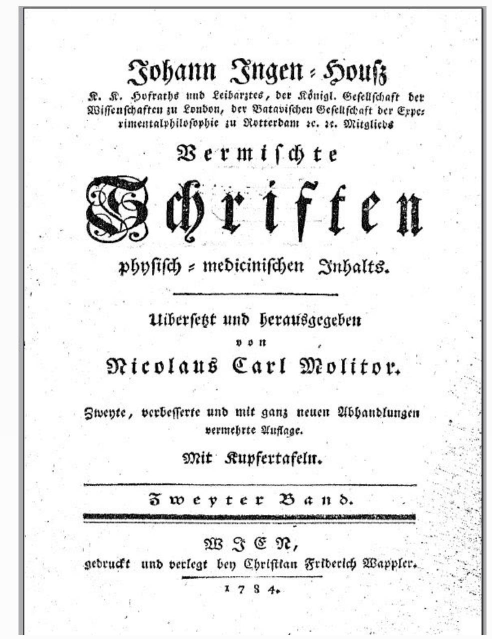
NOUVELLES
EXPÉRIENCES
ET
OBSERVATIONS
SUR DIVERS OBJETS
DE PHYSIQUE,

Par JEAN INGEN-HOUSZ, Conſeiller Aulique; & Médecin du corps de Sa Majeſté l'Empereur & Roi, Membre de la Société royale de Londres, de la Société Philoſophique Américaine de Philadelphie, de la *Société Philoſophique* Batave de Rotterdam, de la Société Provinciale des Arts & des Sciences d'Utrecht, *&c. &c.*

TOME SECOND.

A PARIS,
Chez THÉOPHILE BARROIS le jeune, Libraire, quai des Auguſtins, n°. 18.

M. DCC. LXXXIX.
Avec Approbation, & Privilège du Roi.



Johann Ingen-Houſz
K. K. Hofraths und Leibarztes, der Königl. Geſellſchaft der Wiſſenſchaften zu London, der Bataviſchen Geſellſchaft der Experimentalphiloſophie zu Rotterdam ꝛc. ꝛc. Mitglieds

Vermiſchte
Schriften
phyſiſch-mediciniſchen Inhalts.

Uiberſetzt und herausgegeben
von
Nicolaus Carl Molitor.

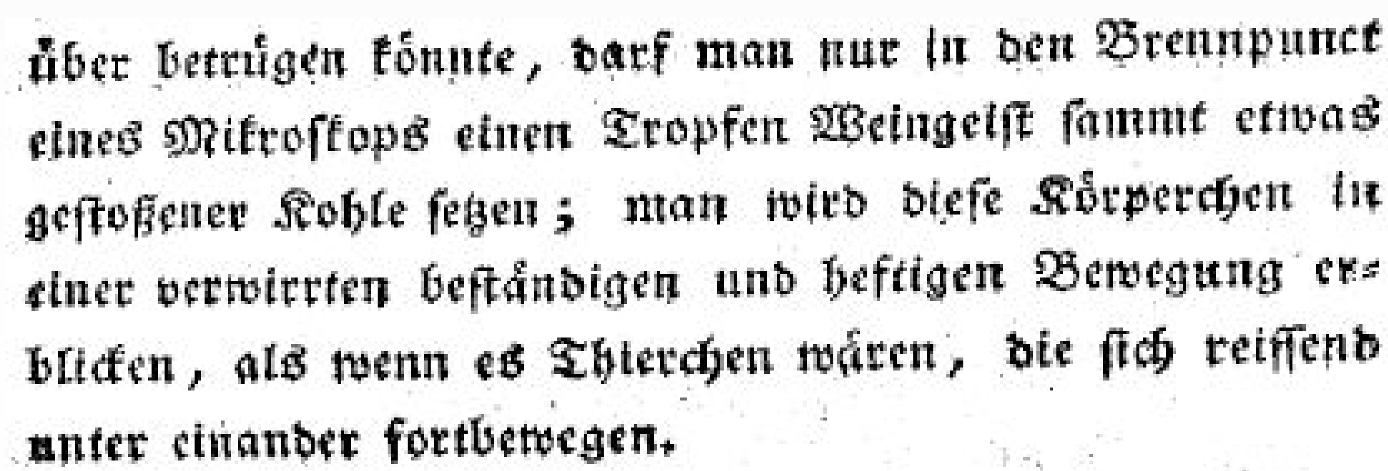
Zweyte, verbeſſerte und mit ganz neuen Abhandlungen vermehrte Auflage.

Mit Kupfertafeln.

Zweyter Band.

WIEN,
gedruckt und verlegt bey Chriſtian Friderich Wappler.
1784.

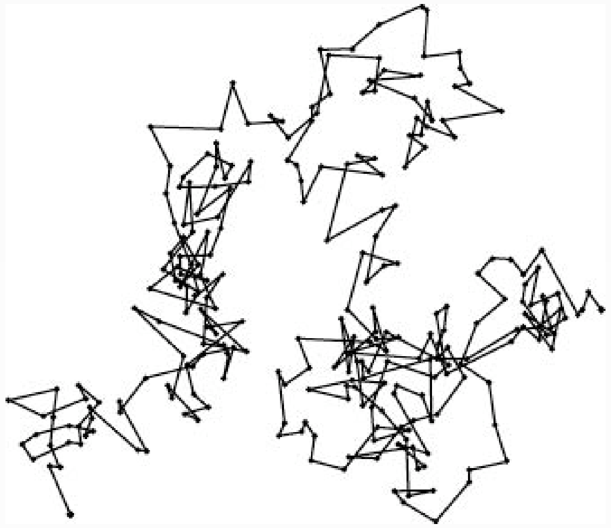
1784/1785:



über betrügen könnte, darf man nur in den Brennpunct eines Mikroſkops einen Tropfen Weingeiſt ſammt etwas geſtoßener Kohle ſetzen; man wird dieſe Körperchen in einer verwirrten beſtändigen und heftigen Bewegung erblicken, als wenn es Thierchen wären, die ſich reiſſend unter einander fortbewegen.

http://www.physik.uni-augsburg.de/theo1/hanggi/History/BM-History.html

Robert Brown (1773-1858)

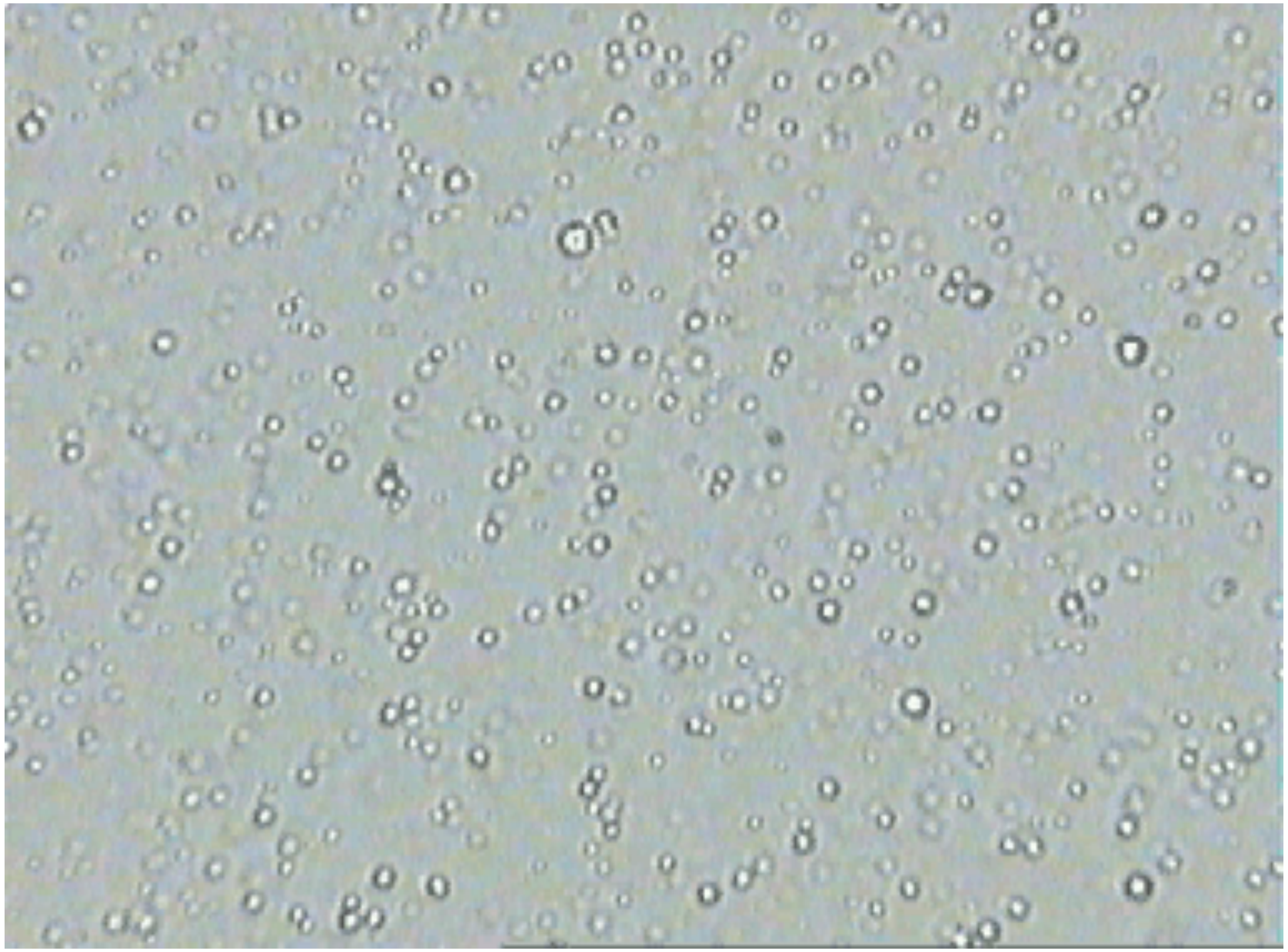


Linnean Society (London)

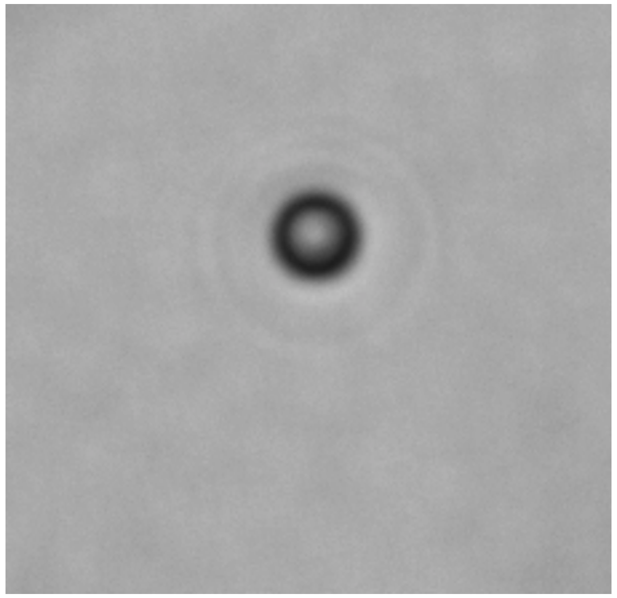
1827: irregular motion of pollen in fluid

