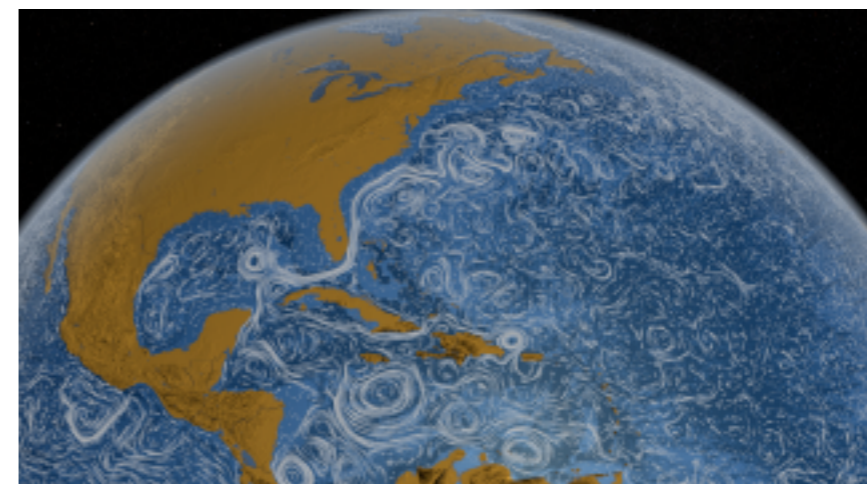
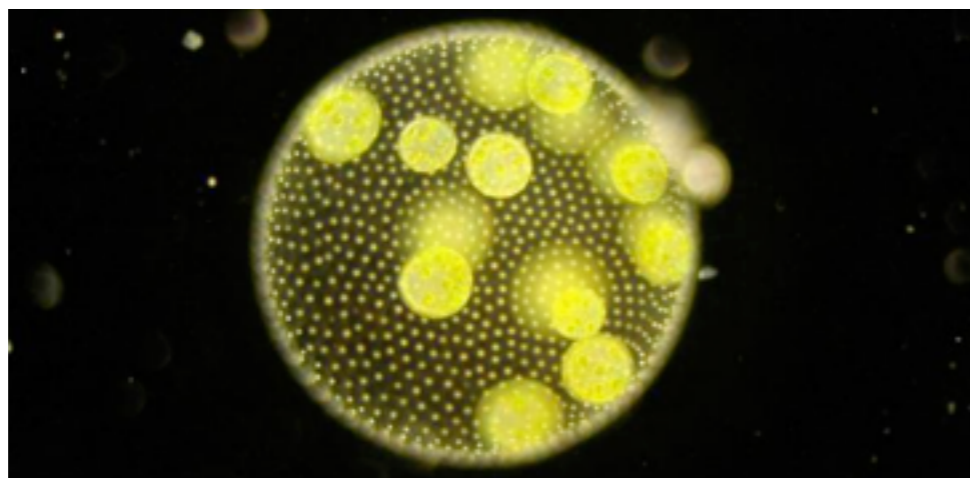
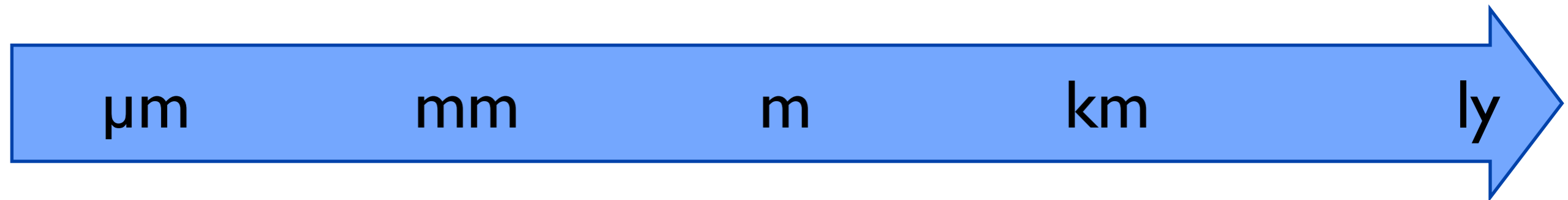
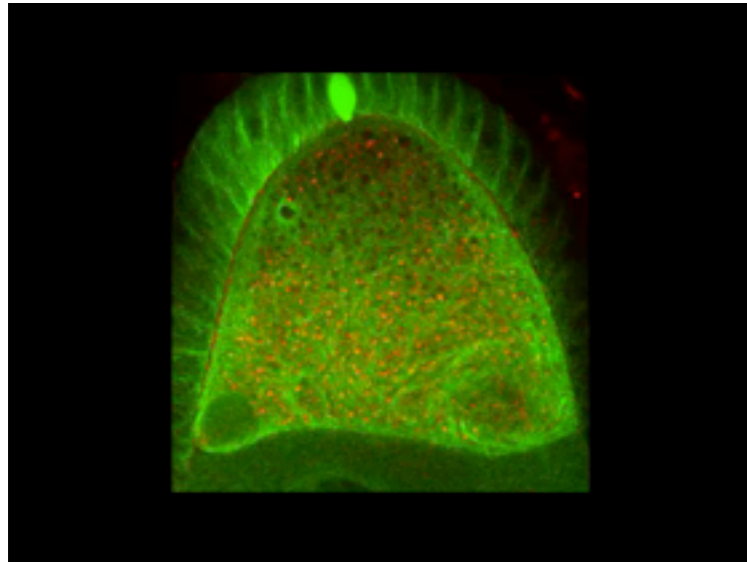


