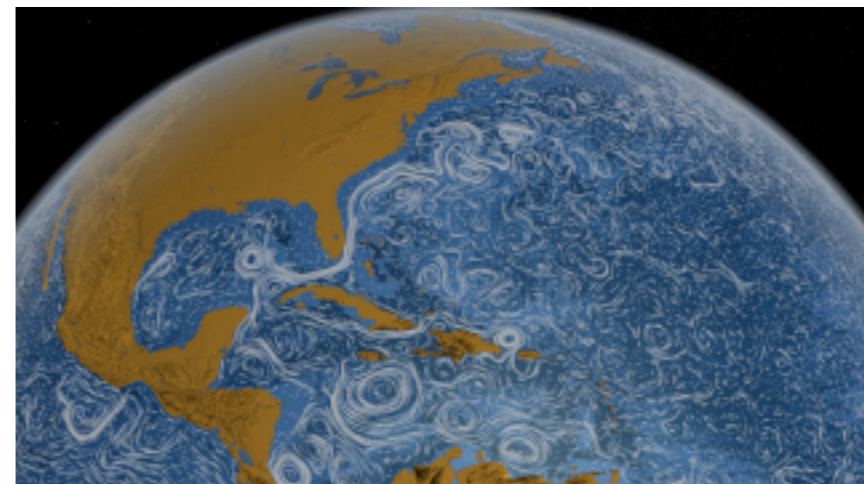
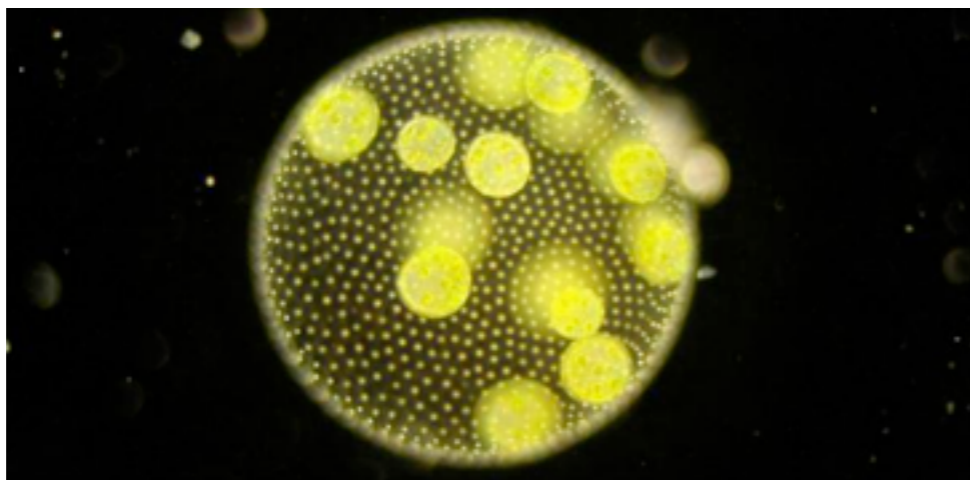
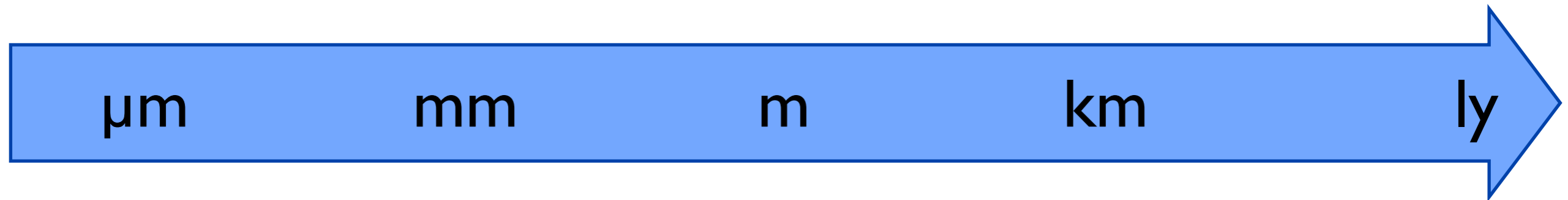
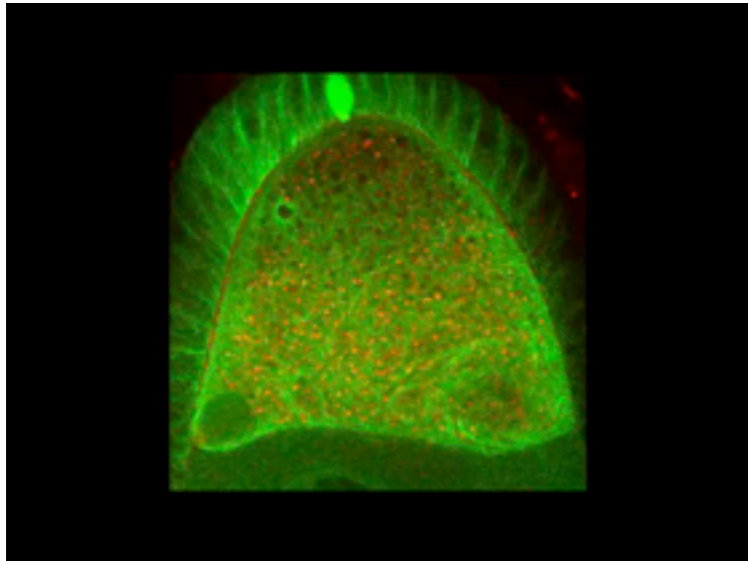


18.354 Nonlinear Dynamics II

Towards hydrodynamics

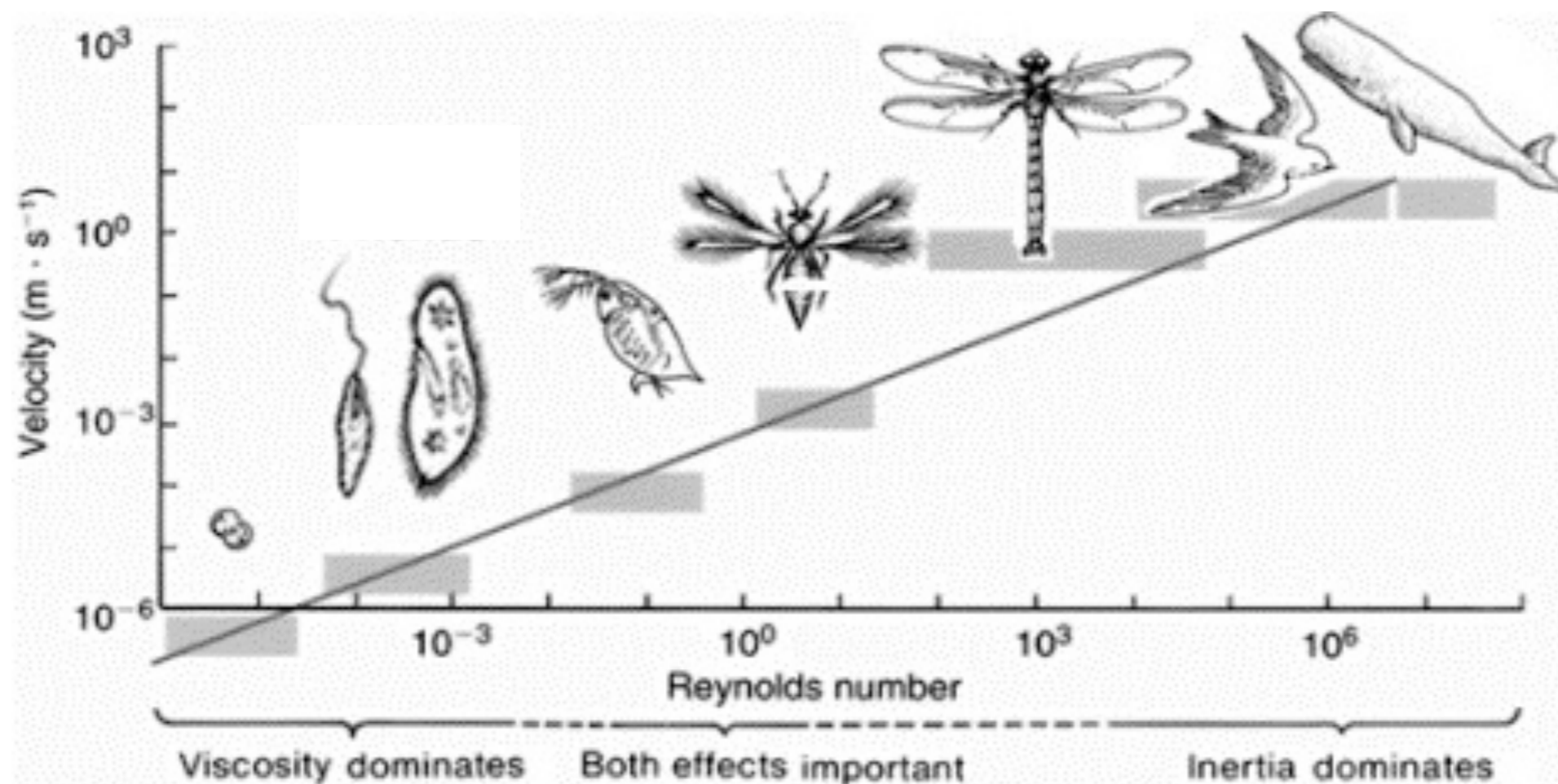
Jörn Dunkel

Hydrodynamics works at **all** these scales!