`http://www.brianjford.com/wbbrownc.htm`

Brownian motion



David Walker



Mark Haw

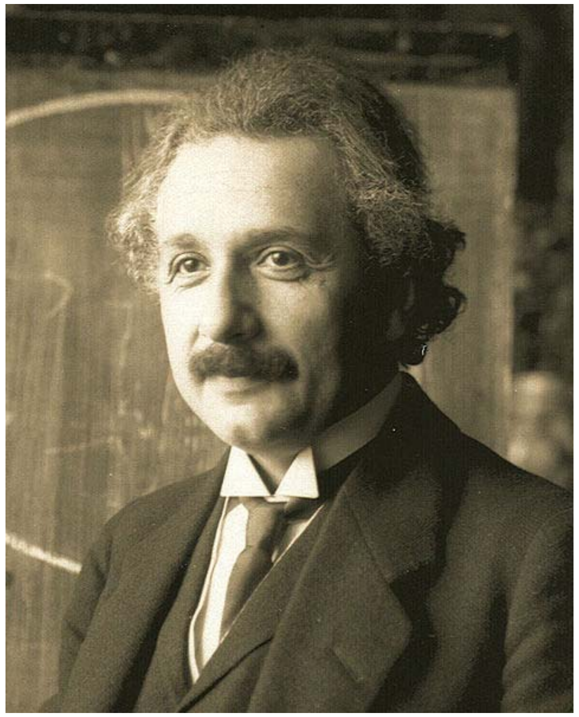
W. Sutherland (1858-1911)

Source: www.theage.com.au

$$D = \frac{RT}{6\pi\eta aC}$$

Phil. Mag. **9**, 781 (1905)

A. Einstein (1879-1955)



Source: wikipedia.org

$$\langle x^2(t) \rangle = 2Dt$$

$$D = \frac{RT}{N}\frac{1}{6\pi kP}$$

Ann. Phys. **17**, 549 (1905)

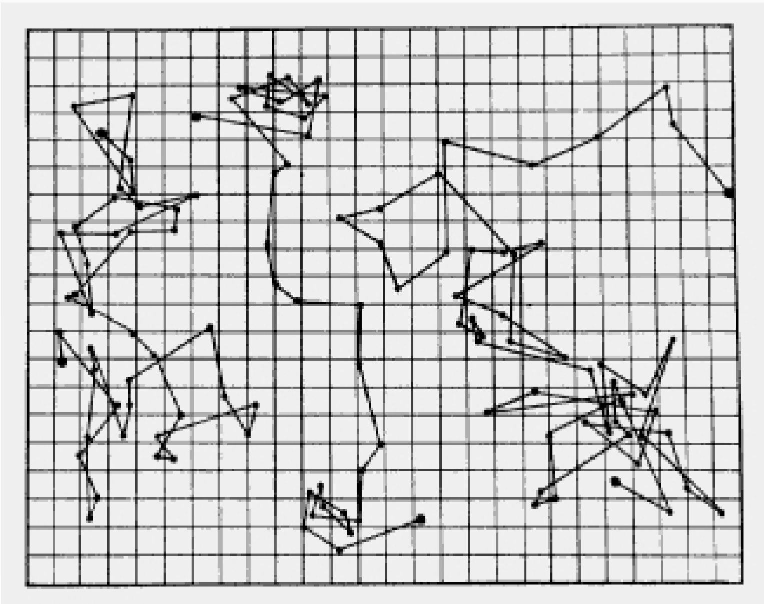
M. Smoluchowski (1872-1917)

Source: wikipedia.org

$$D = \frac{32}{243}\frac{mc^2}{\pi\mu R}$$

Ann. Phys. **21**, 756 (1906)

Jean Baptiste Perrin (1870-1942, Nobel prize 1926)



Mouvement brownien et réalité moléculaire, Annales de chimie et de physique VIII 18, 5-114 (1909)

Les Atomes, Paris, Alcan (1913)

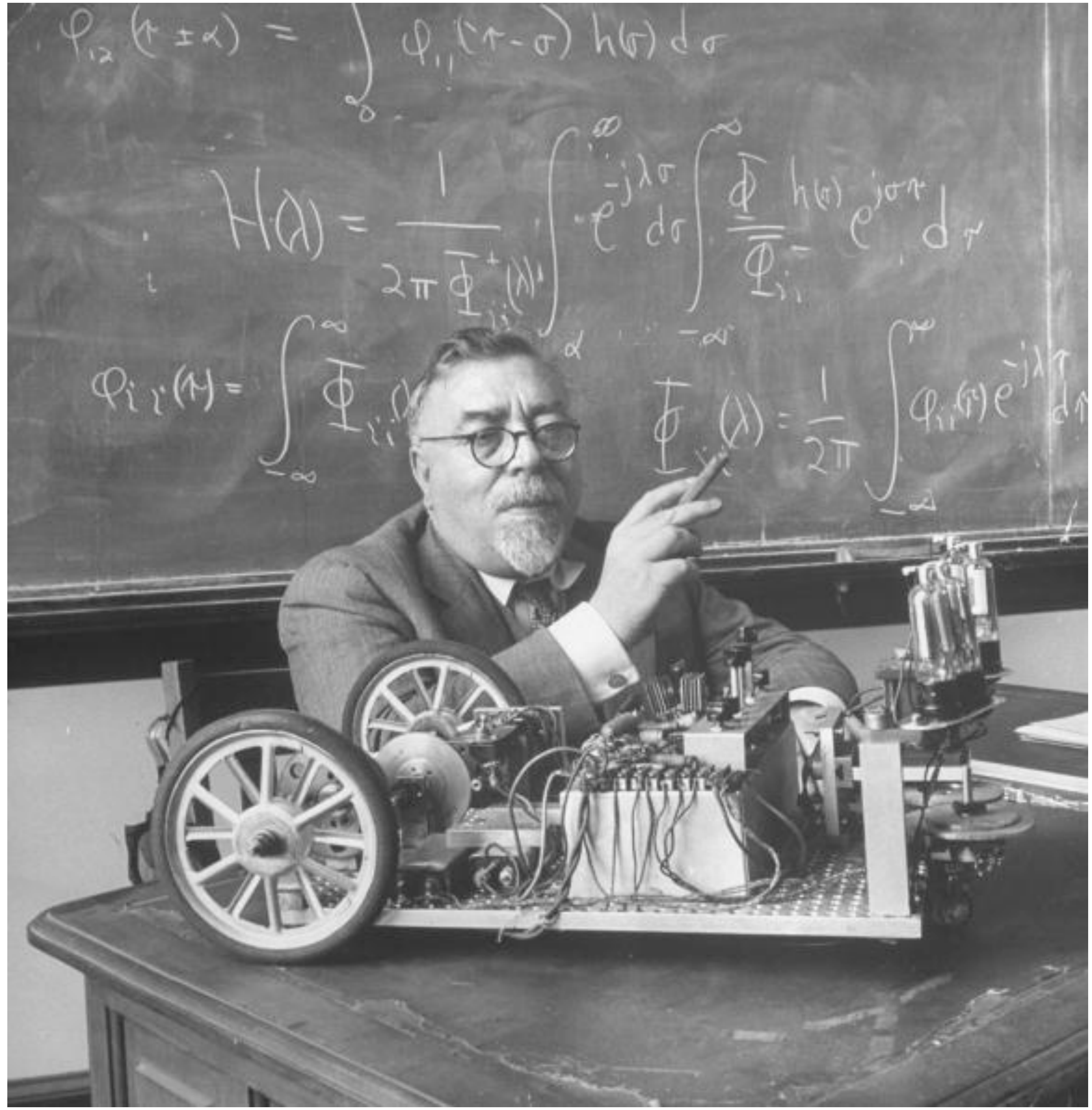
- colloidal particles of radius $0.53\mu m$
- successive positions every 30 seconds joined by straight line segments
- mesh size is $3.2\mu m$

experimental evidence for atomistic structure of matter

Norbert Wiener

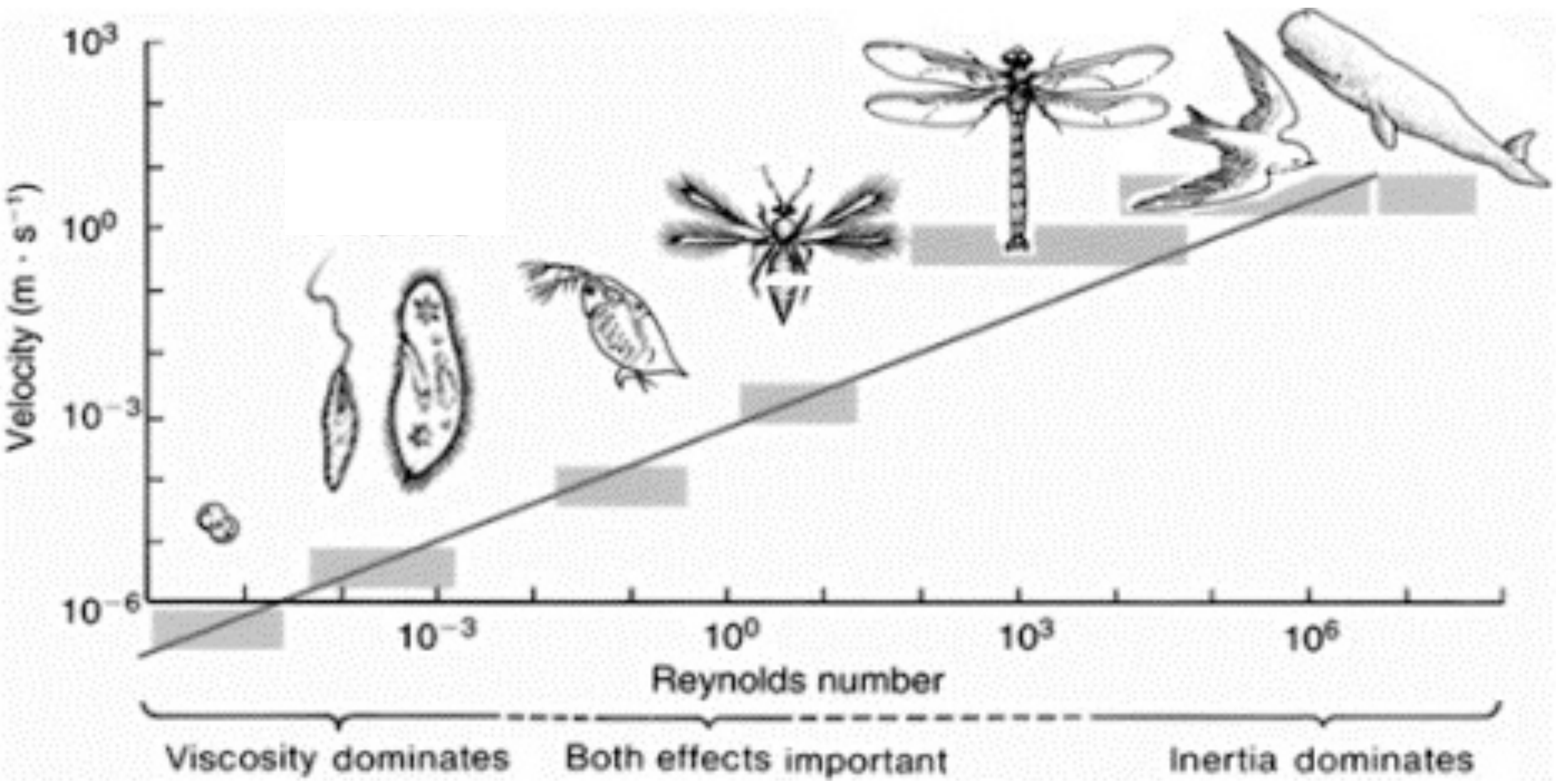
(1894-1864)