18.354 Nonlinear Dynamics II

Towards hydrodynamics

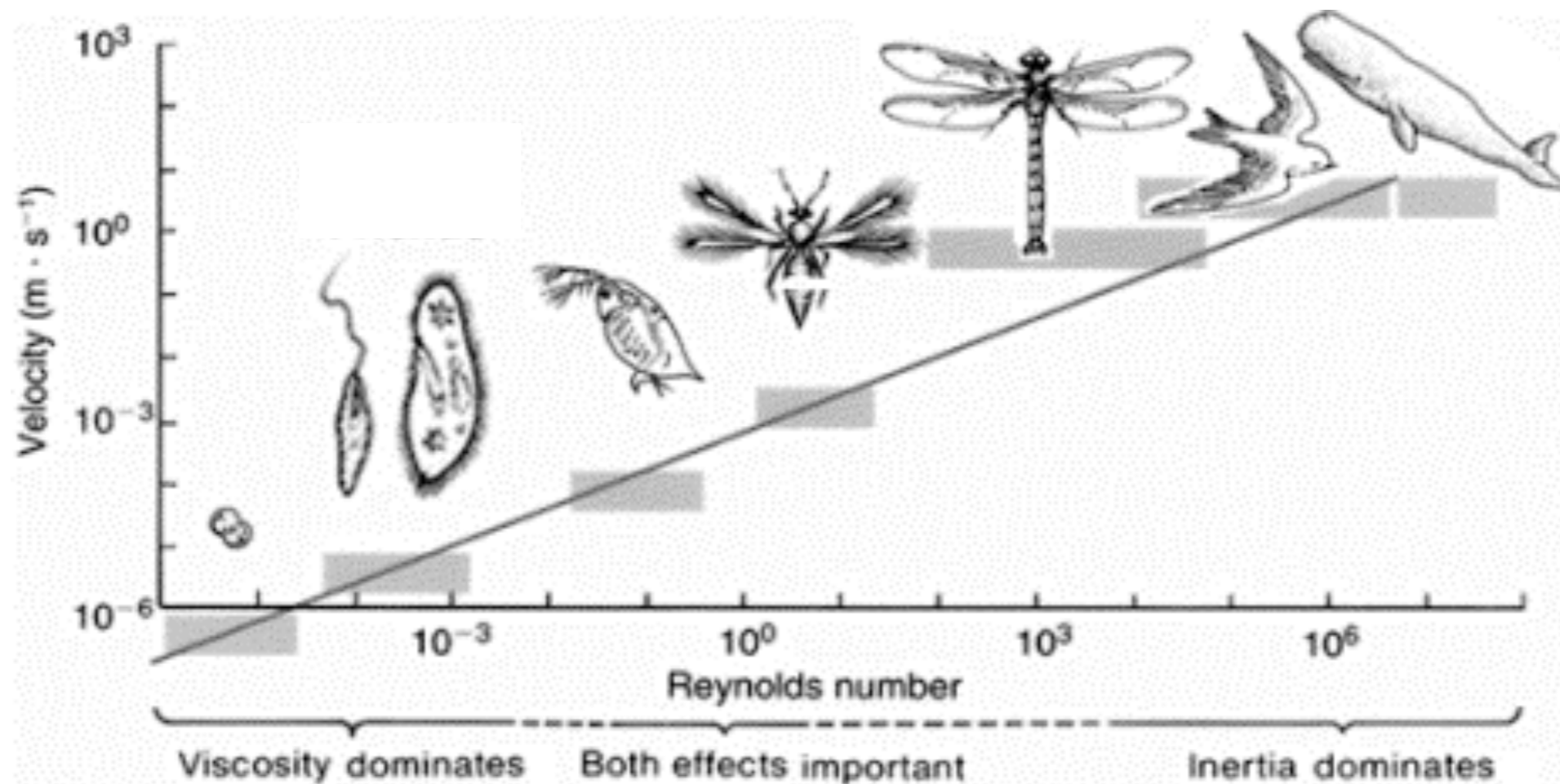
Jörn Dunkel

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



VERY High-Re



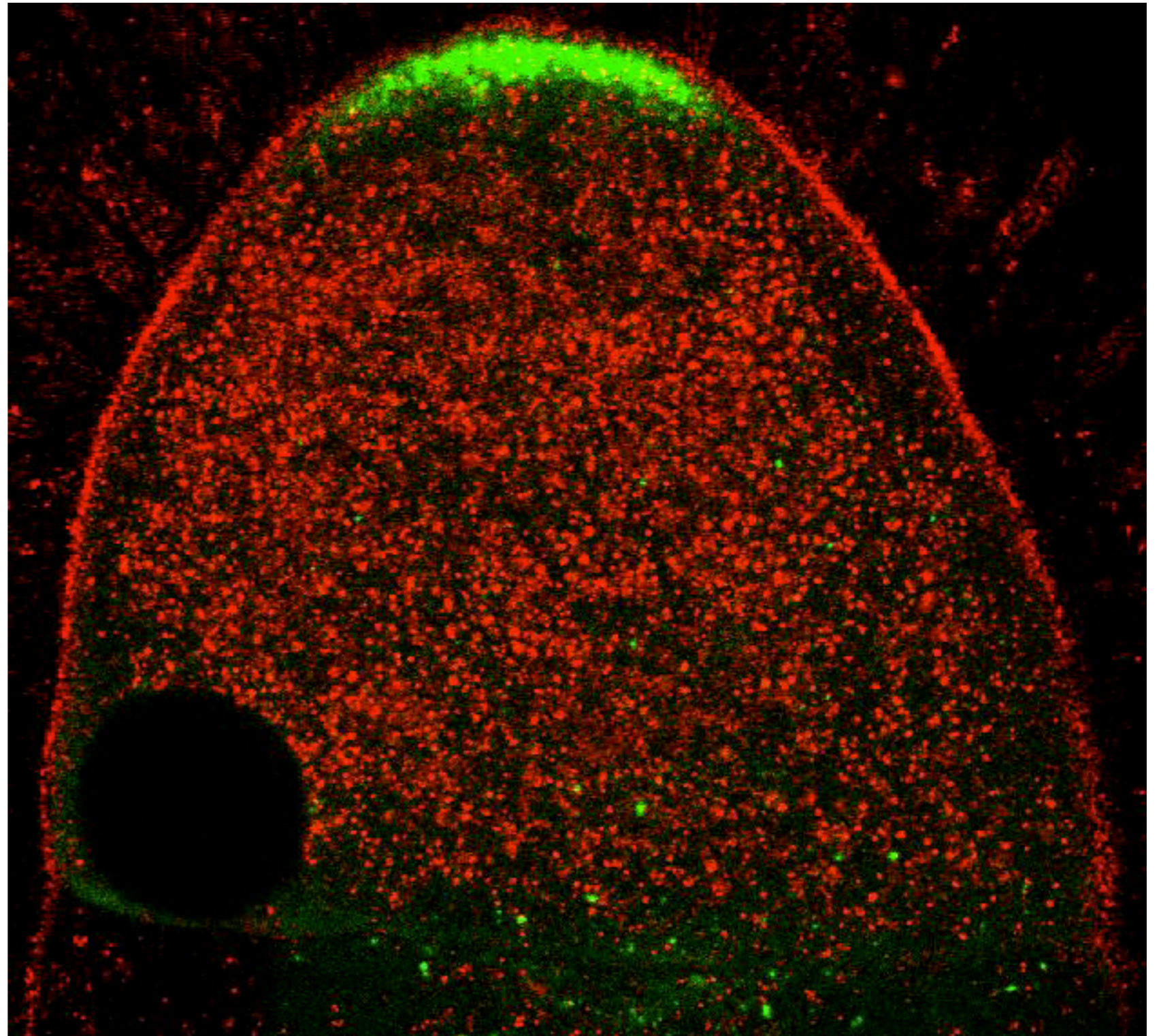
Low-Re (laminar) flow



Flow & transport **in** cells



Drosophila
embryo

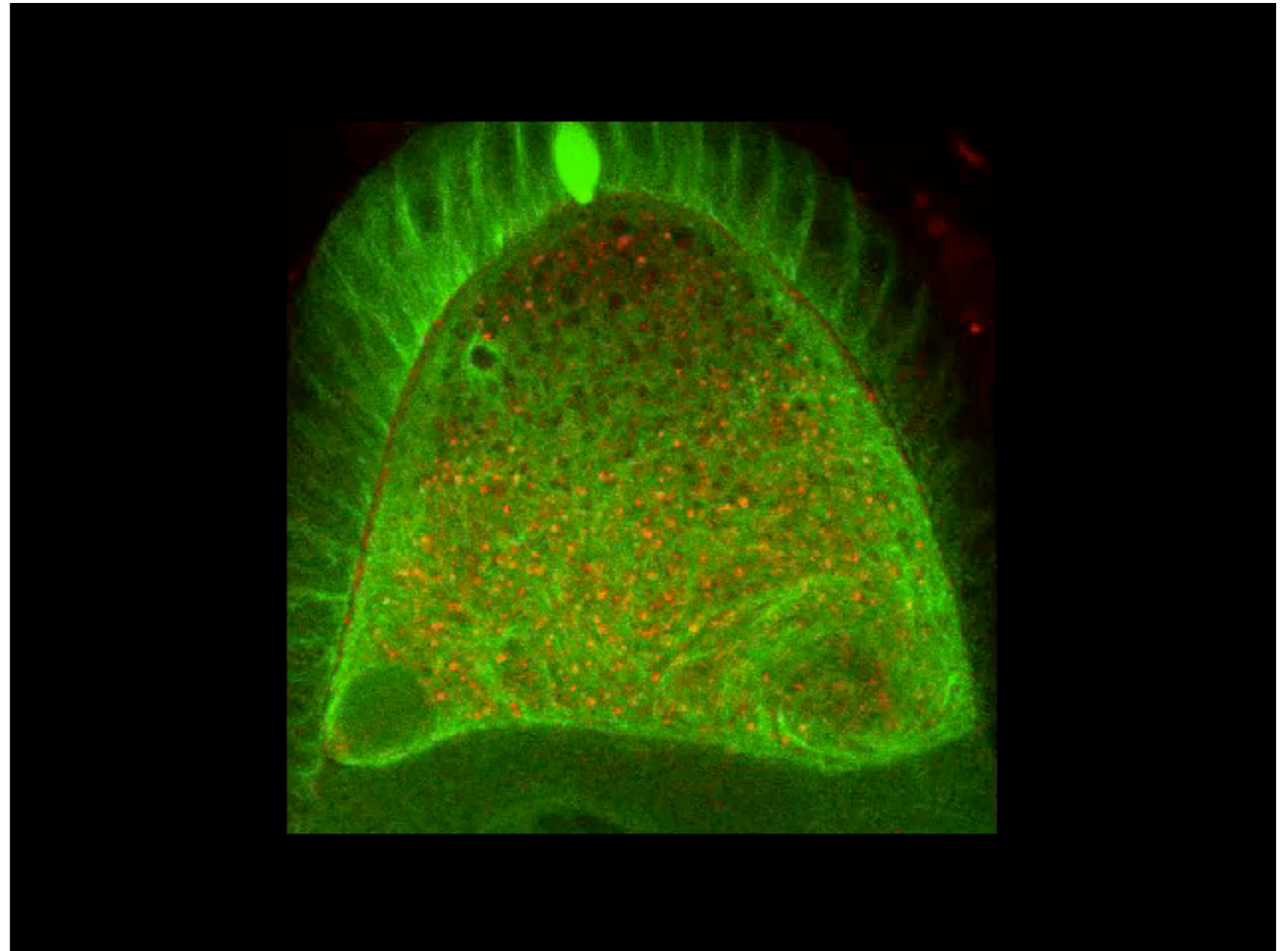


Goldstein lab (Cambridge)