Some typical Reynolds numbers

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



High-Re vs Low-Re



dunkel@math.mit.edu

VERY High-Re



dunkel@math.mit.edu

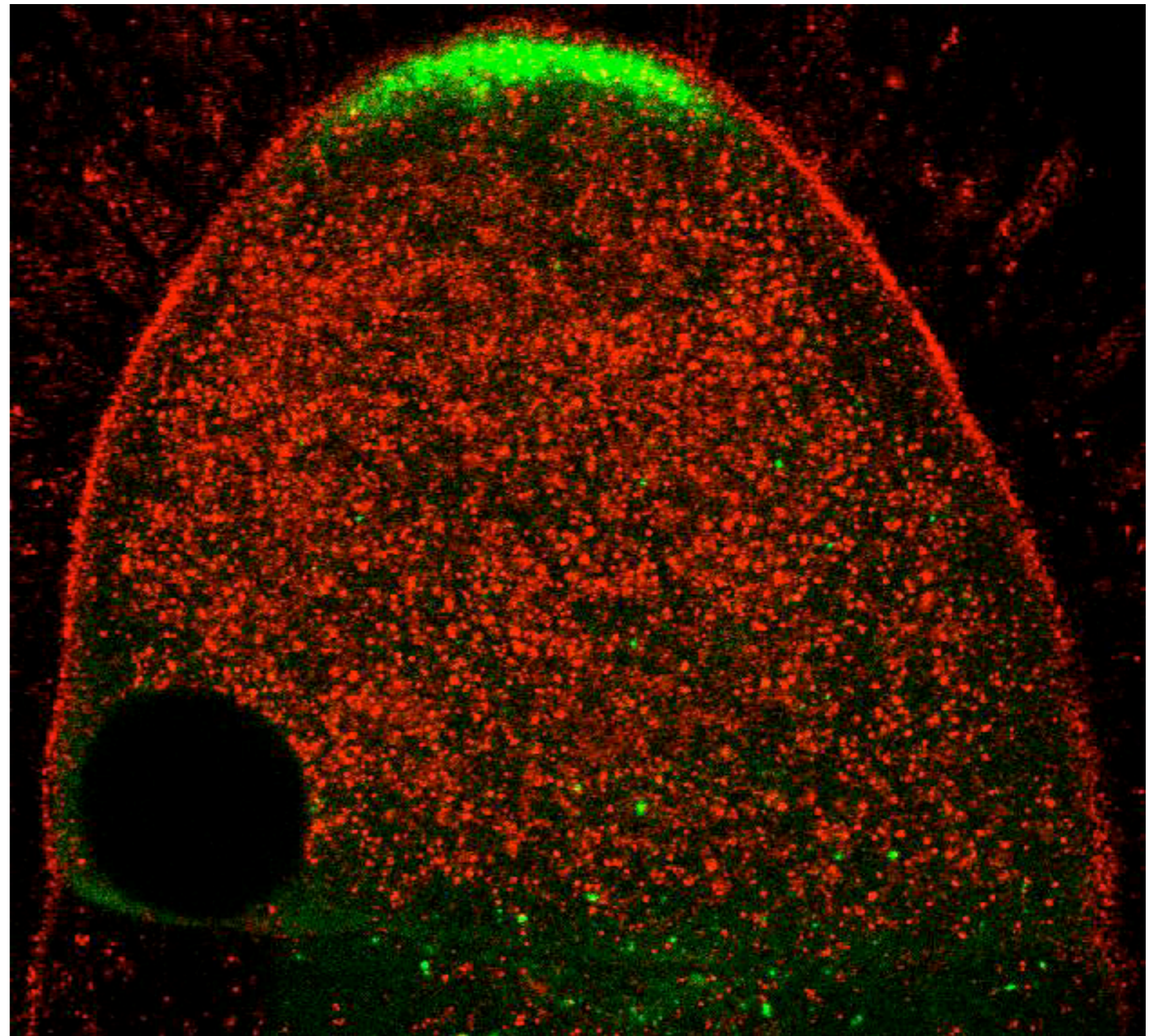
Low-Re (laminar) flow



Flow & transport **in** cells



Drosophila
embryo



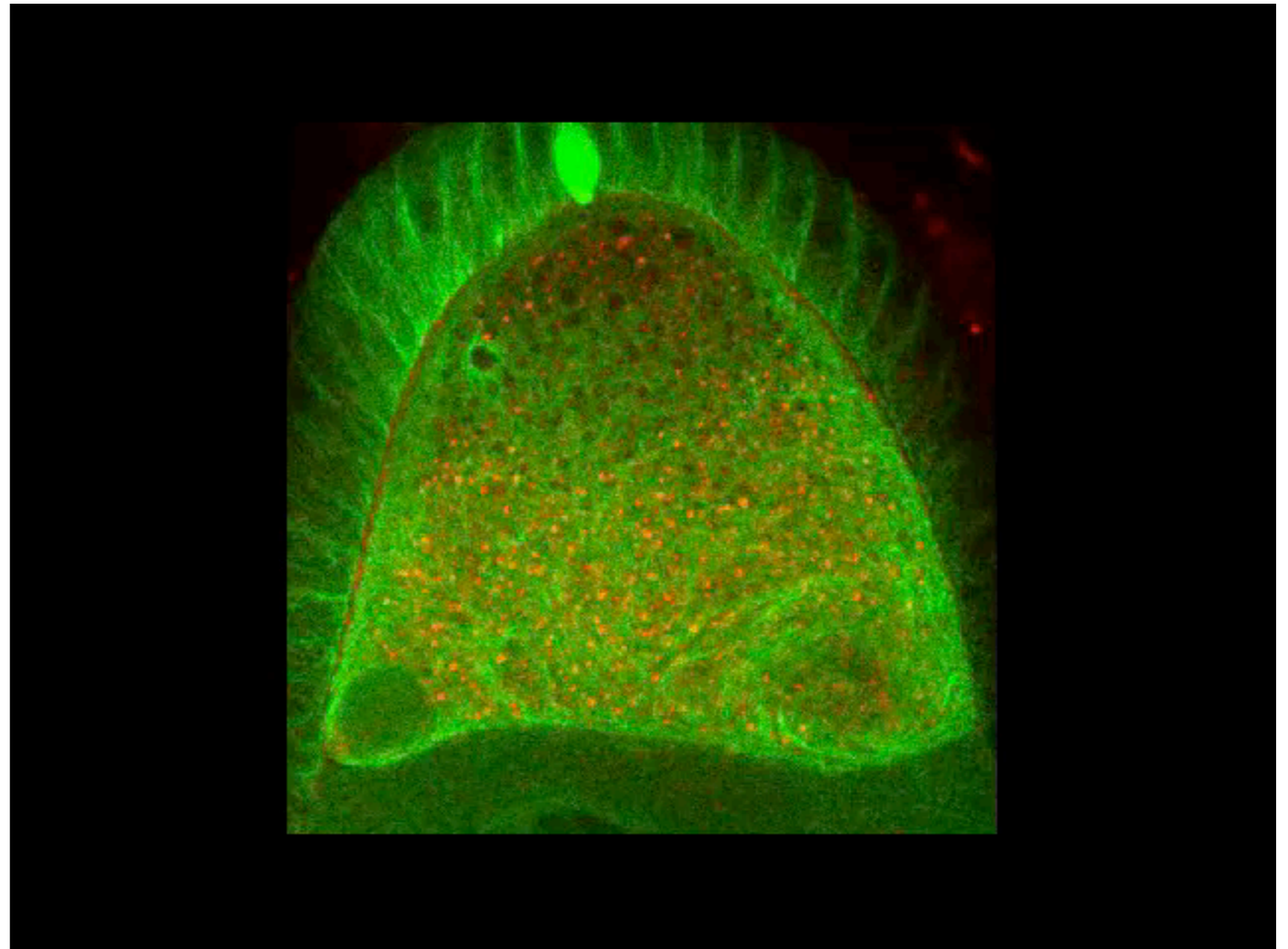
Goldstein lab (Cambridge)