MIT



Reynolds numbers

$$Re = \frac{\rho U L}{\mu} = \frac{UL}{\nu}$$



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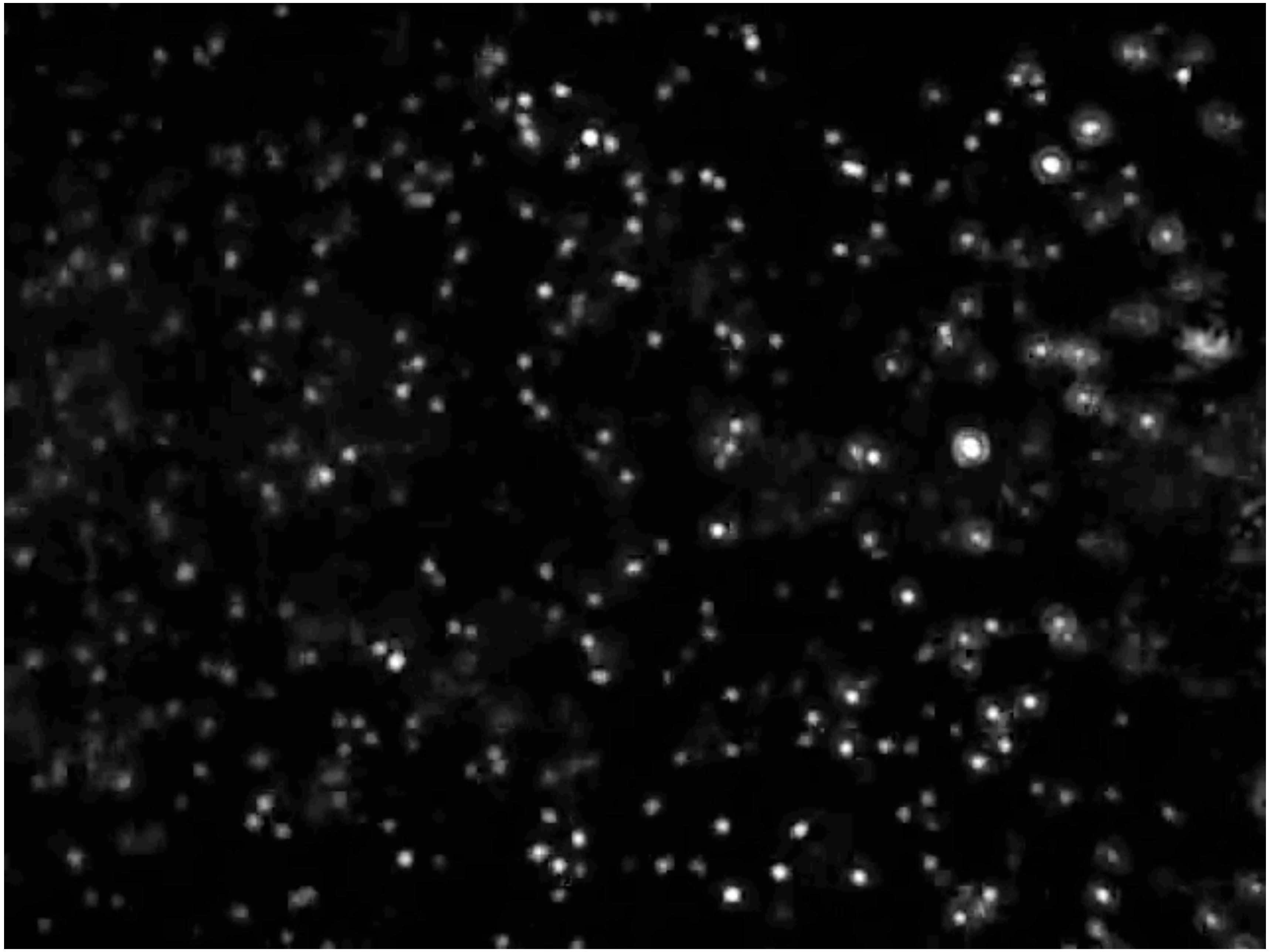
Nano-spheres in water



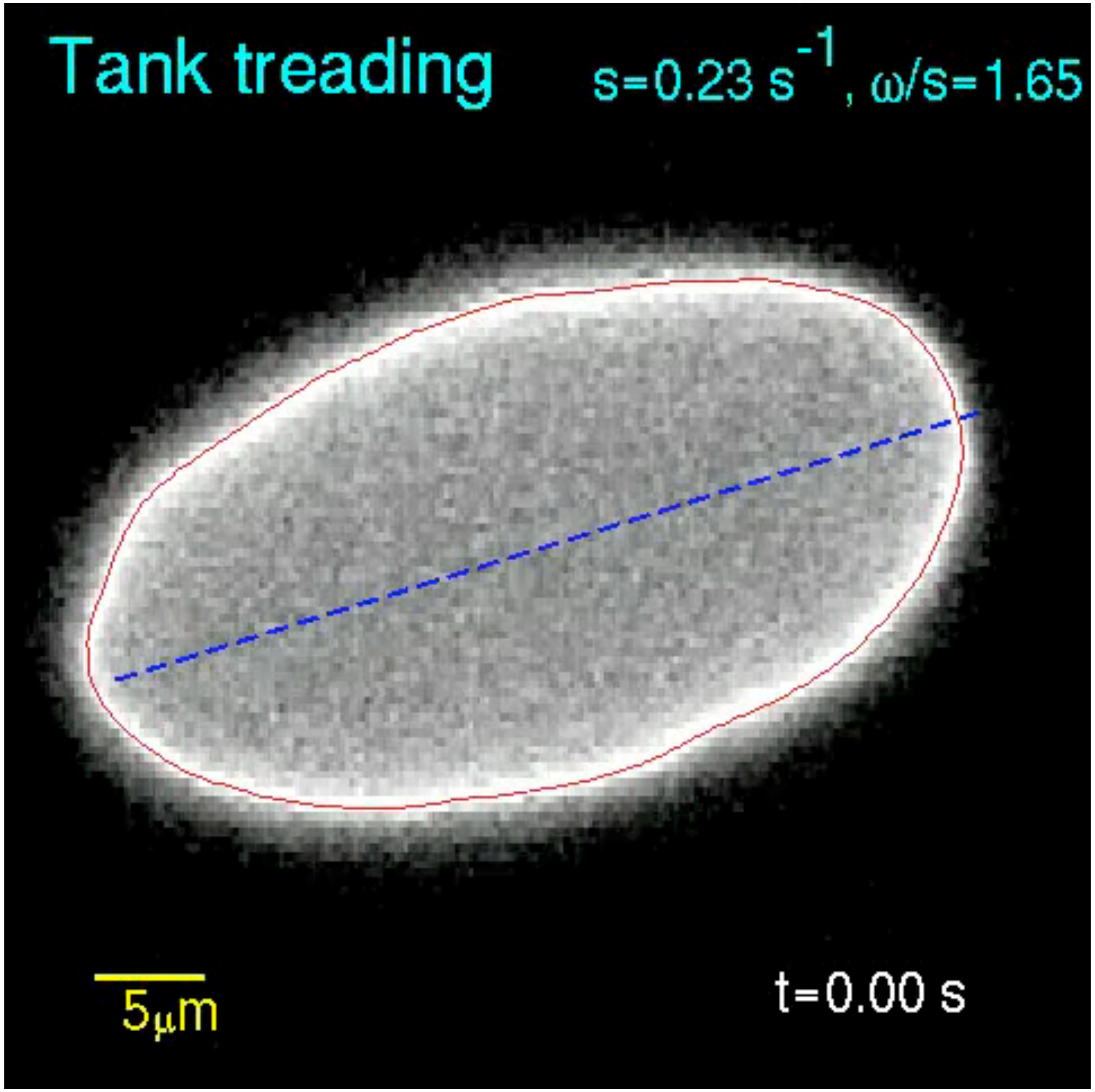
Polymer in a fluid

Dogic lab
(Brandeis)

Ring-polymer in a fluid

Dogic lab
(Brandeis)

Vesicles in a shear flow



Vasily Kantsler

model for blood cells dynamics

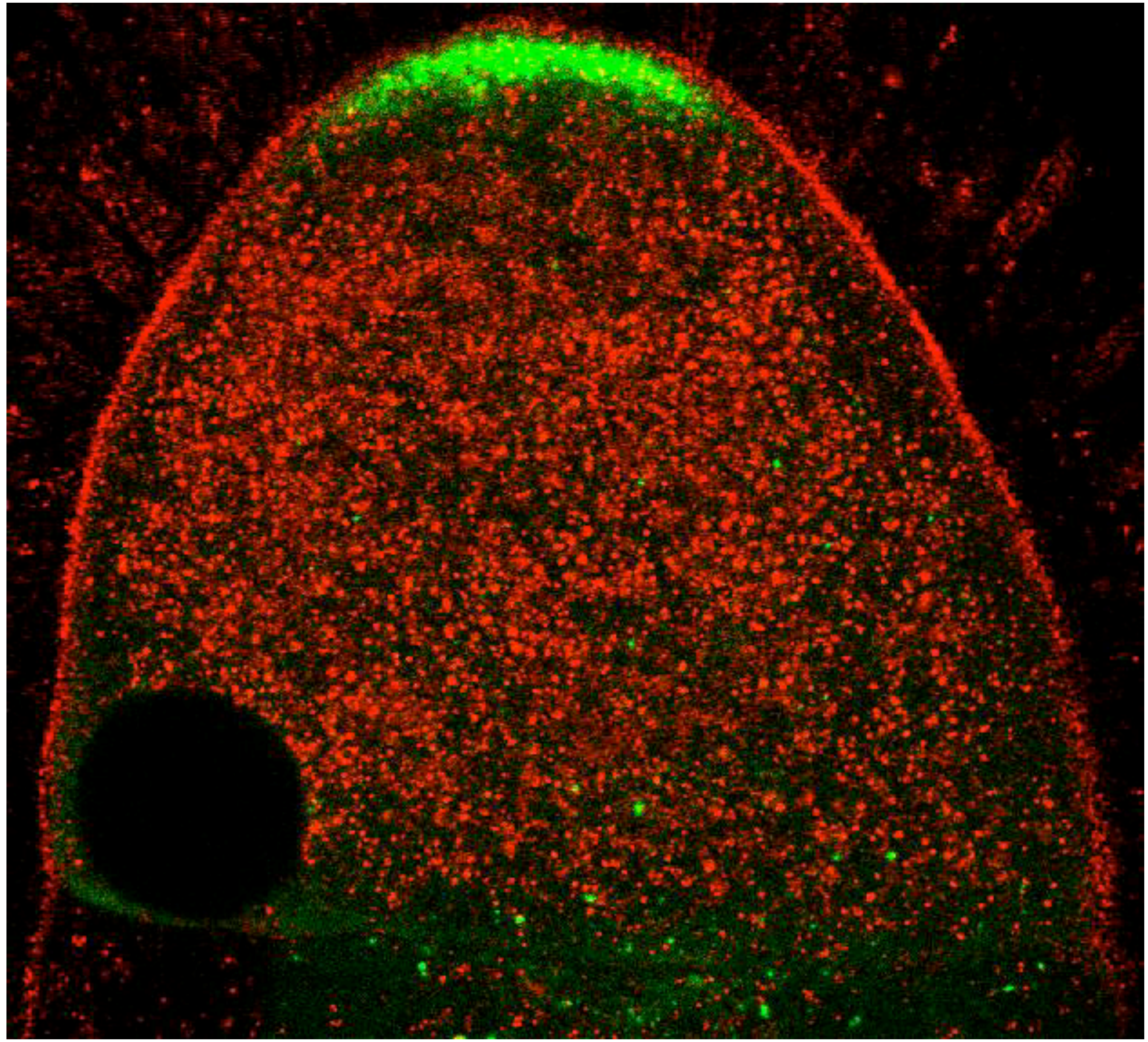
Relevance in biology

- intracellular transport
- intercellular transport
- microorganisms must beat BM to achieve directed locomotion
- tracer diffusion = important experimental "tool"