Flow & transport in cells



Drosophila
embryo



Goldstein lab (Cambridge)

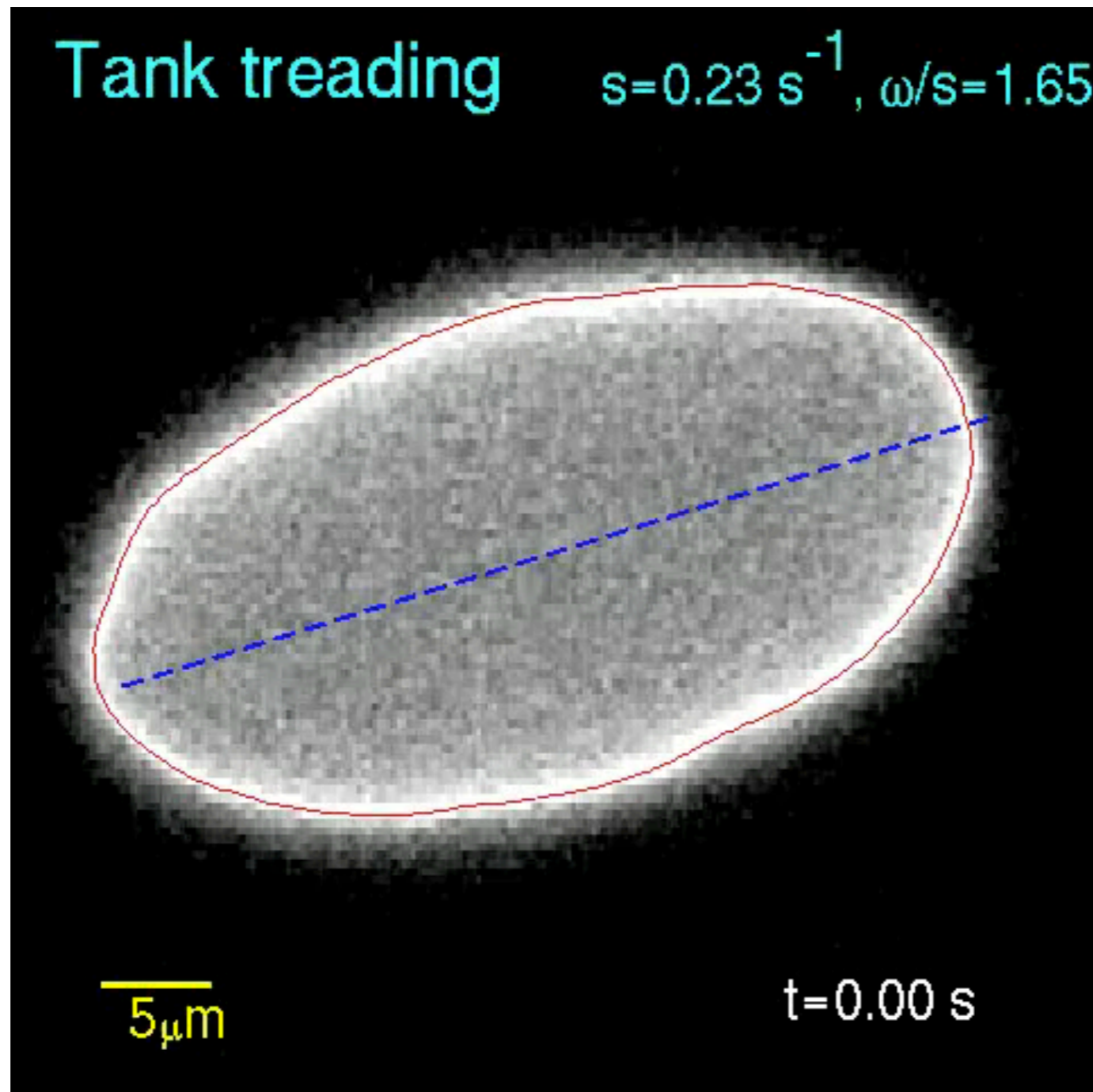
Intracellular transport



Giant cell

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

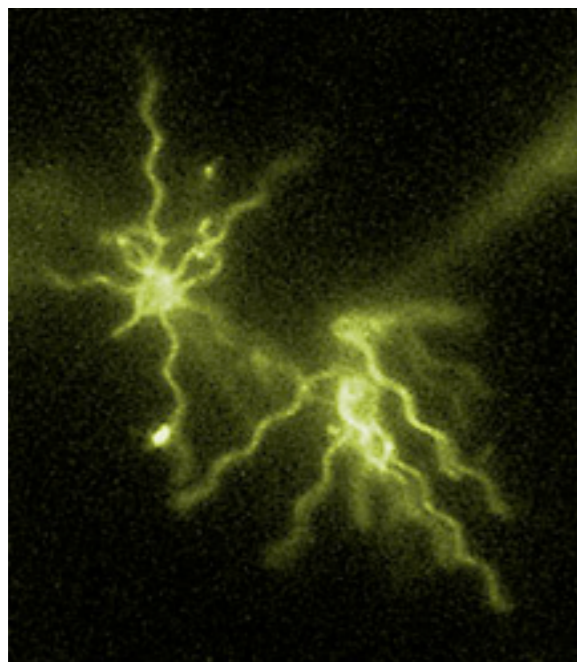
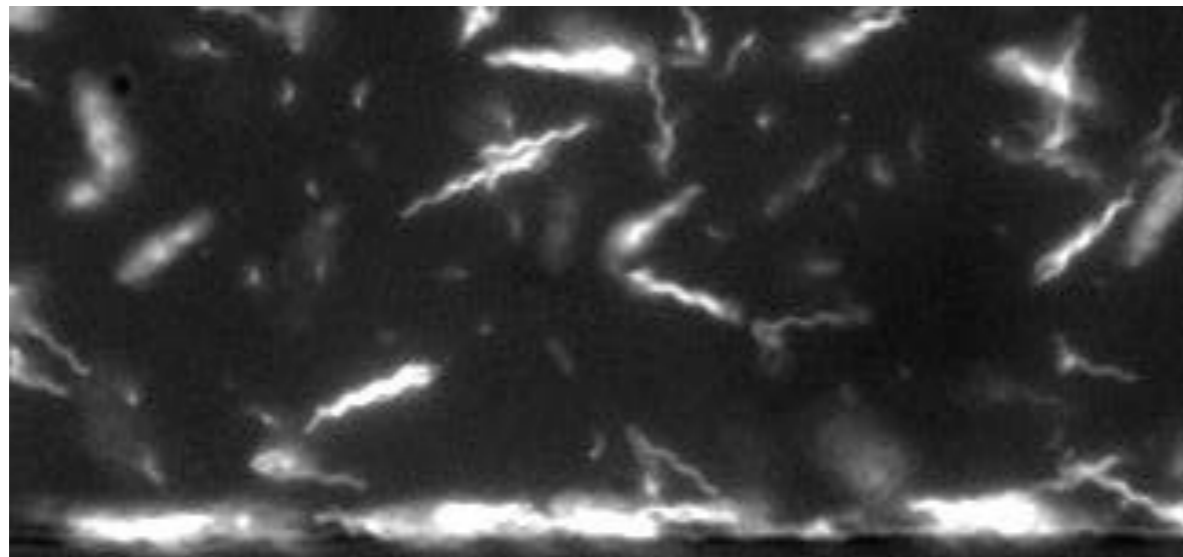
Vesicles in a shear flow