Flow & transport in cells



Drosophila
embryo



Goldstein lab (Cambridge)



Intracellular transport

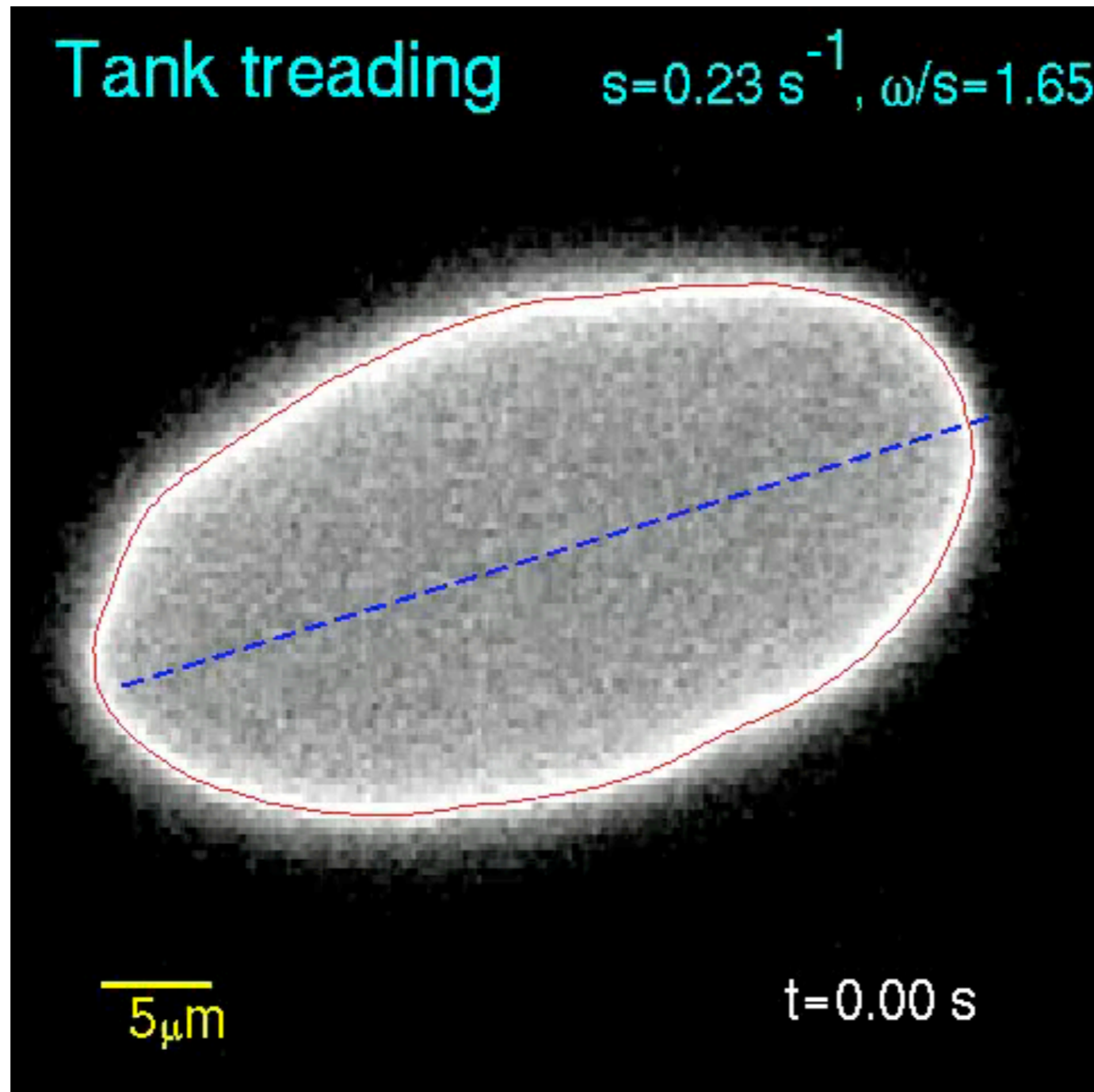


Giant cell

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



Vesicles in a shear flow

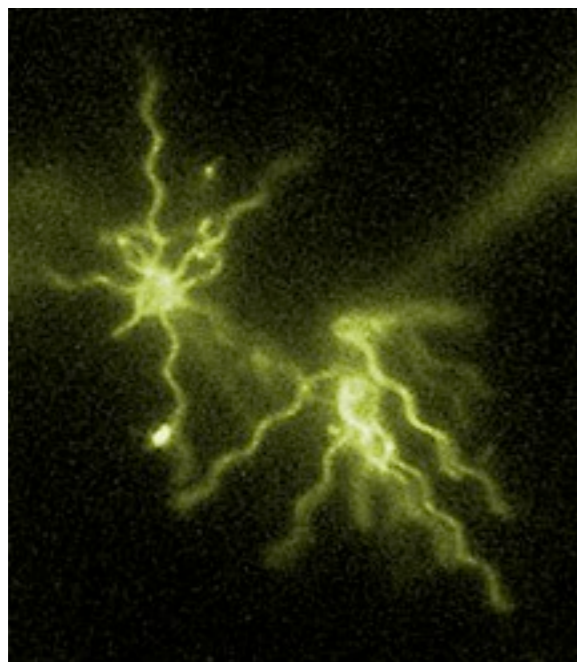
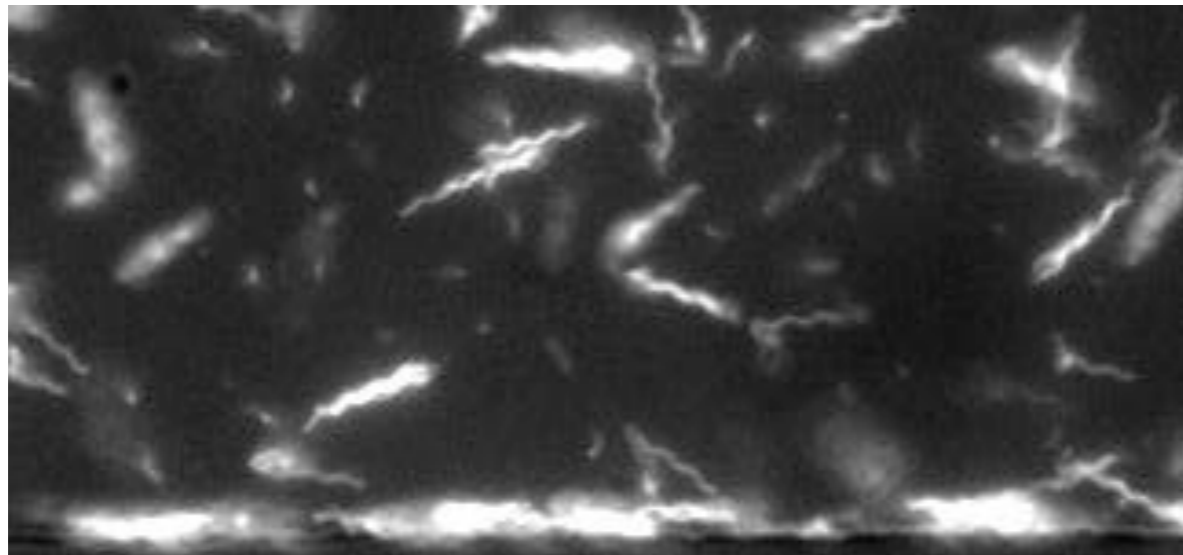