Flow in cells

Flow & transport in cells

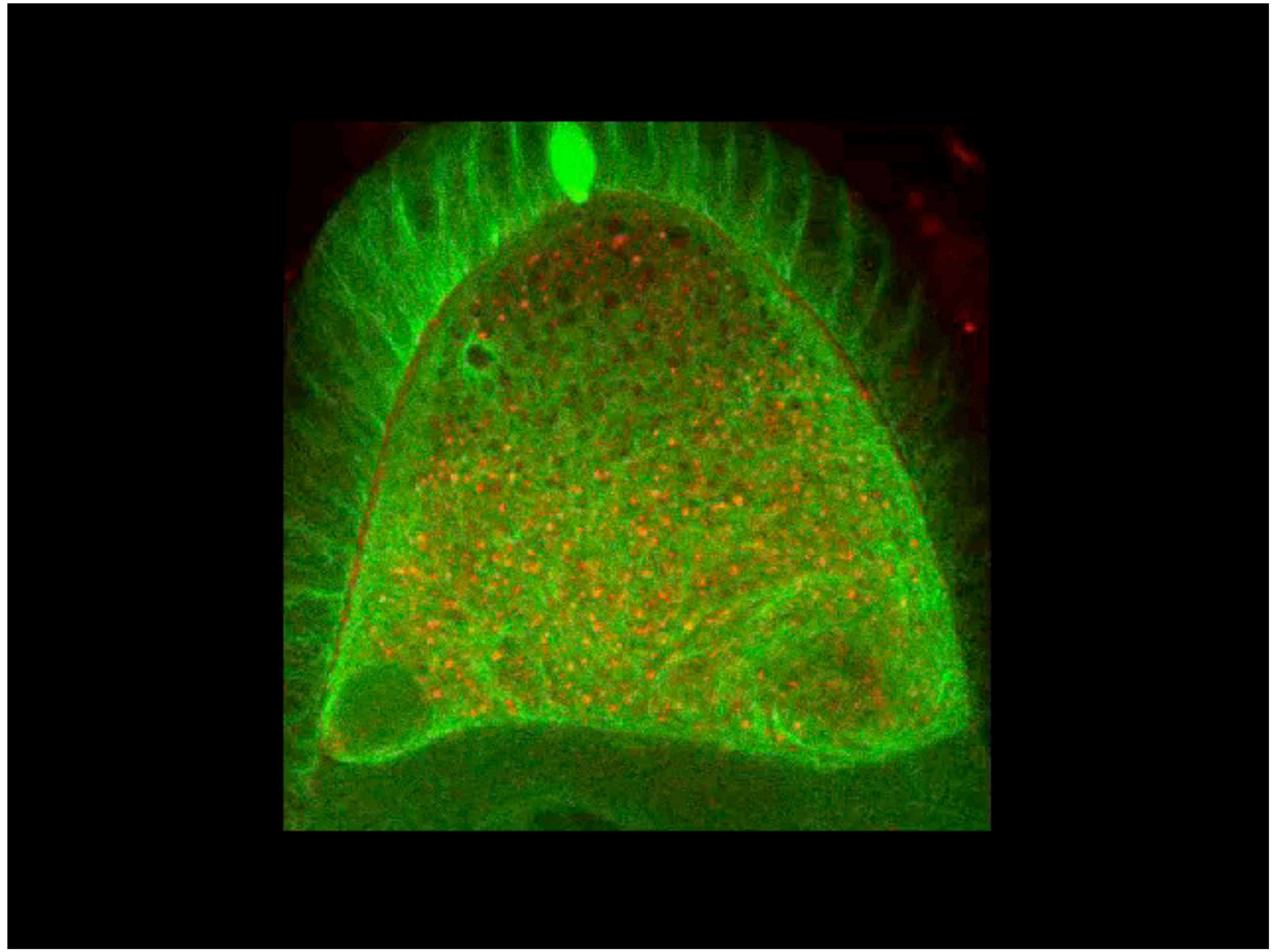
Drosophila embryo



Goldstein lab (Cambridge)

Flow & transport in cells

Drosophila embryo



Goldstein lab (Cambridge)