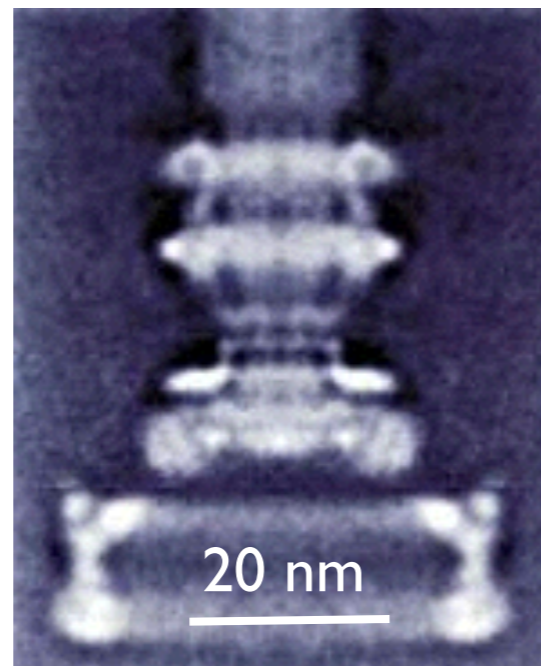
model for
blood cells
dynamics

Swimming bacteria

movie: V. Kantsler

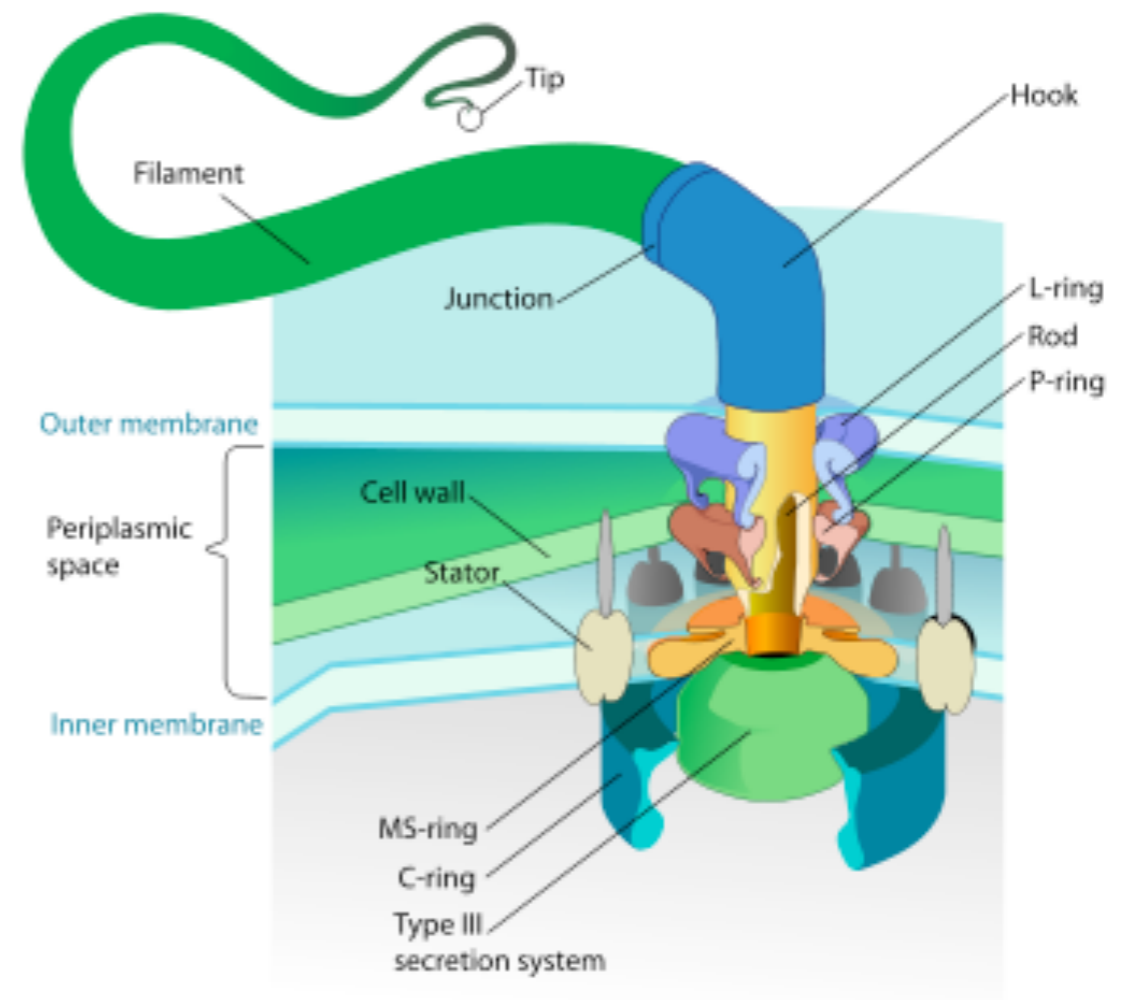


Berg (1999) Physics Today



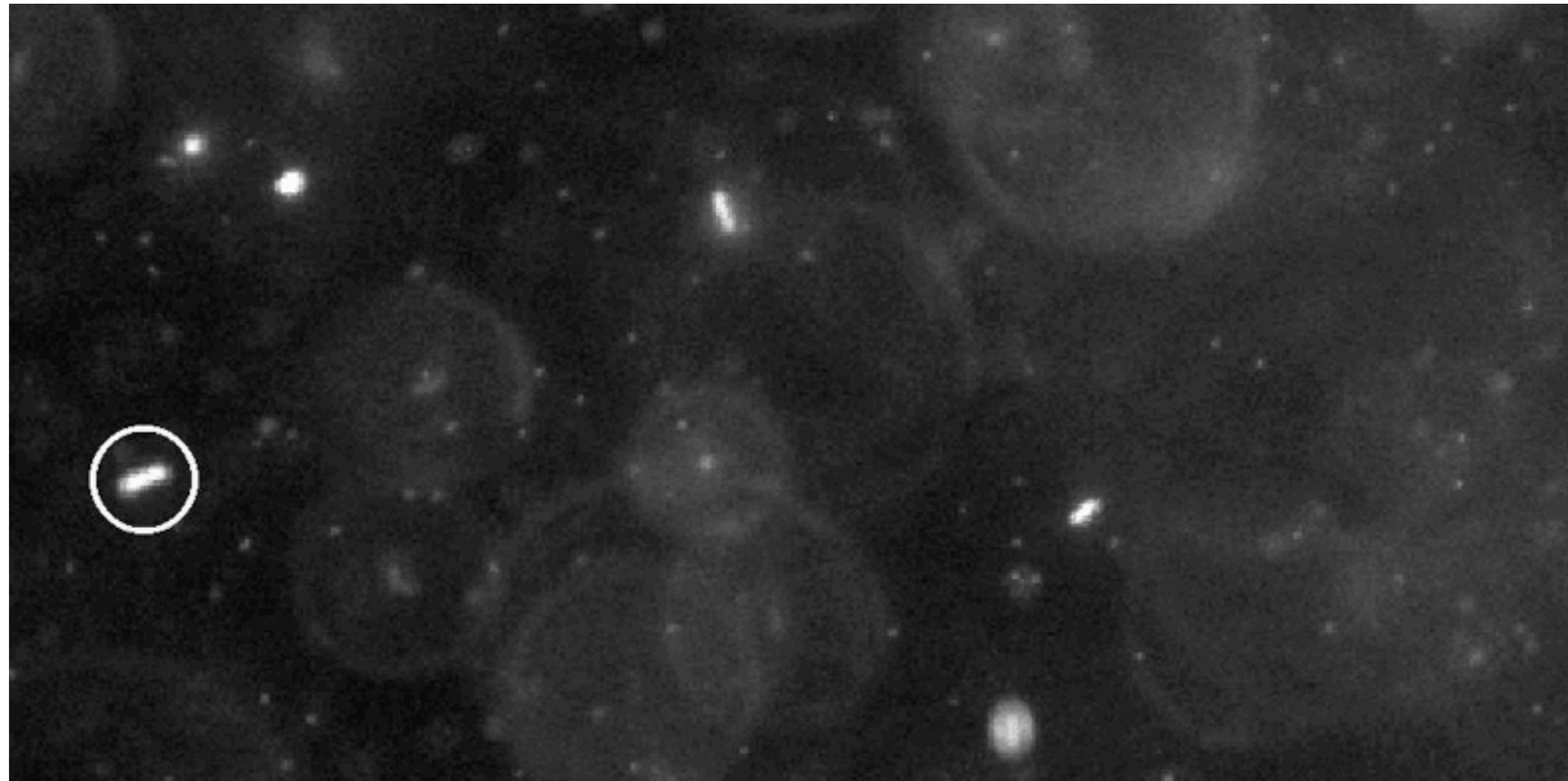
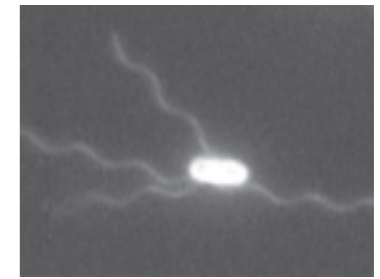
Chen et al (2011) EMBO Journal