model for
blood cells
dynamics

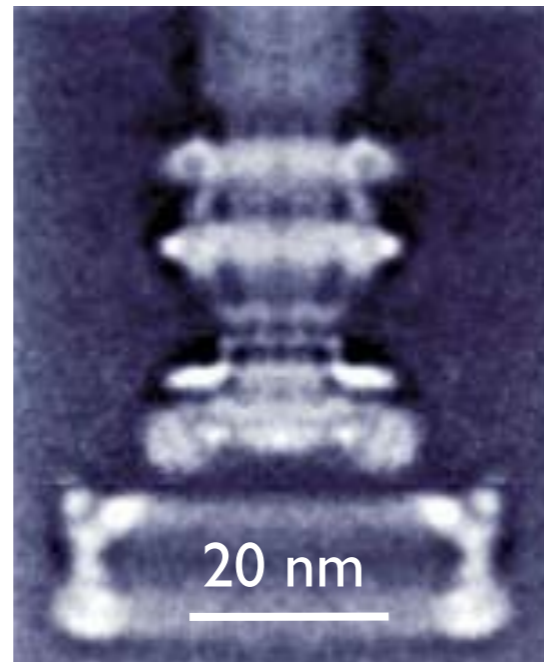
Vasily Kantsler

Swimming bacteria

movie: V. Kantsler

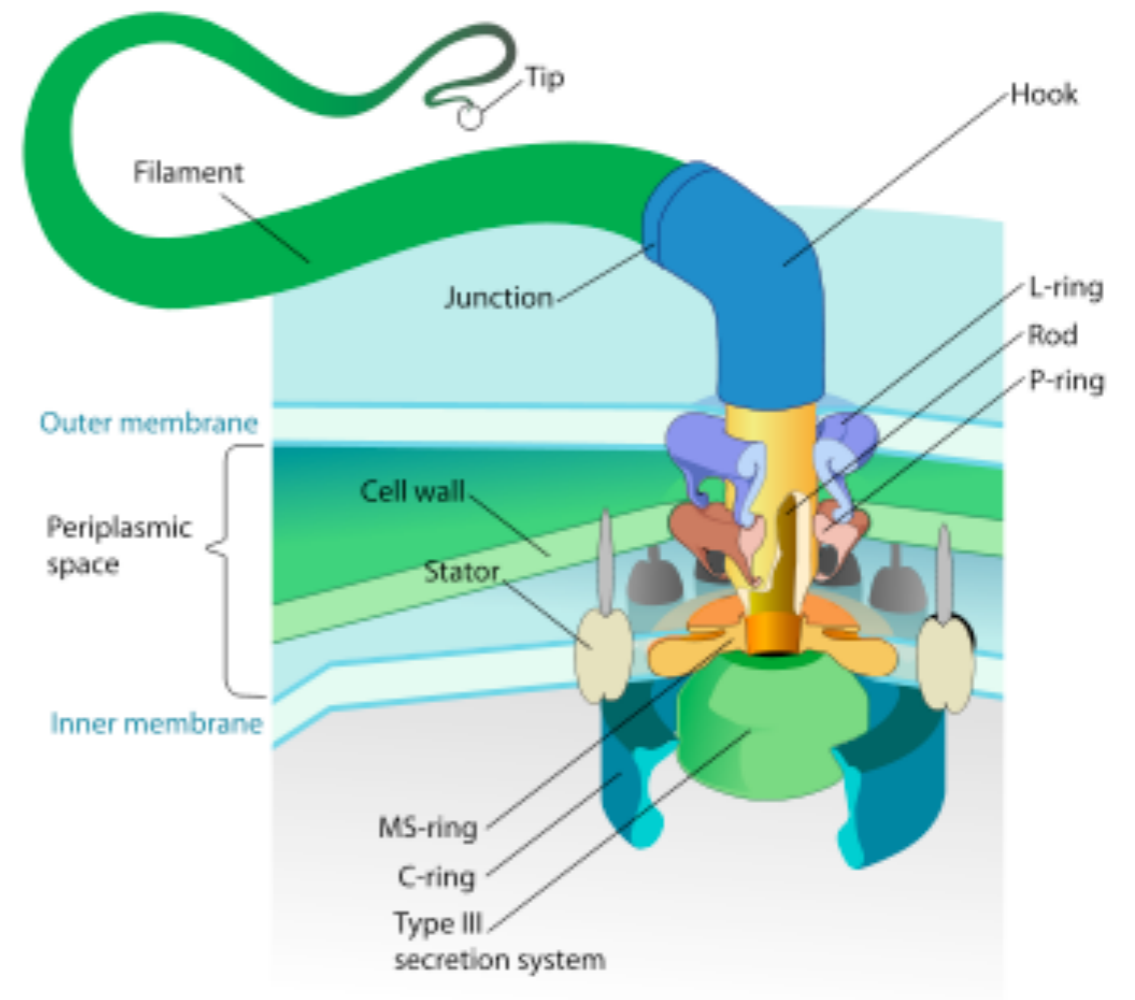


Berg (1999) Physics Today



Chen et al (2011) EMBO Journal

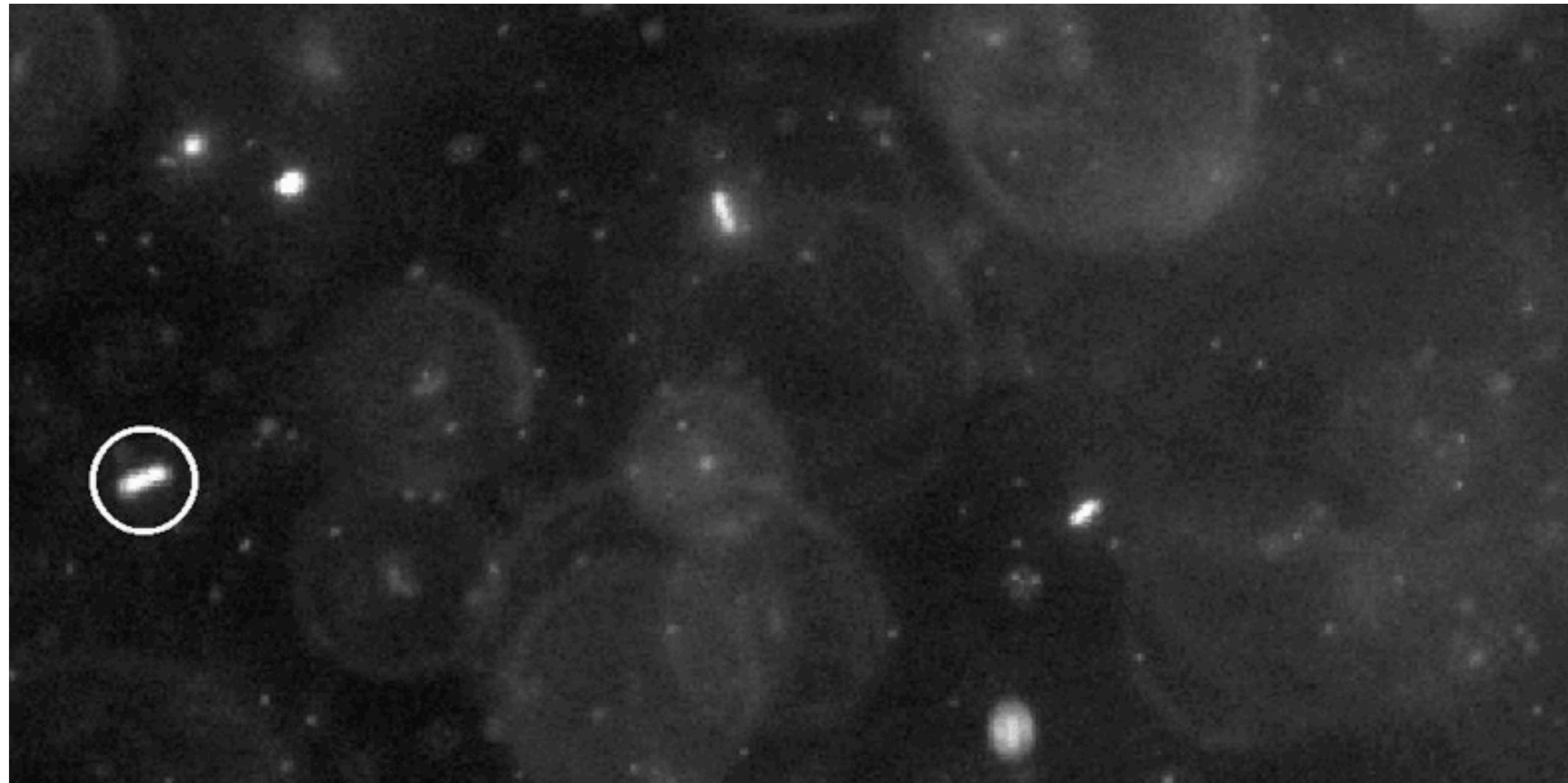
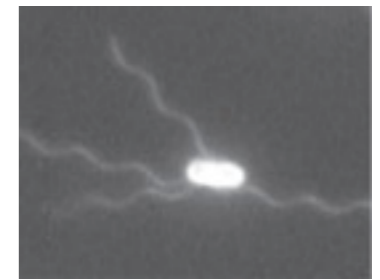
~20 parts



source: wiki

dunkel@math.mit.edu

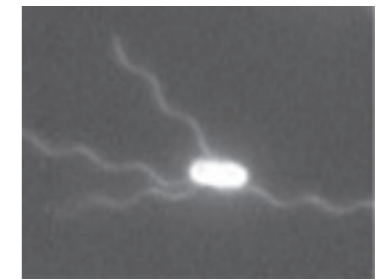
E. coli (non-tumbling HCB 437)