Intracellular transport

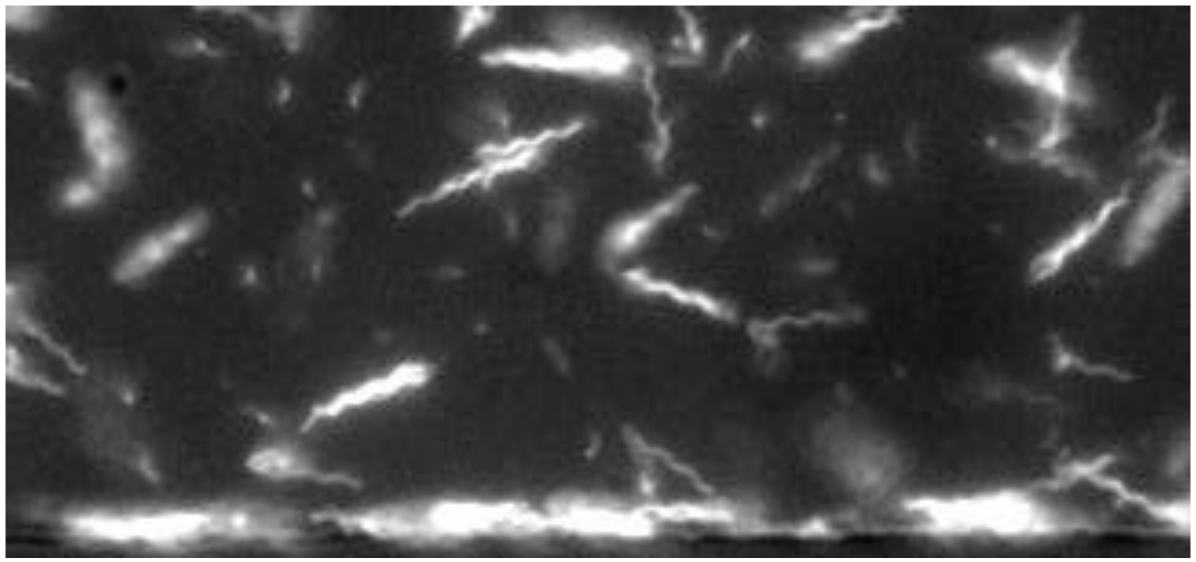
Giant cell

http://damtp.cam.ac.uk/user/gold/movies.html

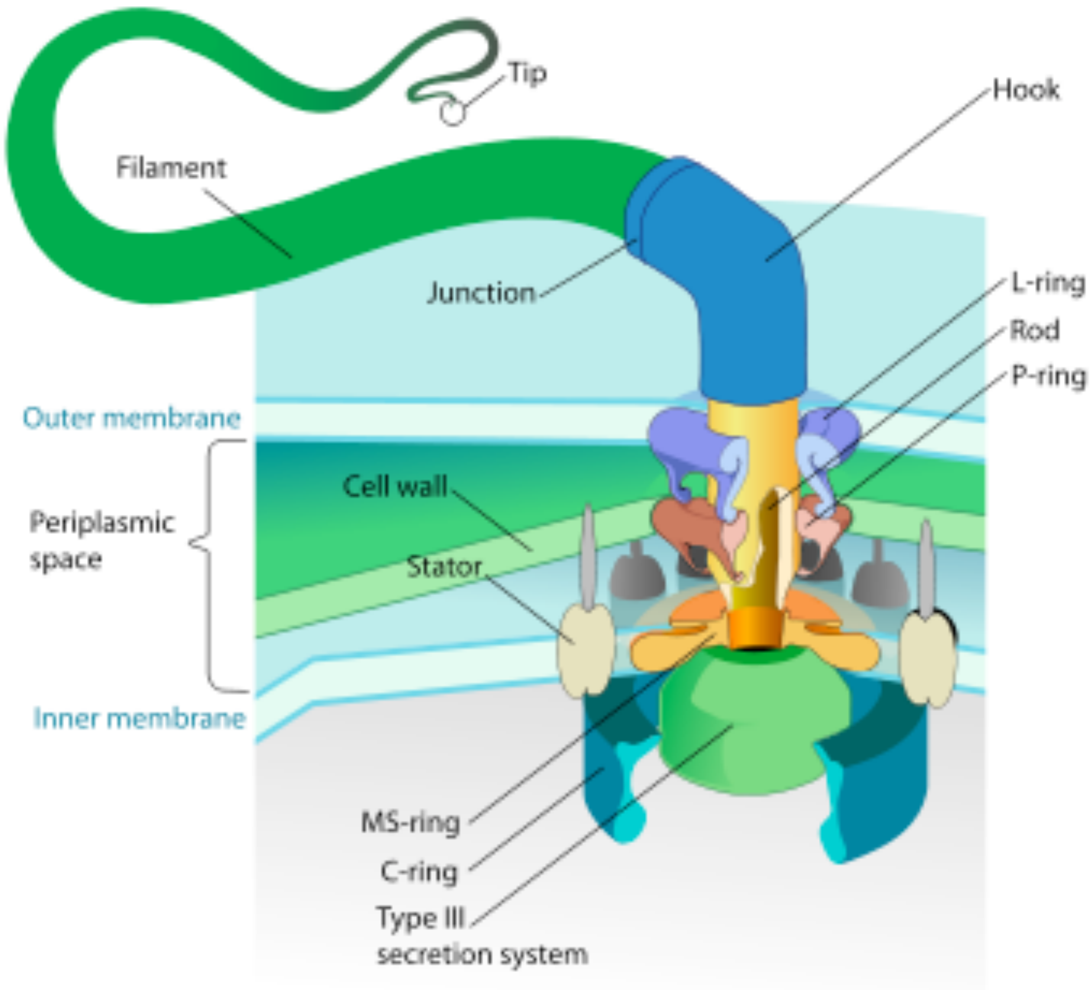
Flow around cells

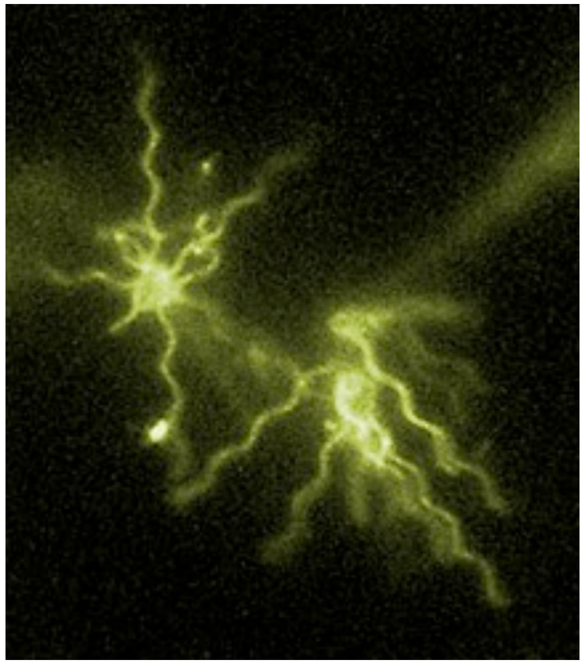
Swimming bacteria

movie: V. Kantsler

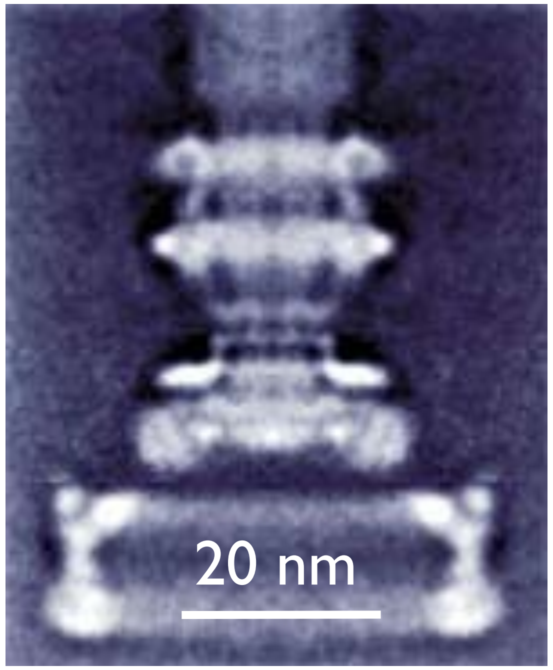


~20 parts





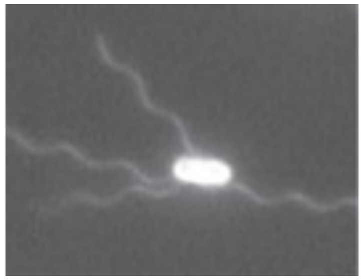
Berg (1999) Physics Today

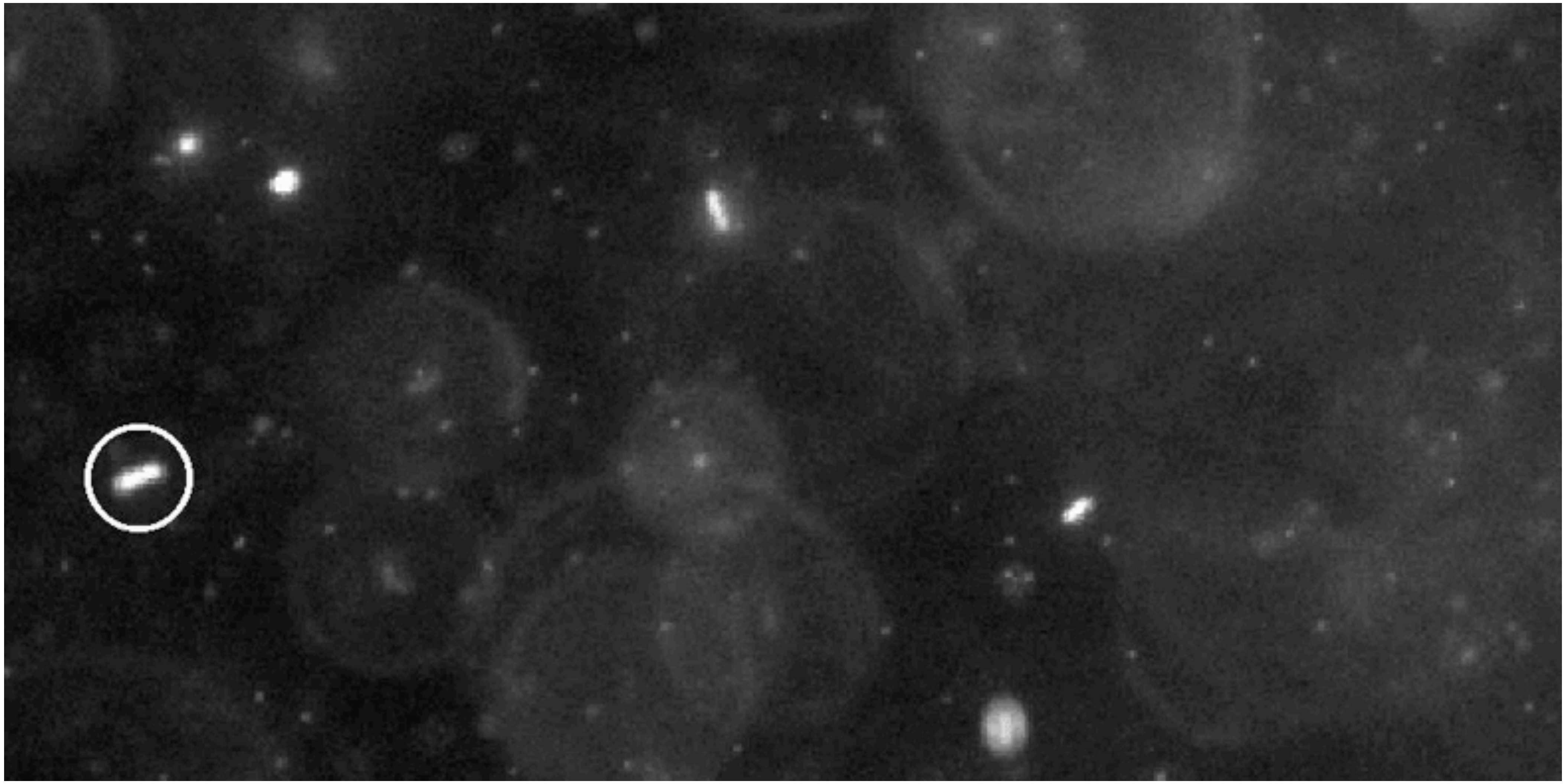


Chen et al (2011) EMBO Journal

source: wiki

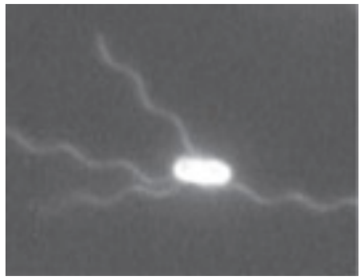
E.coli (non-tumbling HCB 437)

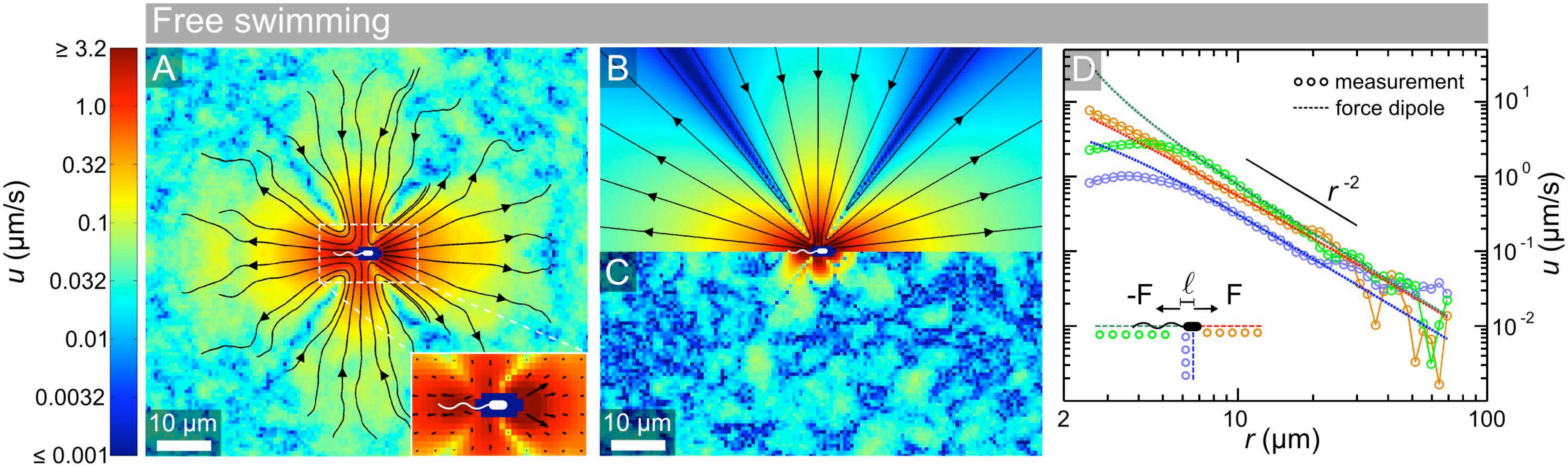




Drescher, Dunkel, Ganguly, Cisneros, Goldstein (2011) PNAS

E.coli (non-tumbling HCB 437)