~20 parts

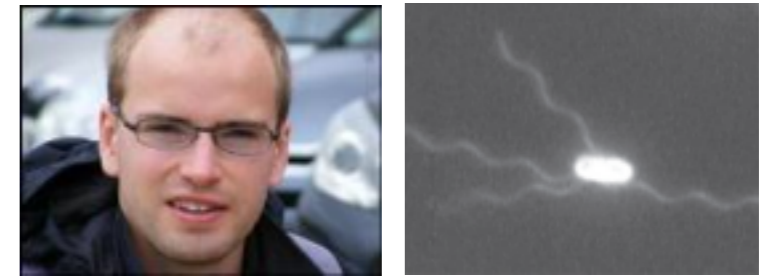


source: wiki

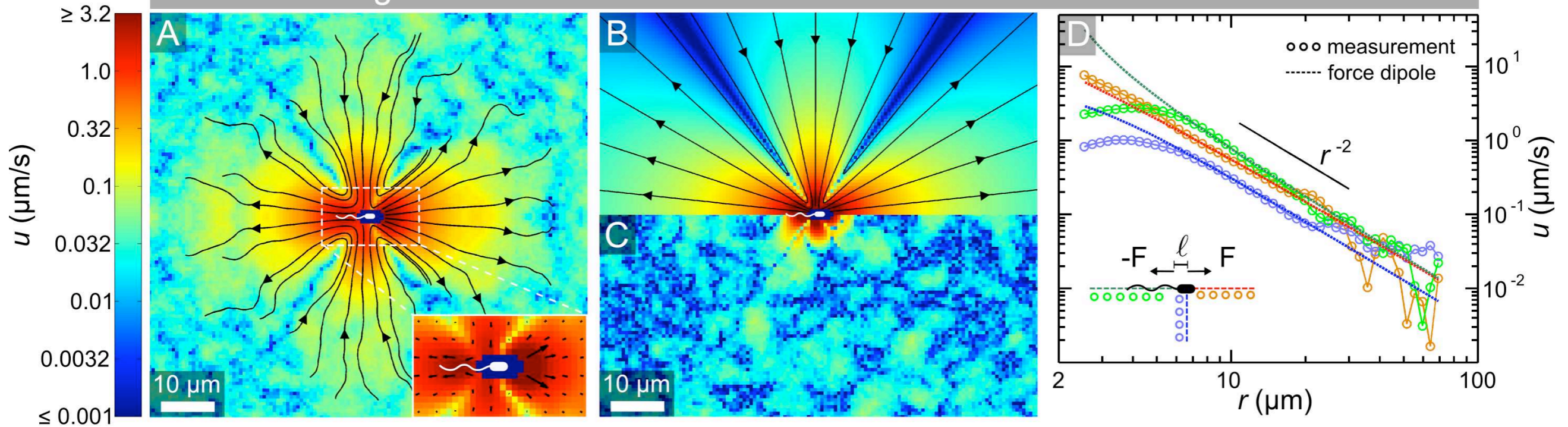
E.coli (non-tumbling HCB 437)



E.coli (non-tumbling HCB 437)