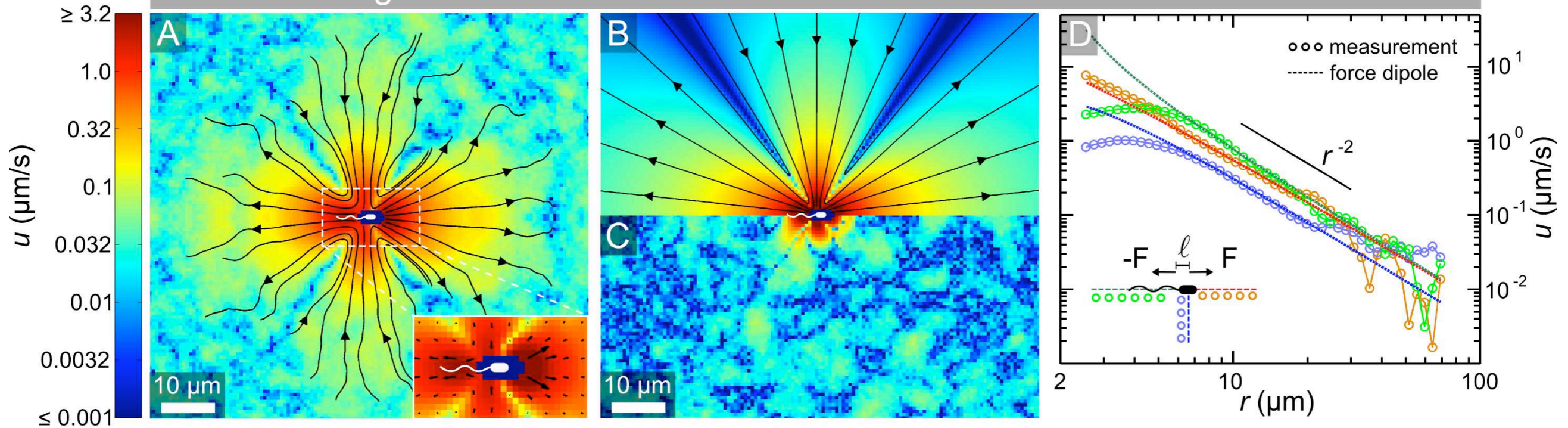
Drescher, Dunkel, Ganguly, Cisneros, Goldstein (2011) PNAS



E.coli (non-tumbling HCB 437)



Free swimming



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

$$V_0 = 22 \pm 5 \text{ } \mu\text{m/s}$$

$$\ell = 1.9 \text{ } \mu\text{m}$$

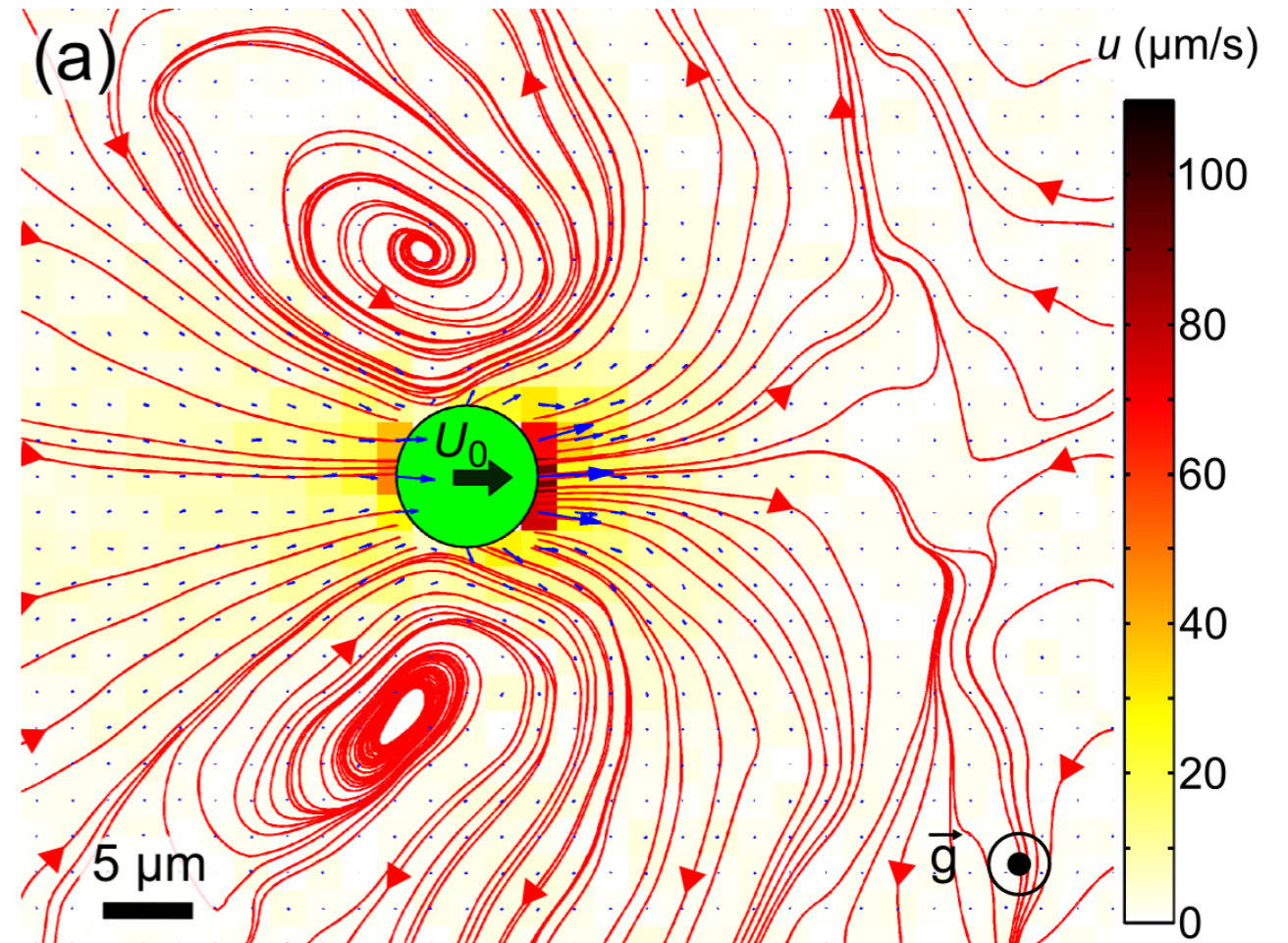
$$F = 0.42 \text{ pN}$$

weak 'pusher' dipole

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



Chlamydomonas



Movie: Jeff Guasto (TUFTS)

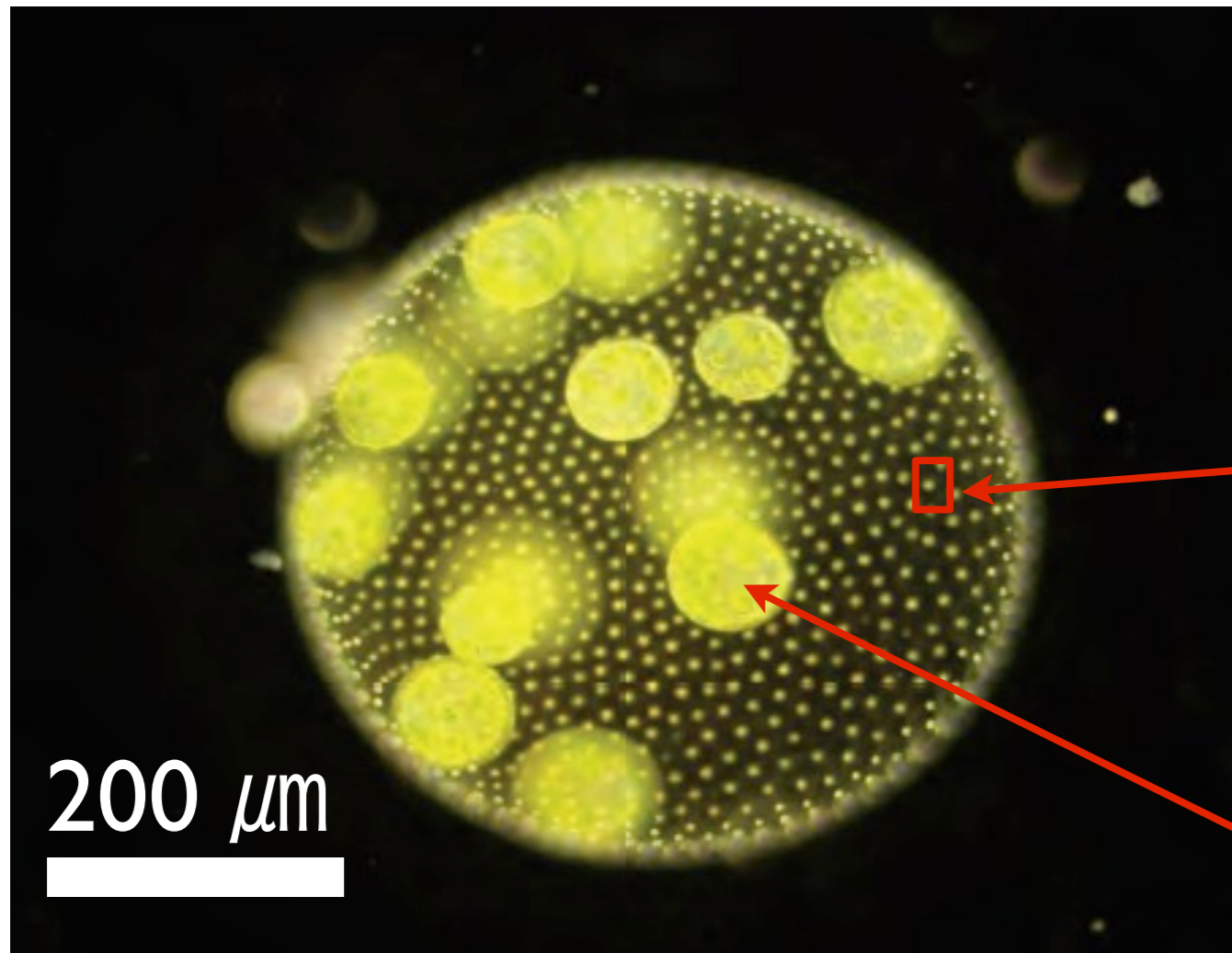
Drescher et al PRL 2010
Guasto et al PRL 2010