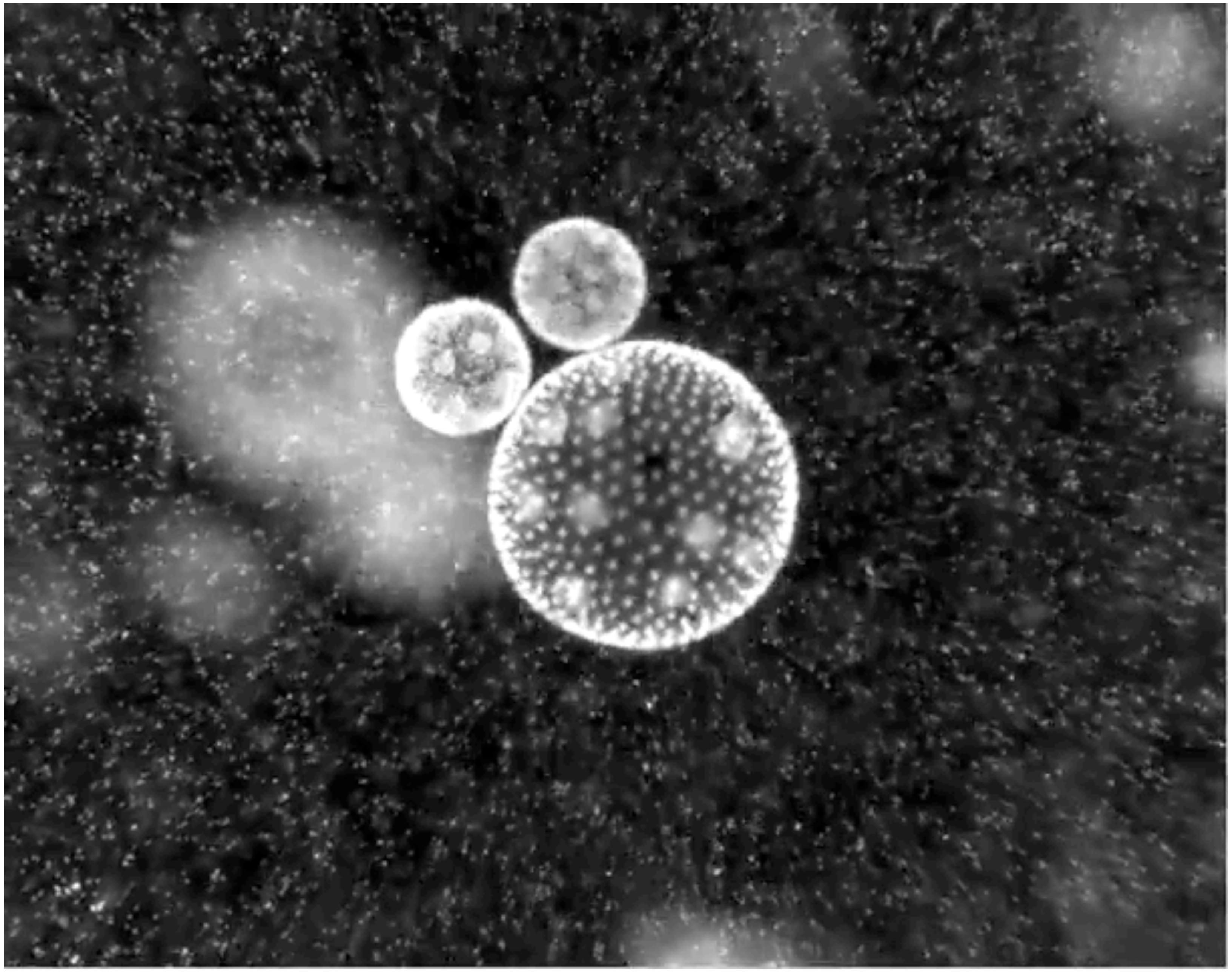
$$\boldsymbol{u}(\boldsymbol{r}) = \frac{A}{|\boldsymbol{r}|^2}\left[3(\hat{\boldsymbol{r}}.\hat{\boldsymbol{d}})^2 - 1\right]\hat{\boldsymbol{r}}, \quad A = \frac{\ell F}{8\pi\eta}, \quad \hat{\boldsymbol{r}} = \frac{\boldsymbol{r}}{|\boldsymbol{r}|}$$

$$V_0 = 22 \pm 5 \ \ \mu\text{m/s}$$
$$\ell = 1.9 \ \mu\text{m}$$
$$F = 0.42 \ \text{pN}$$

weak 'pusher' dipole

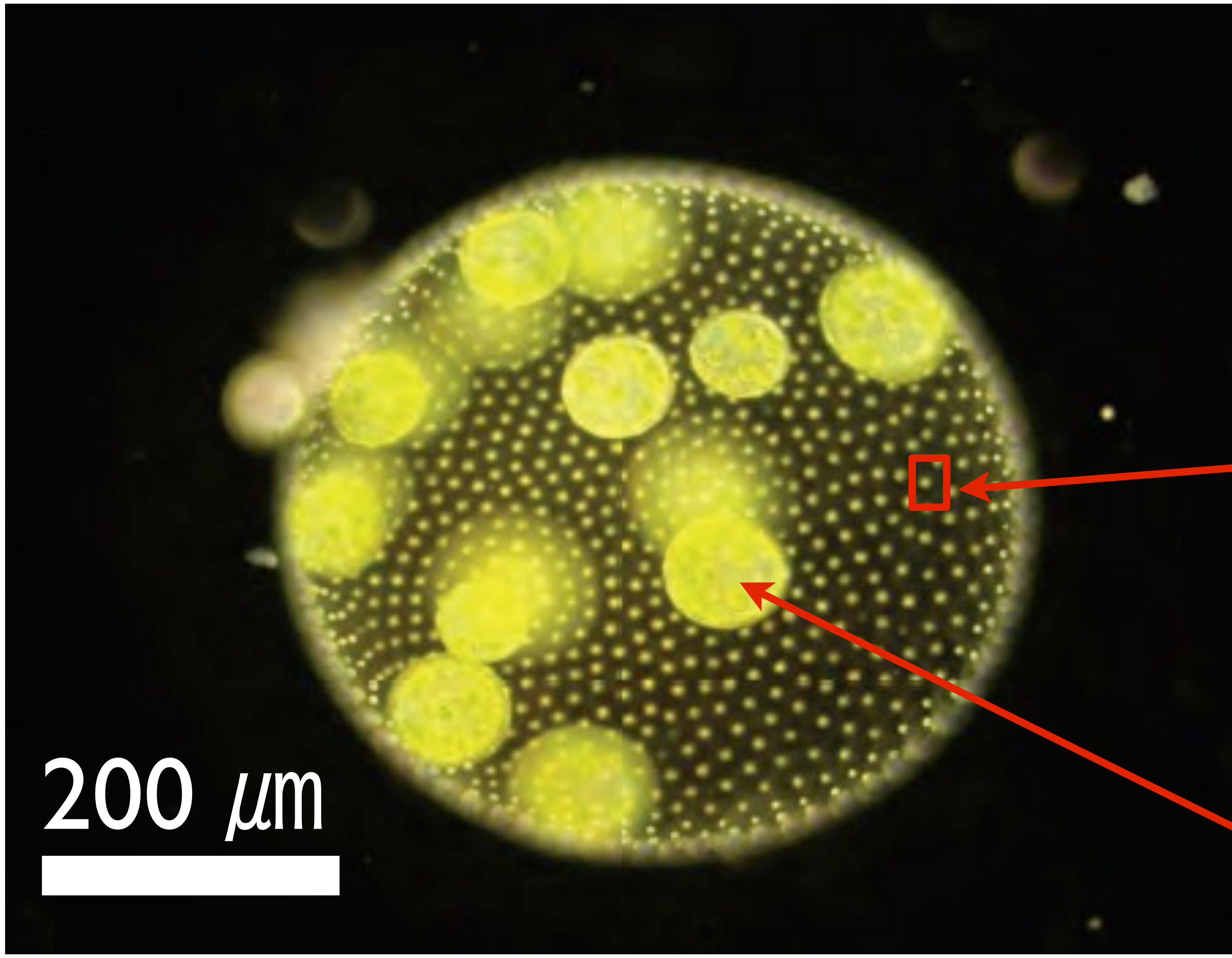
Drescher, Dunkel, Ganguly, Cisneros, Goldstein (2011) PNAS

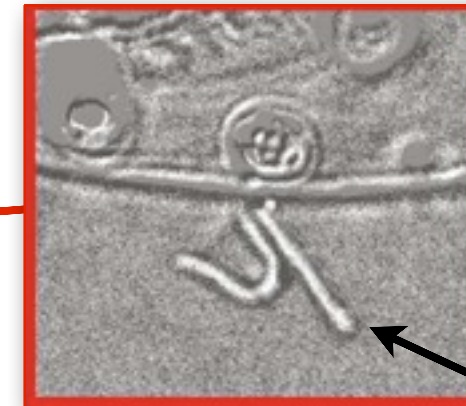
Volvox (dancing)

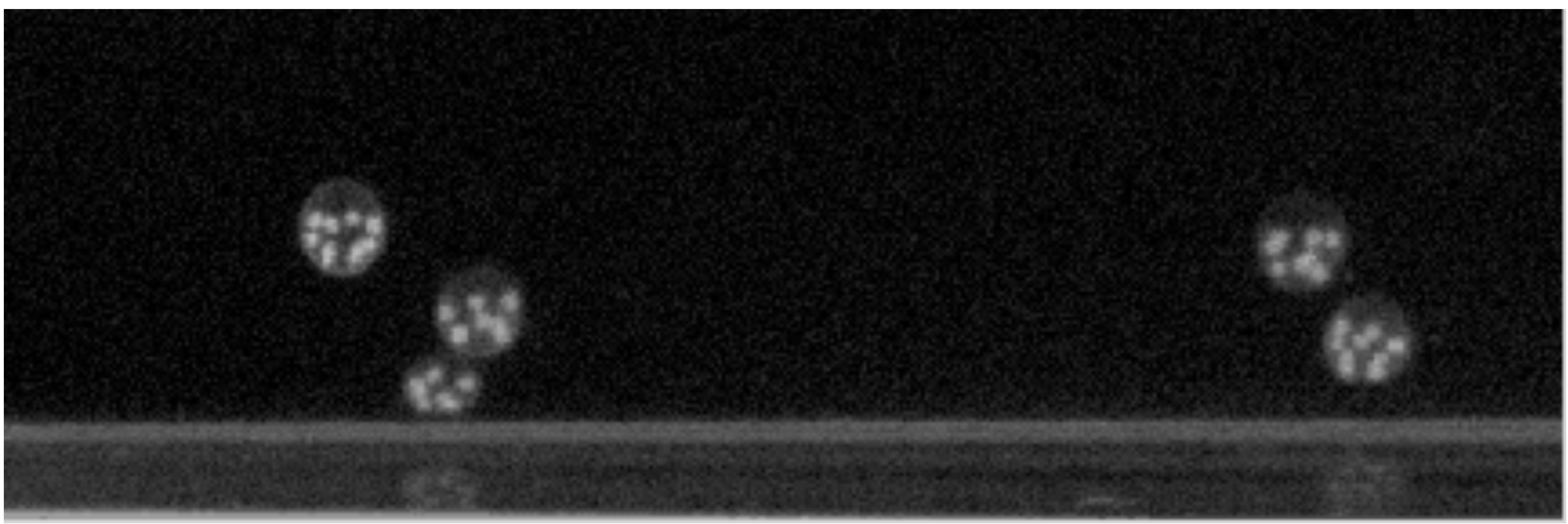


Goldstein lab (Cambridge)