Free swimming



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

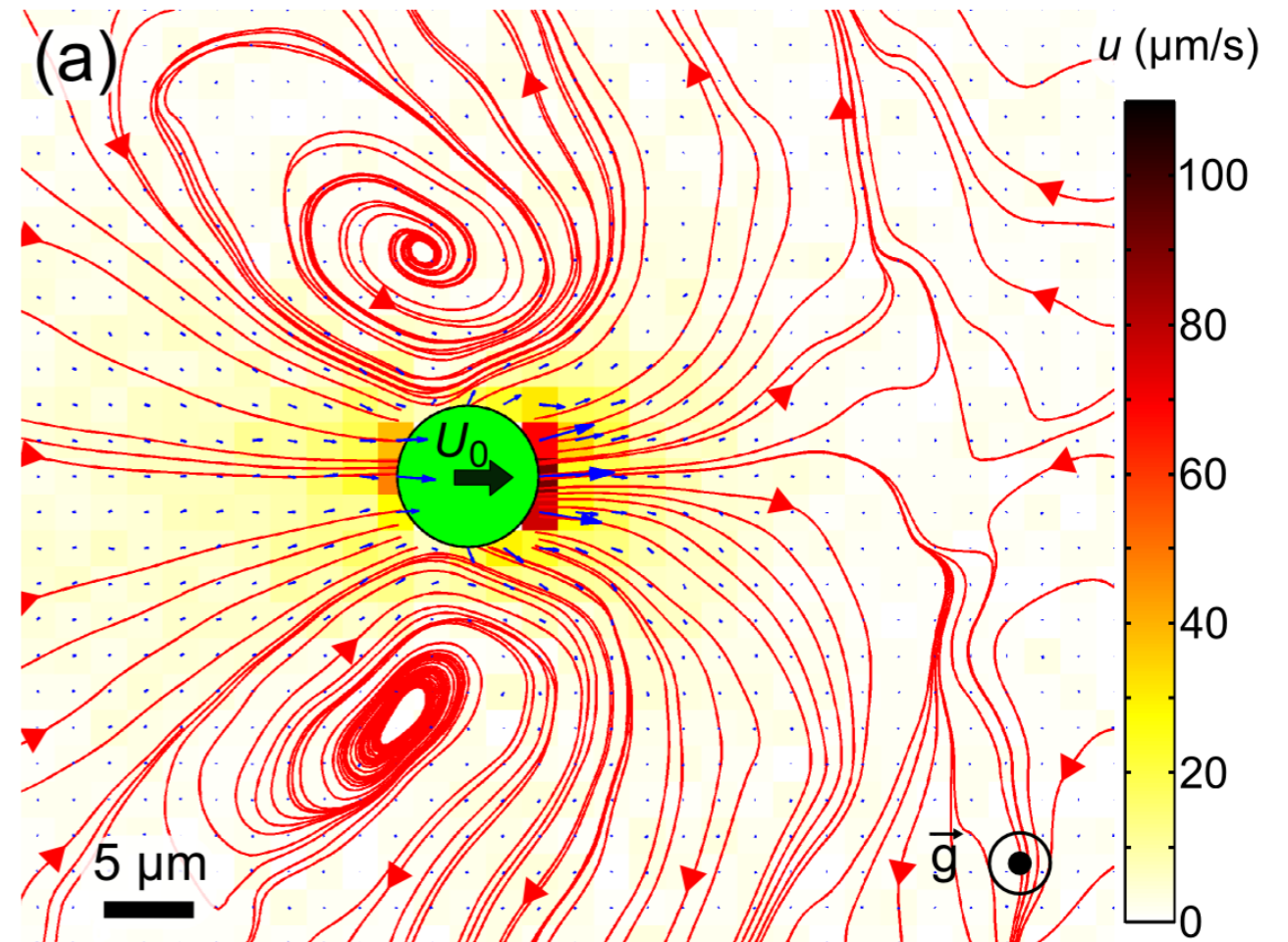
$$V_0 = 22 \pm 5 \mu\text{m/s}$$

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

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

weak 'pusher' dipole

Chlamydomonas



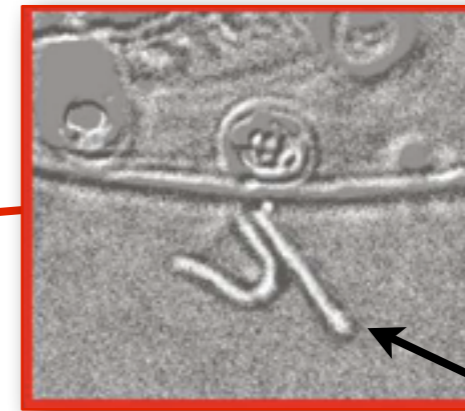
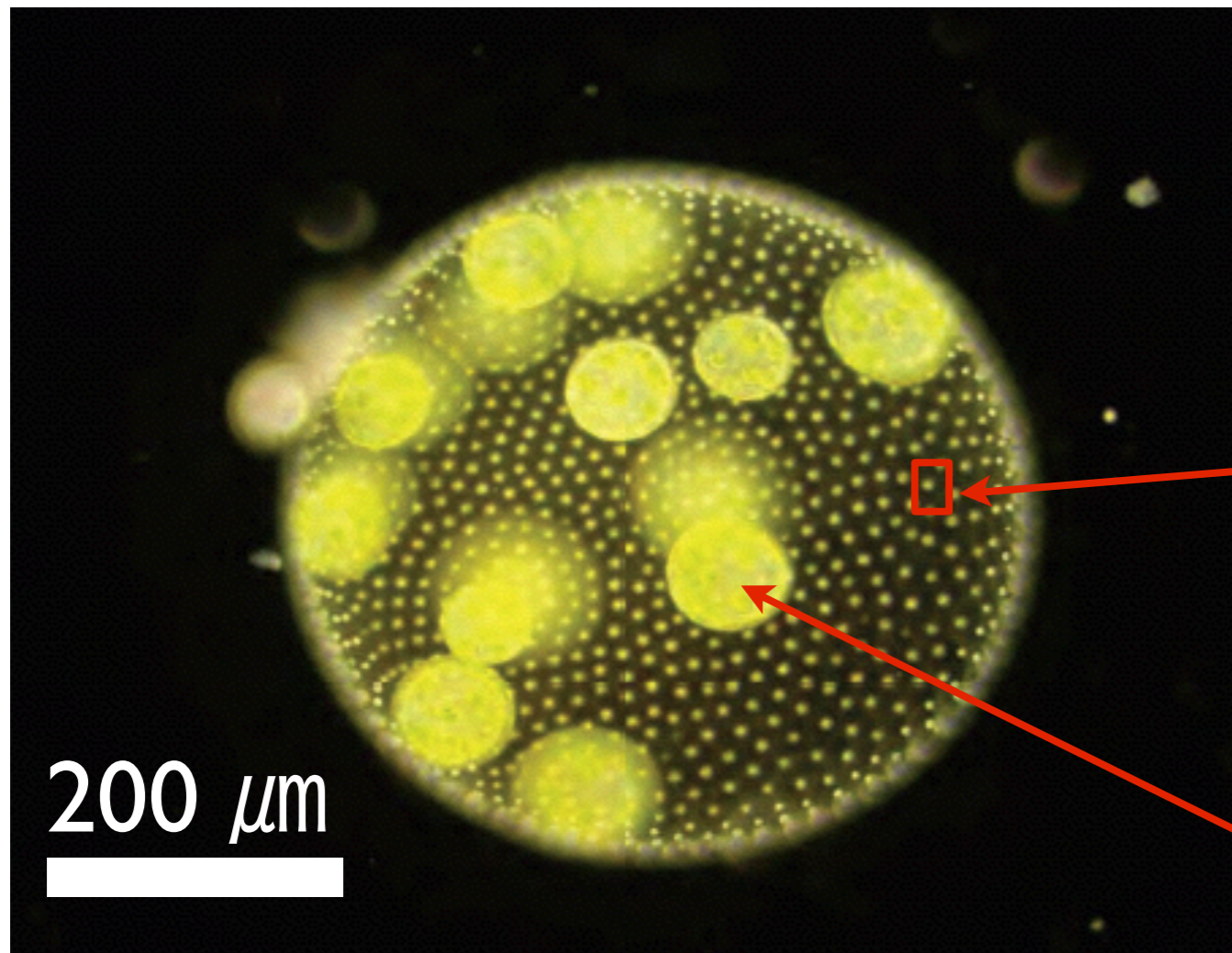
Movie: Jeff Guasto (TUFTS)