‘puller’

size $\sim 20 \mu\text{m}$
speed $\sim 100 \mu\text{m/s}$
beat frequency $\sim 30 \text{ Hz}$



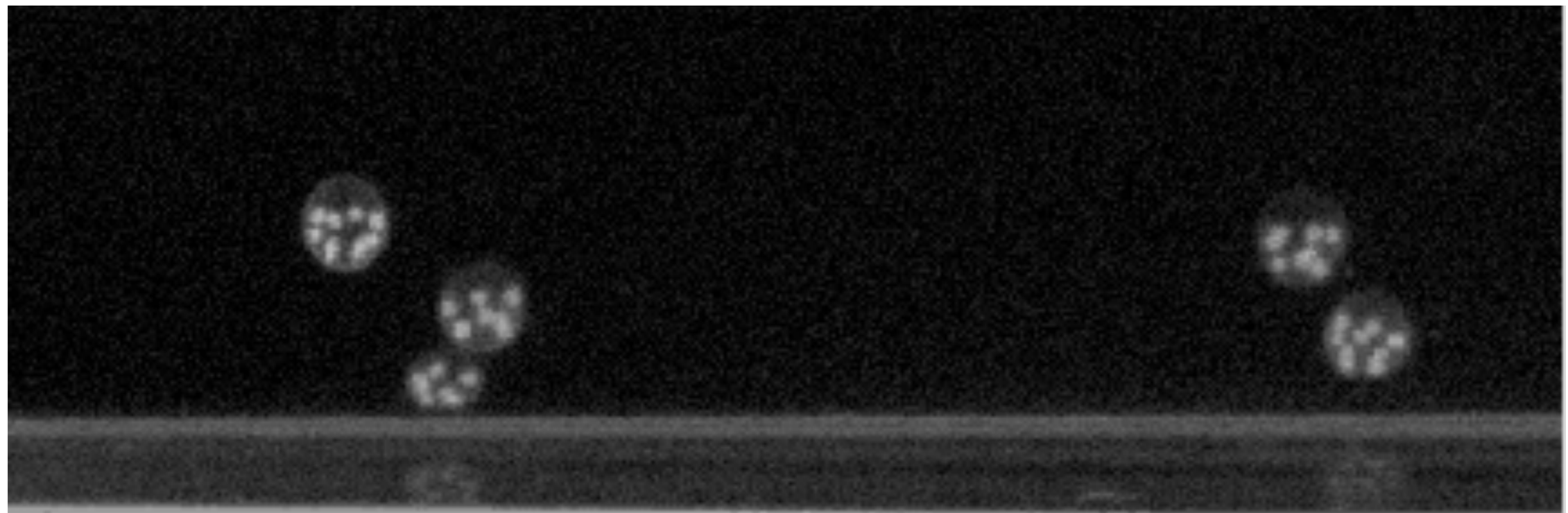
Volvox carteri



somatic
cell

cilia

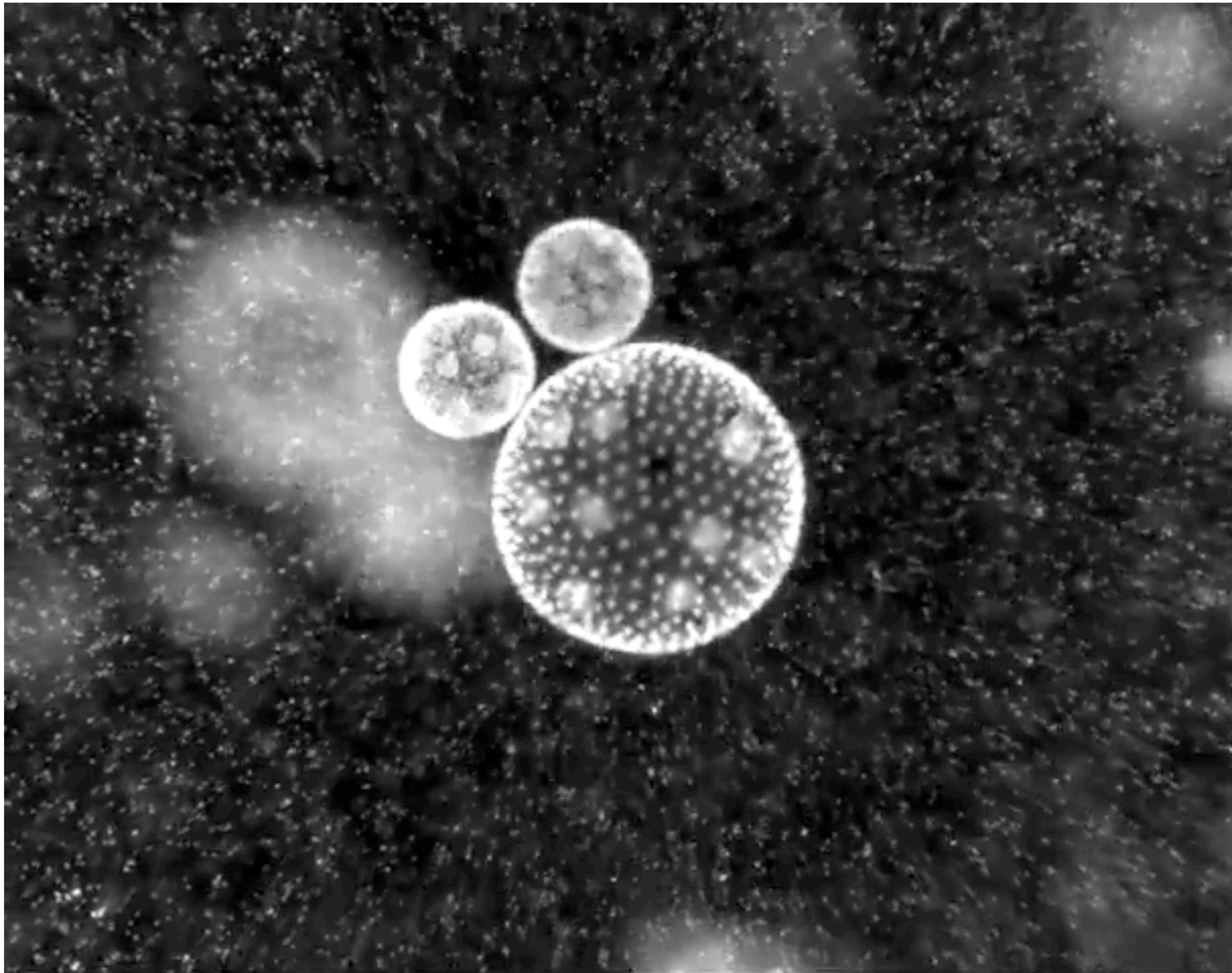
daughter colony