Volvox carteri







Drescher et al (2010) PRL

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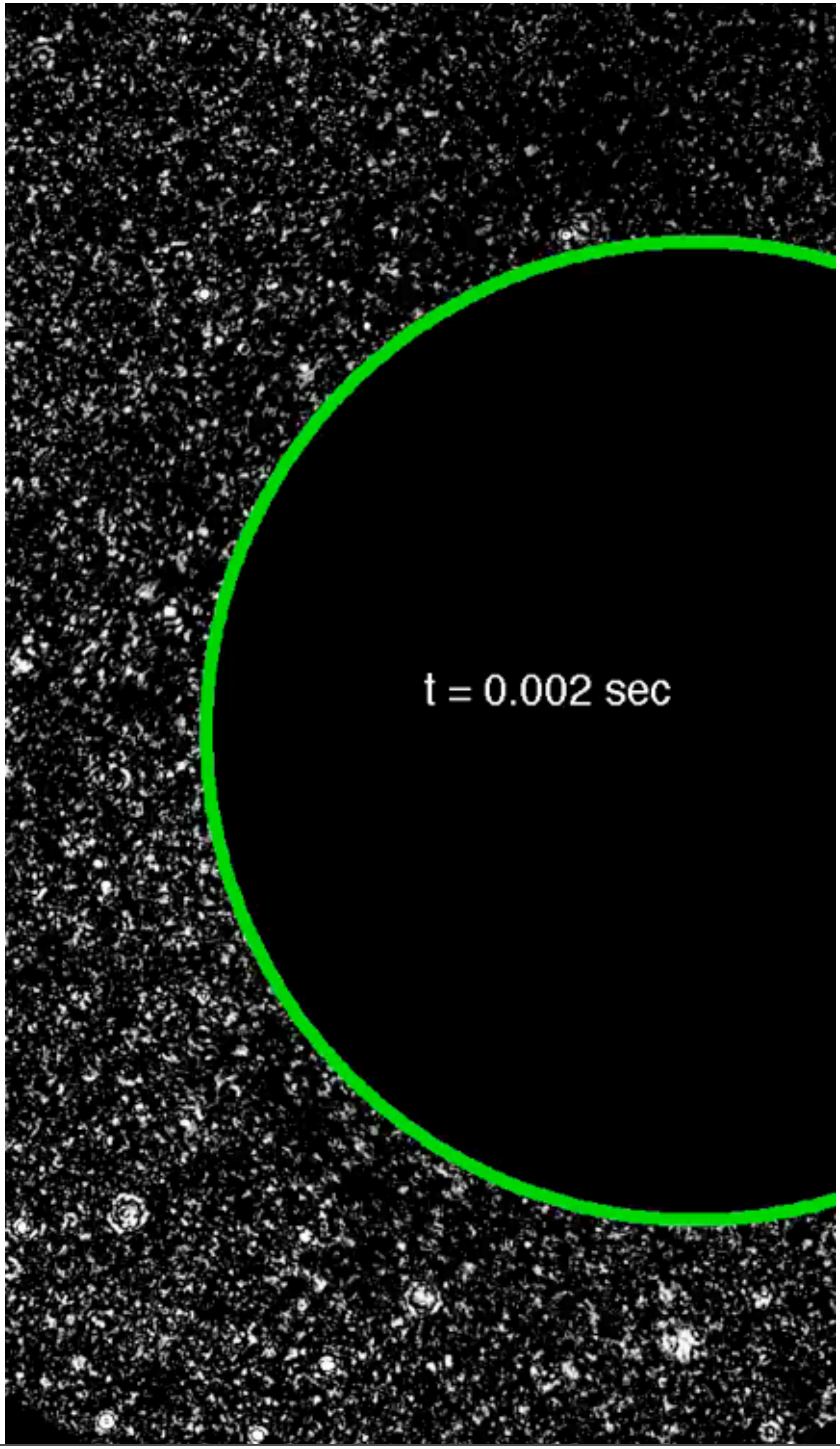
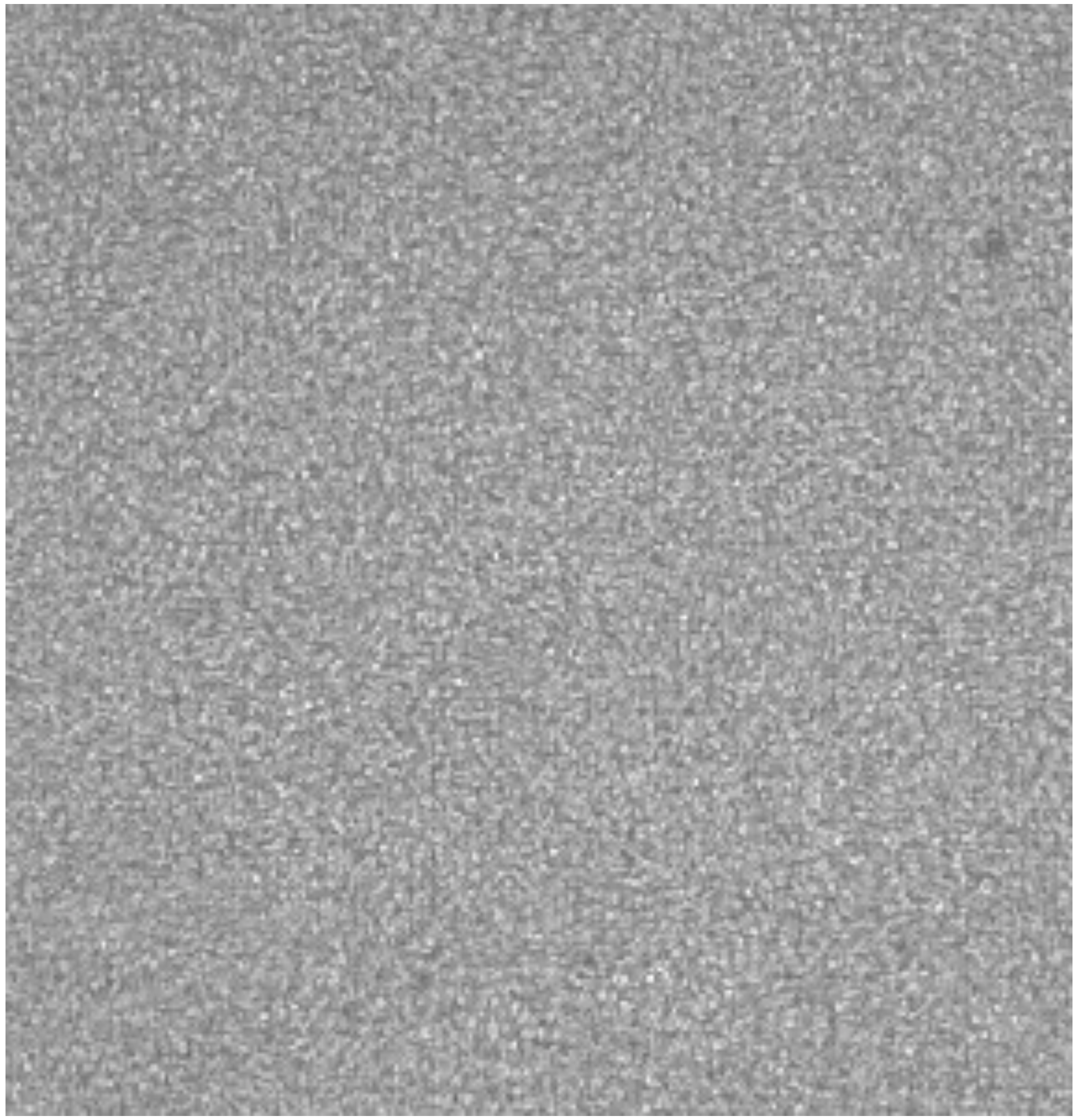