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 $\sim 30 \text{ Hz}$

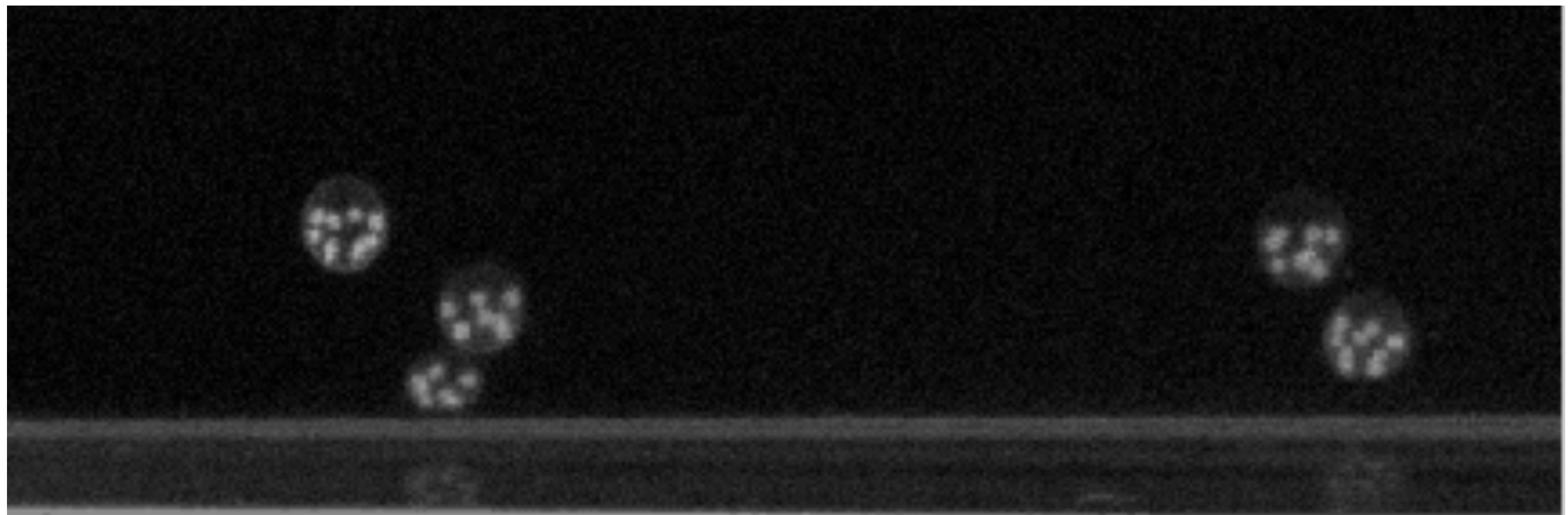
Volvox carteri



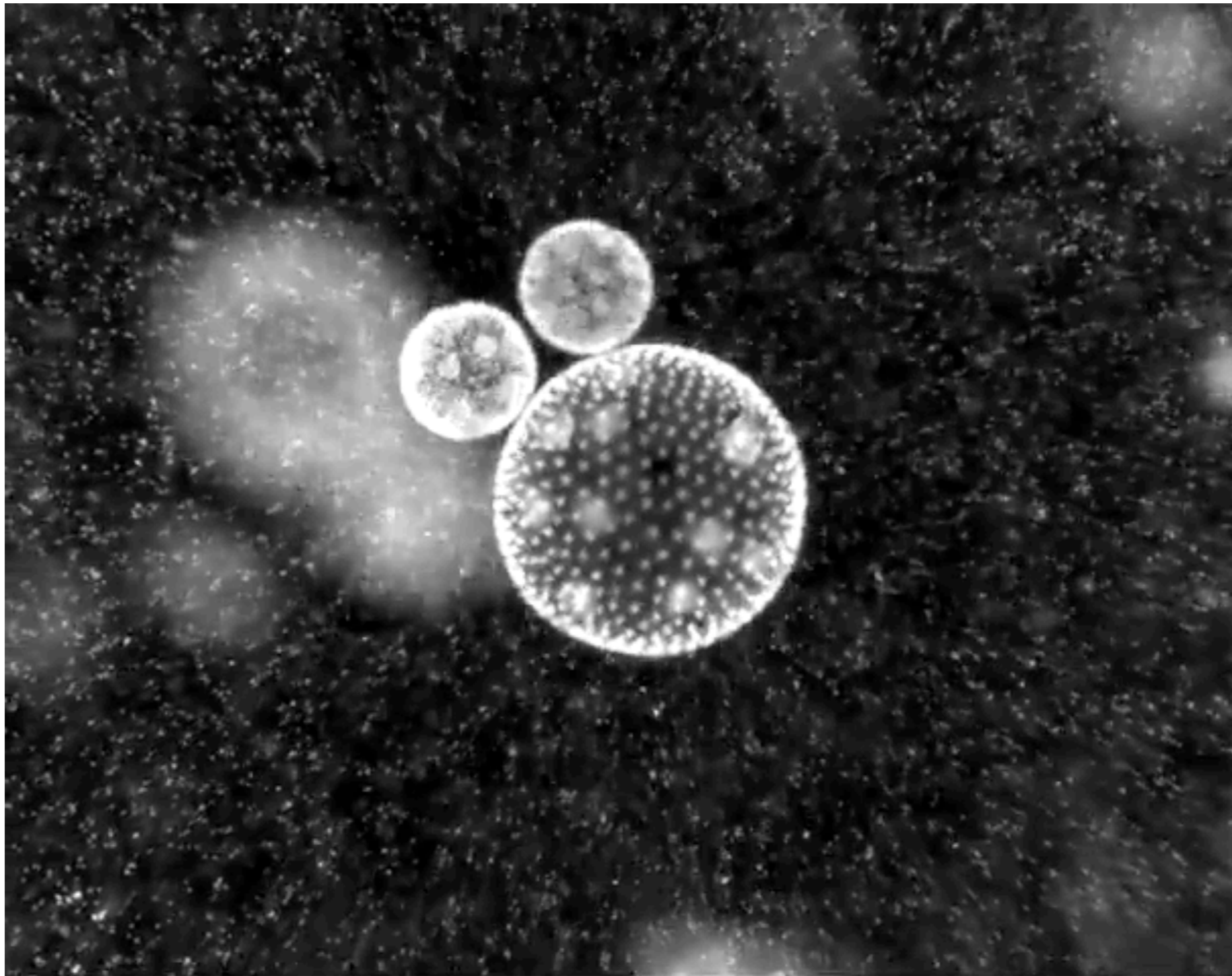
somatic
cell

cilia

daughter colony



Volvox

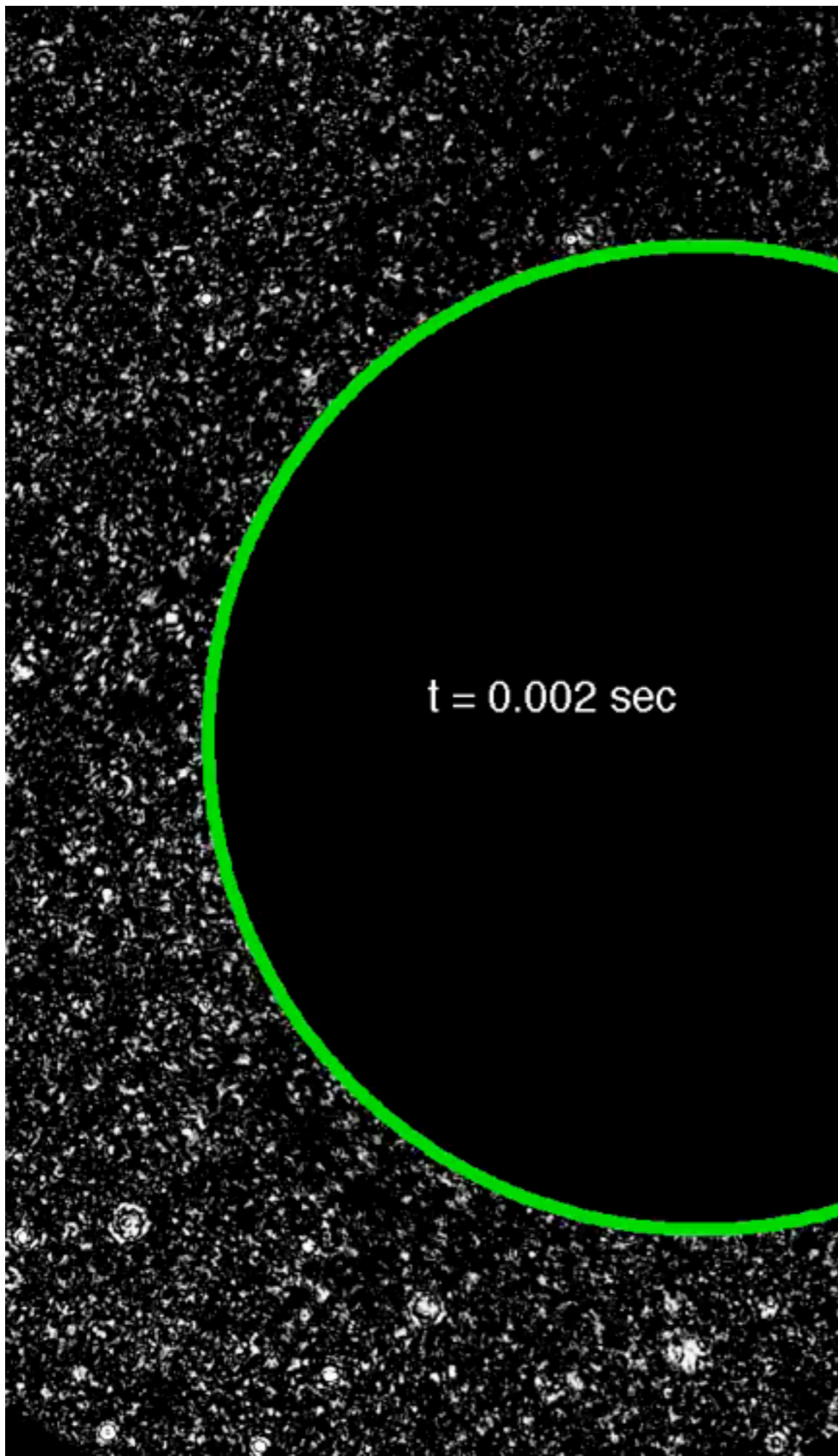


Goldstein lab (Cambridge)

Volvox

meta-chronal waves

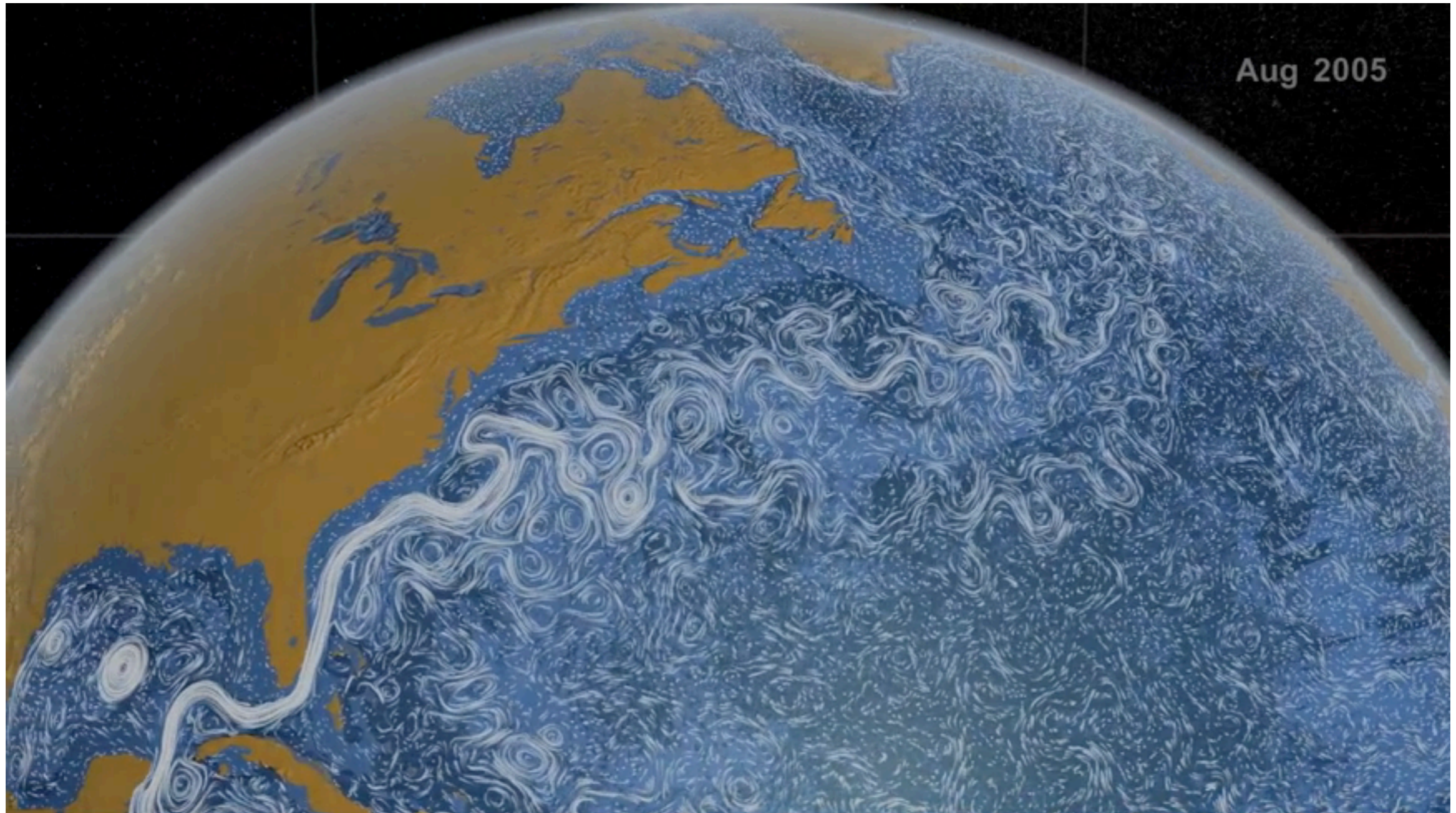
Brumley et al (2012) PRL



meters



kilometers (miles)