Drescher et al (2010) PRL

dunkel@math.mit.edu

Volvox



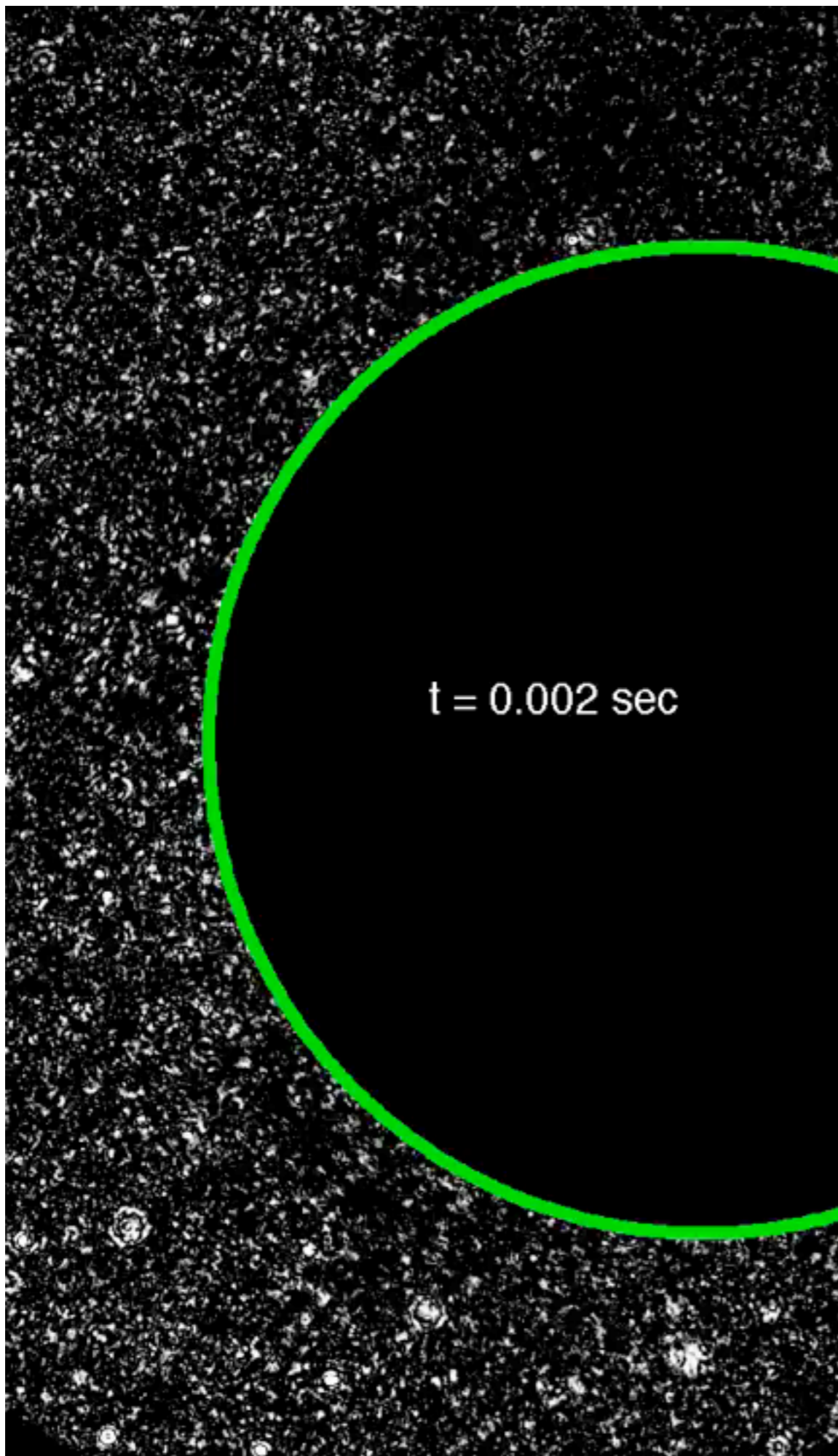
Goldstein lab (Cambridge)



Volvox

meta-chronal waves

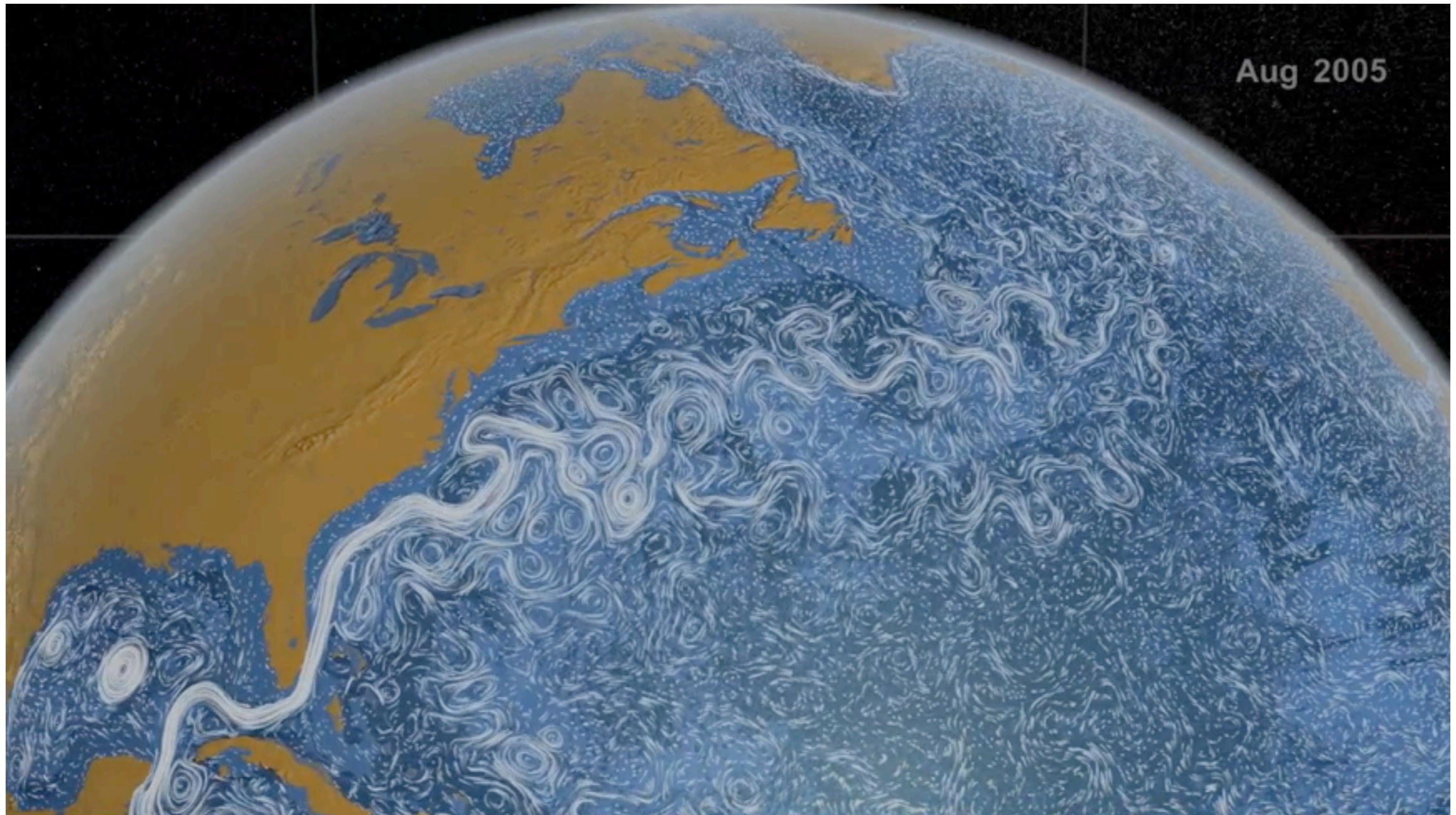
Brumley et al (2012) PRL



meters



kilometers (miles)