Volvox

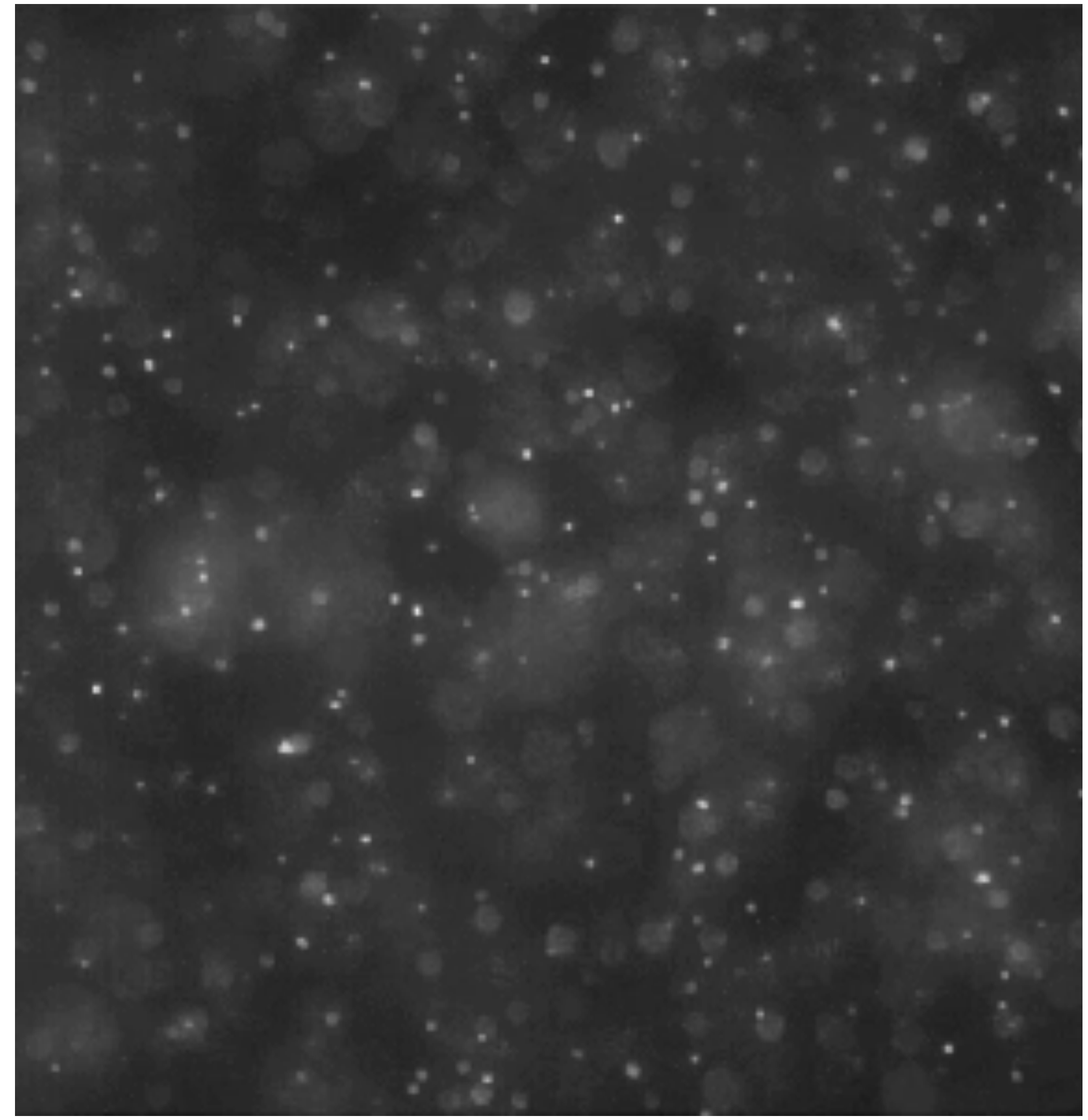
Meta-chronal waves

Brumley et al (2012) PRL

Brownian tracer particles in a bacterial suspension



Bacillus subtilis

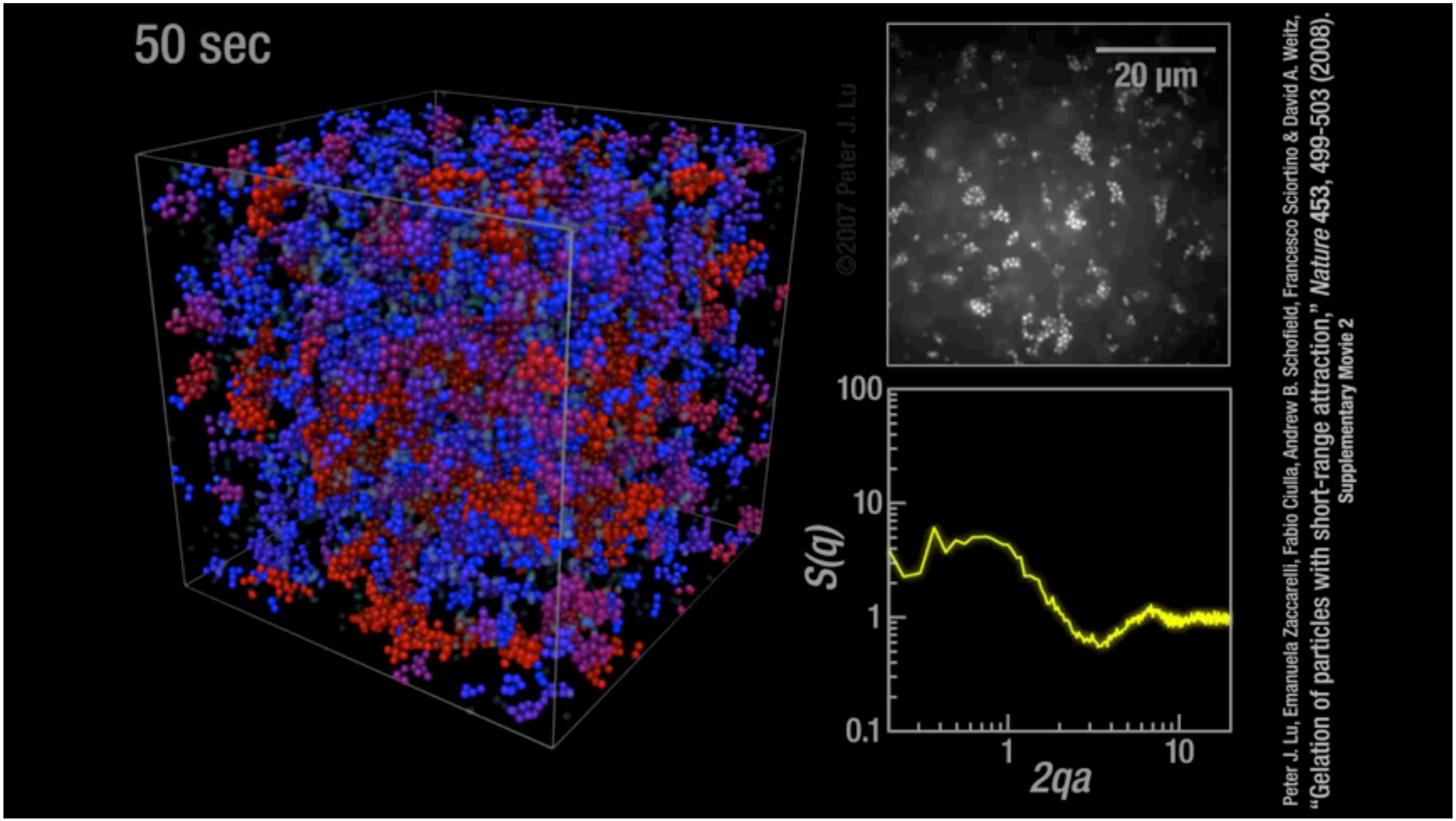


Tracer colloids

PRL 2013

Ecological implications
&
technical applications

Colloidal gel formation via spinoidal decomposition



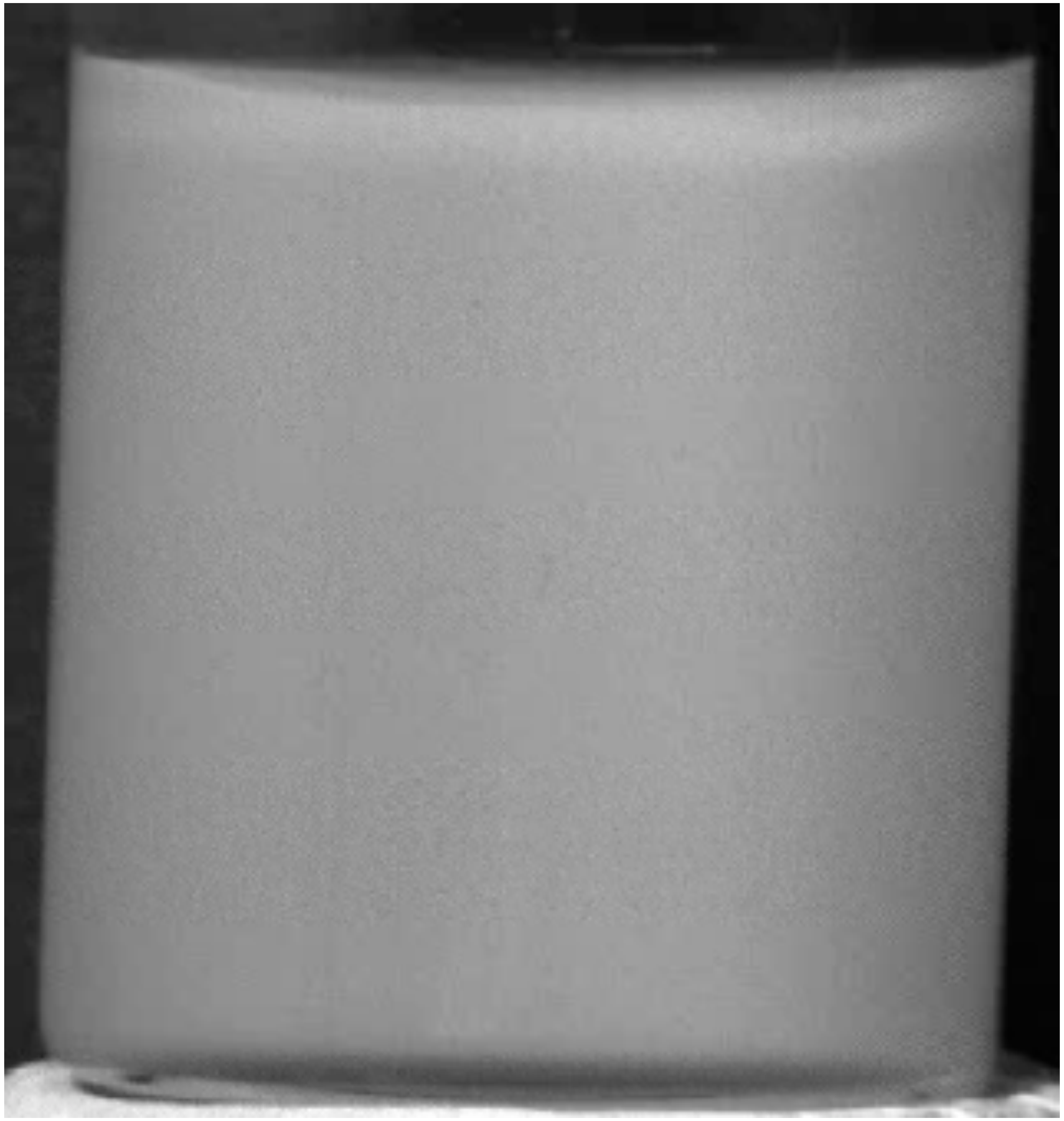
Peter Lu

Sedimentation

Mississippi

NASA Earth Observatory

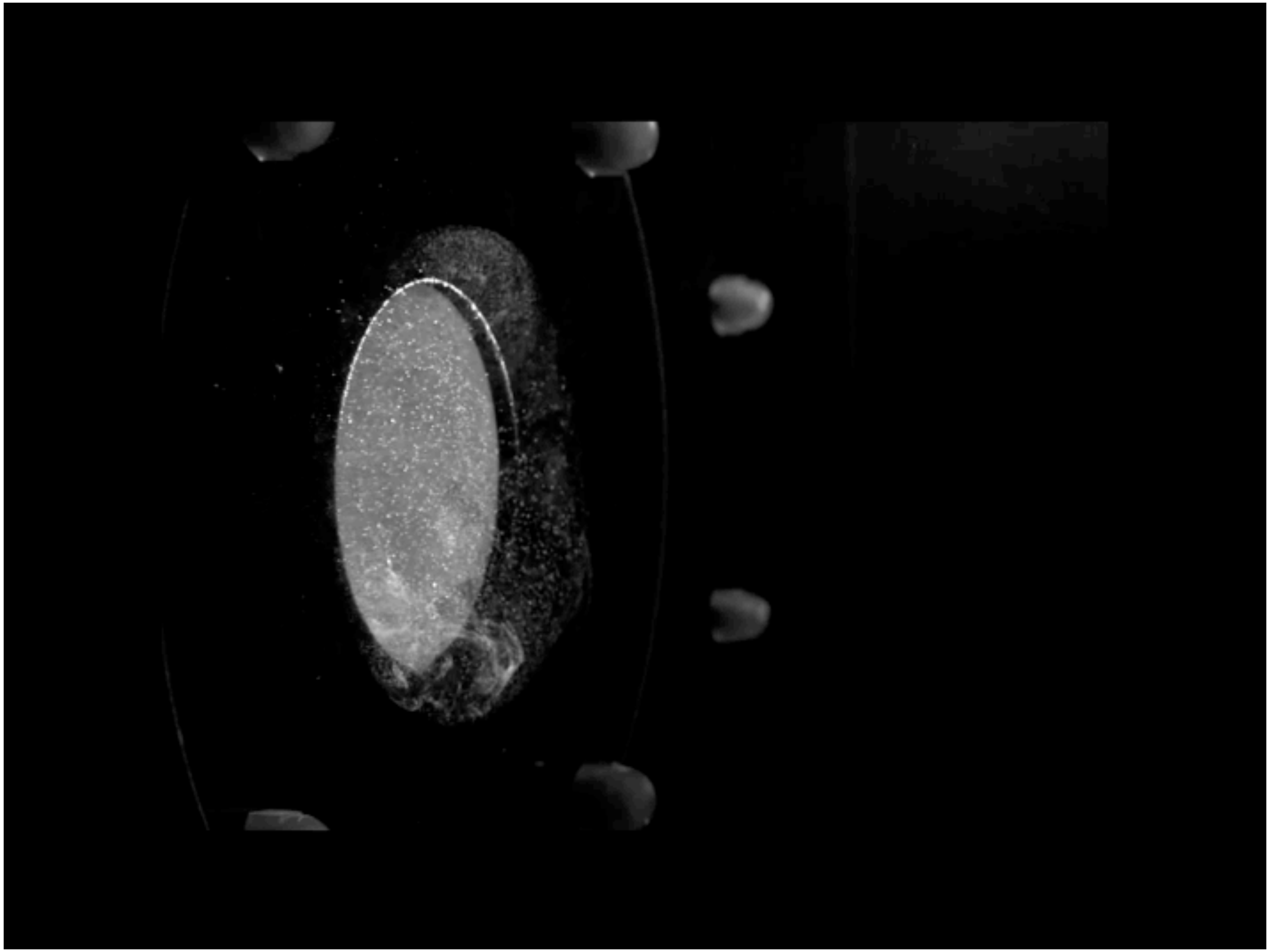
Sedimentation



Particle separation

Falk Renth

Water knots



Irvine lab (Chicago)