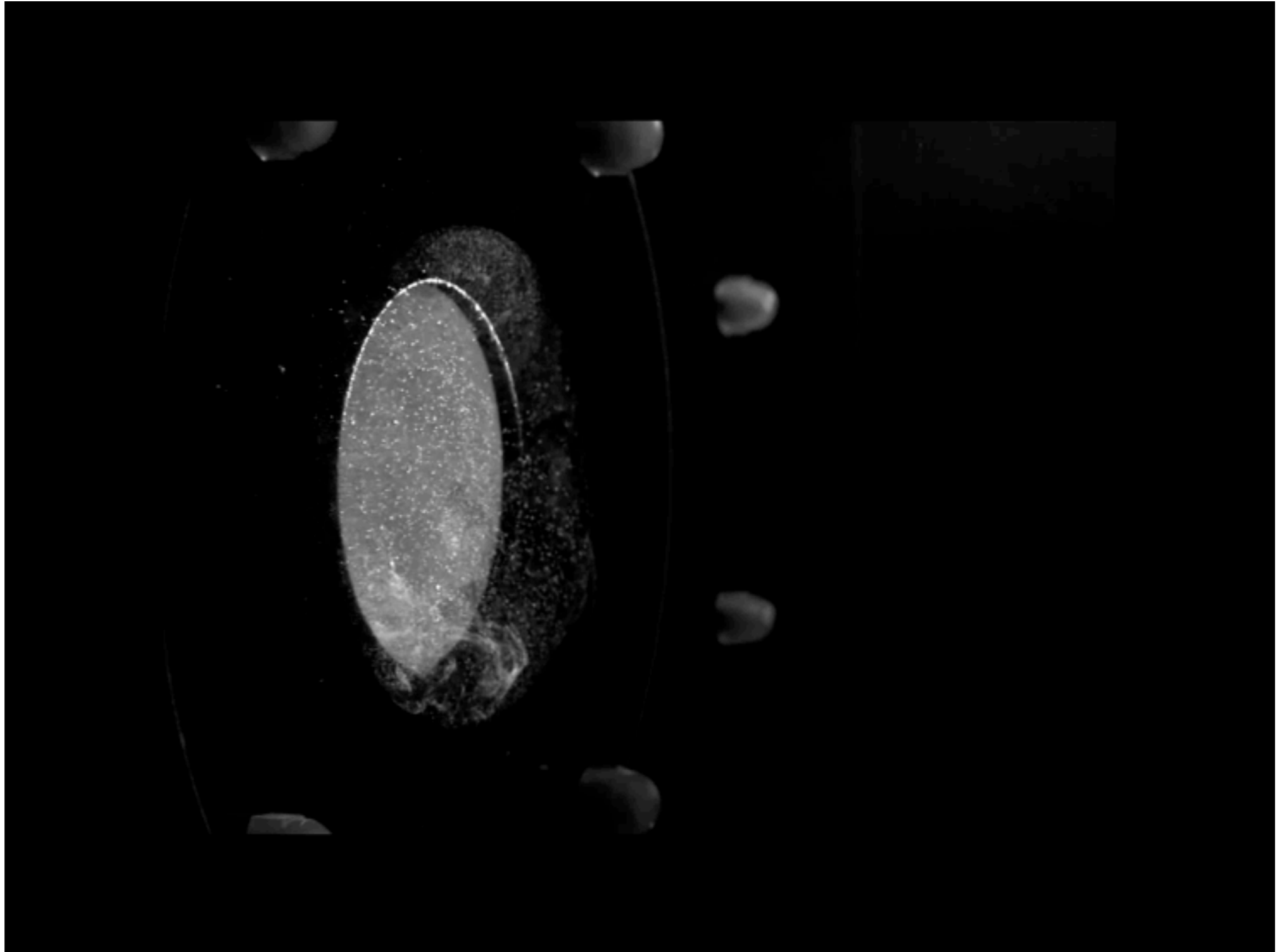
http://svs.gsfc.nasa.gov/site_usage/site_reqts.html

Galactic & intergalactic gas dynamics



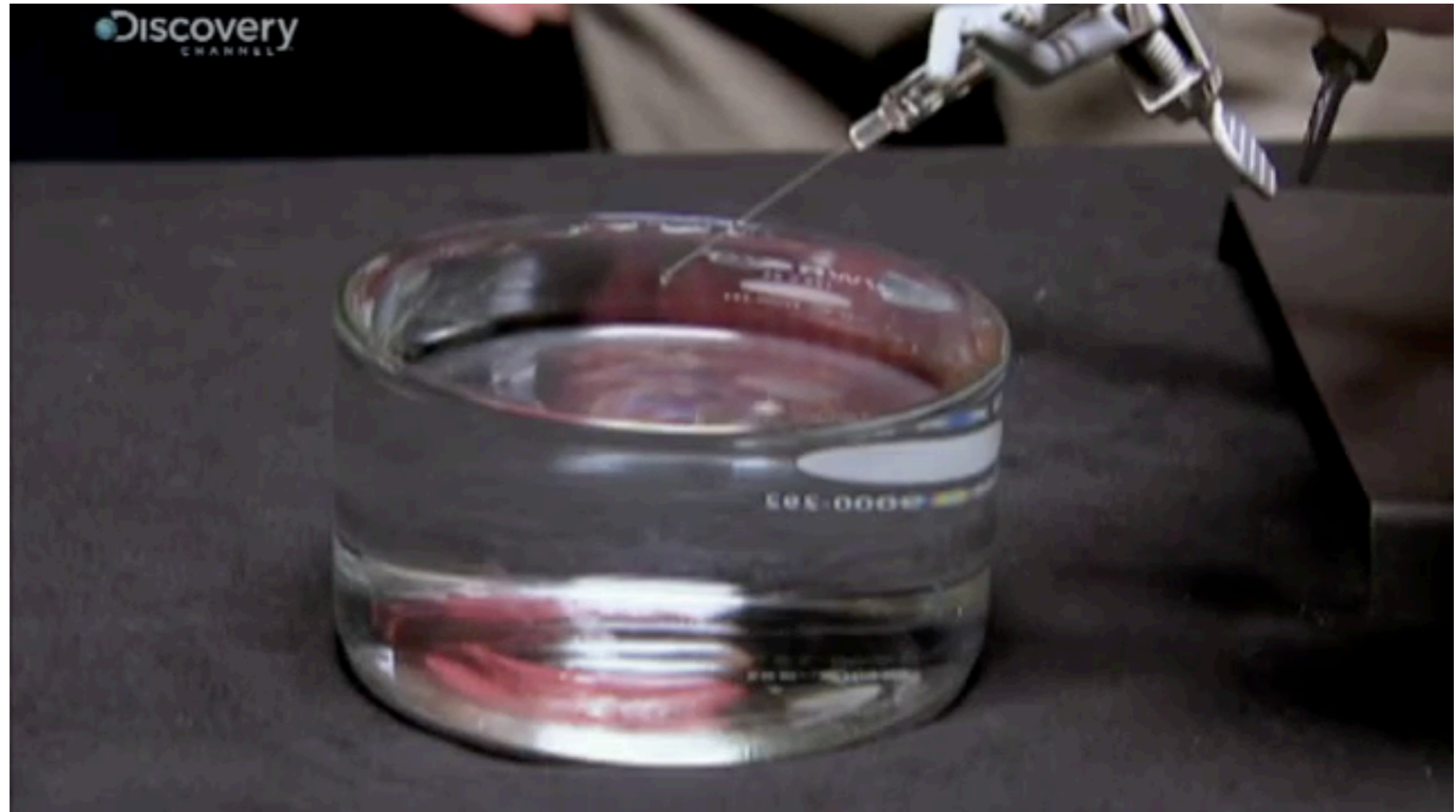
horsehead nebula (hubble)

Water knots



Irvine lab (Chicago)

Surface effects



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

Bush group

“Quantum” HD



Couder lab (Paris)

Bush group