http://svs.gsfc.nasa.gov/site_usage/site_reqts.html



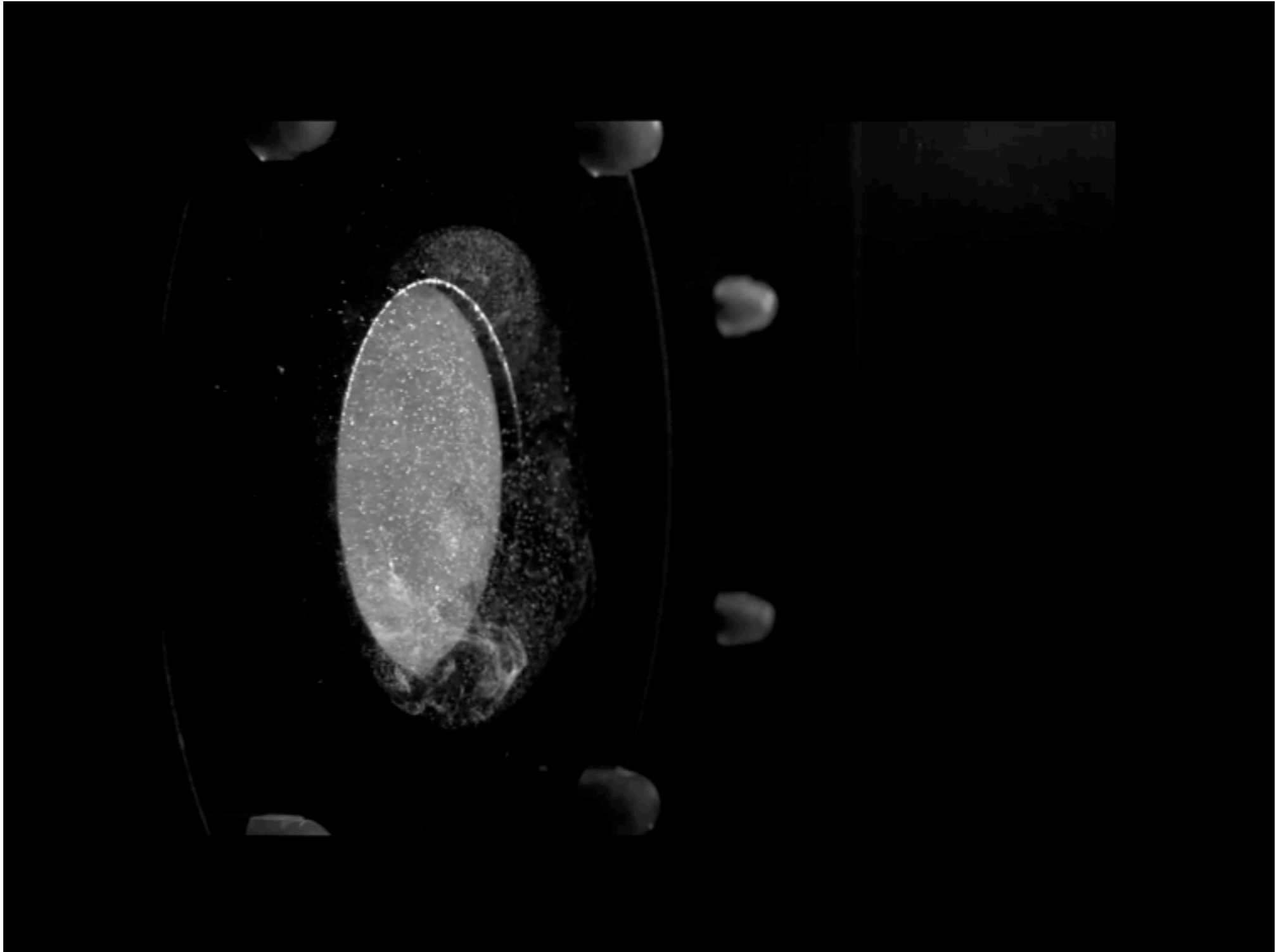
Galactic & intergalactic gas dynamics



horsehead nebula (hubble)



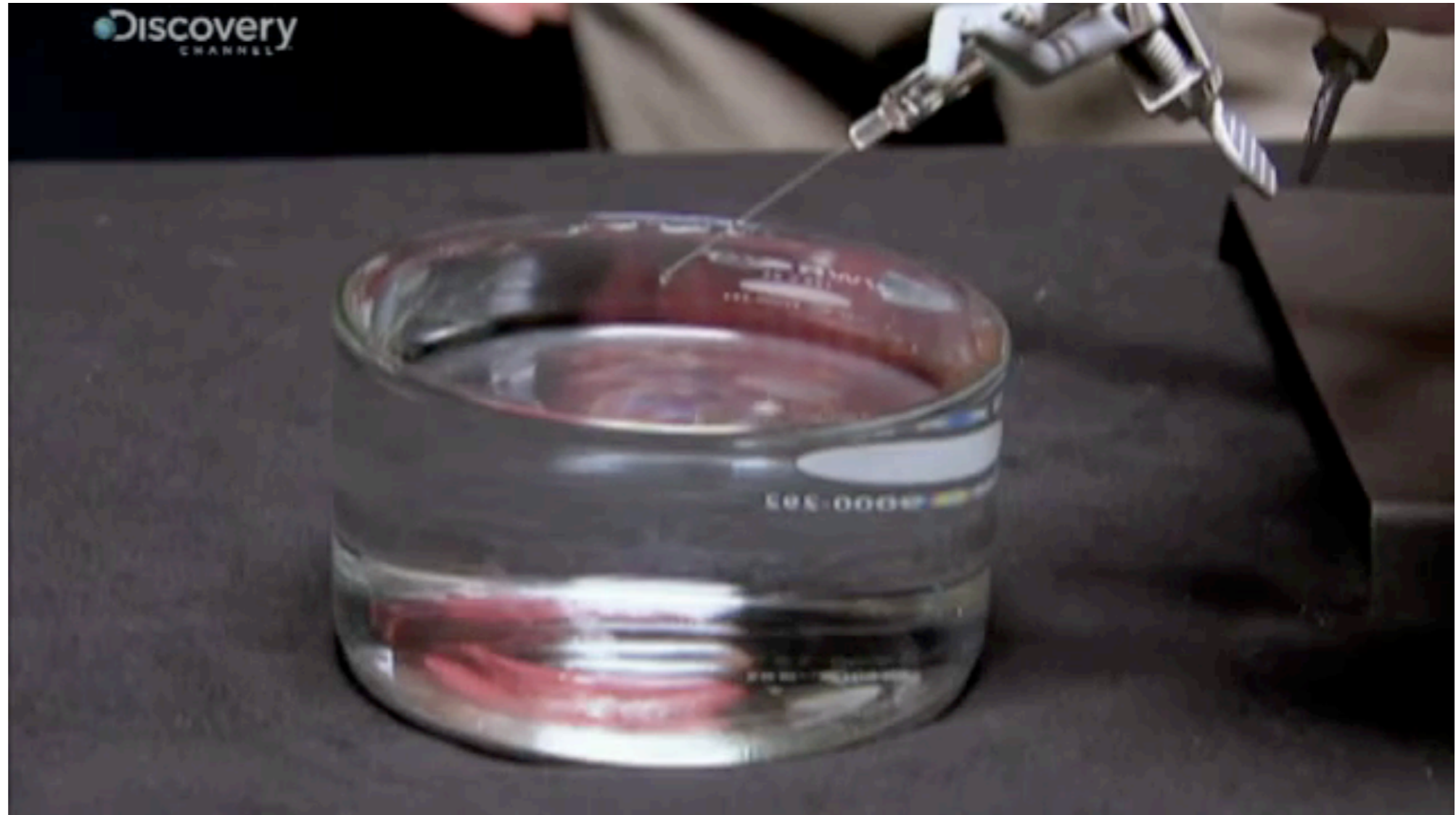
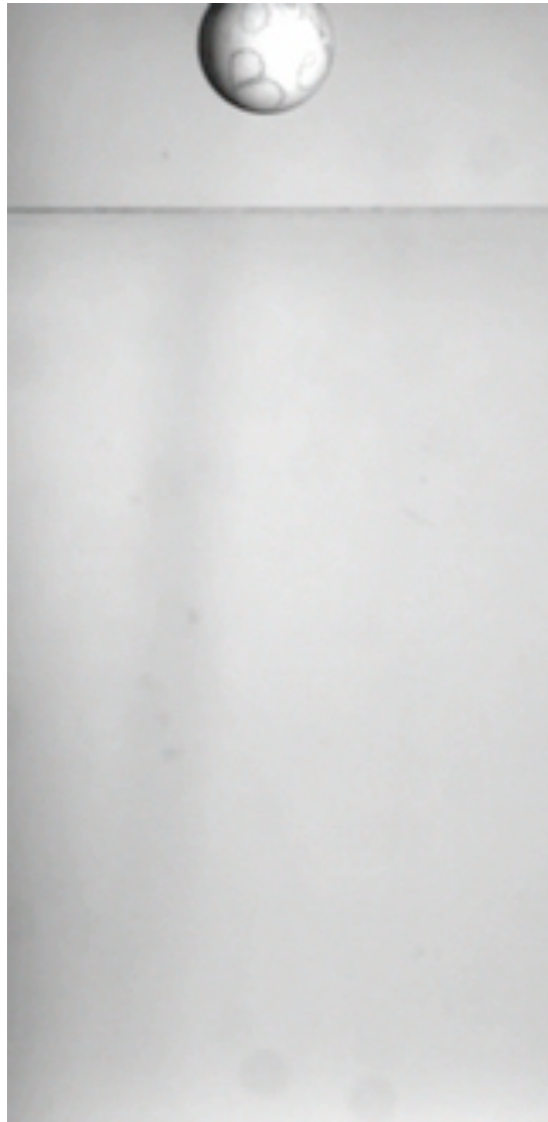
Water knots



Irvine lab (Chicago)



Surface effects



<http://web.mit.edu/ehl/www/Home.html>

Bush group



“Quantum” HD



Couder lab (Paris)

Bush group

