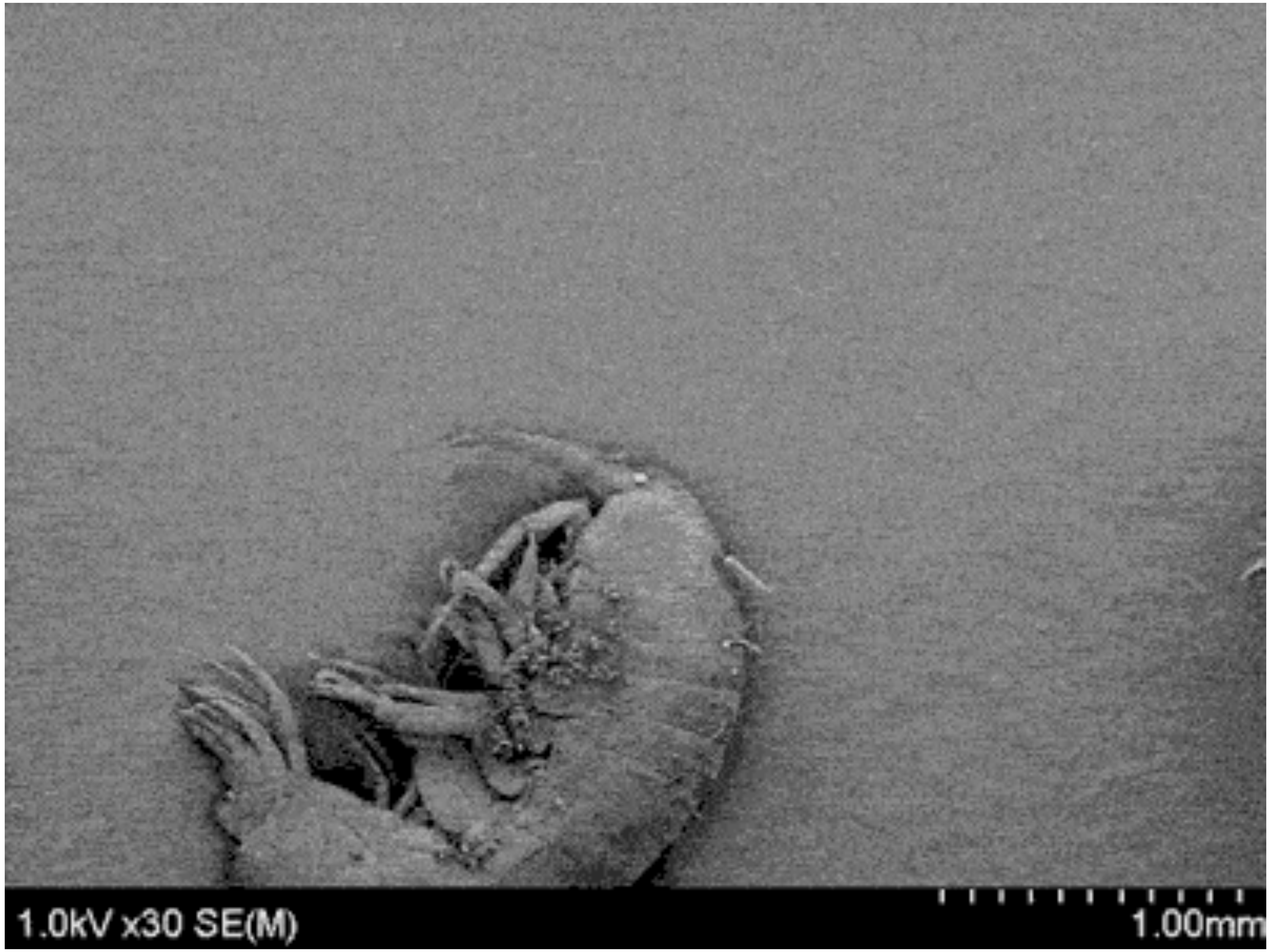
Mechanics at the viscous end of food webs

Stuart Humphries

UNIVERSITY OF LINCOLN

physical ecology lab

Size matters

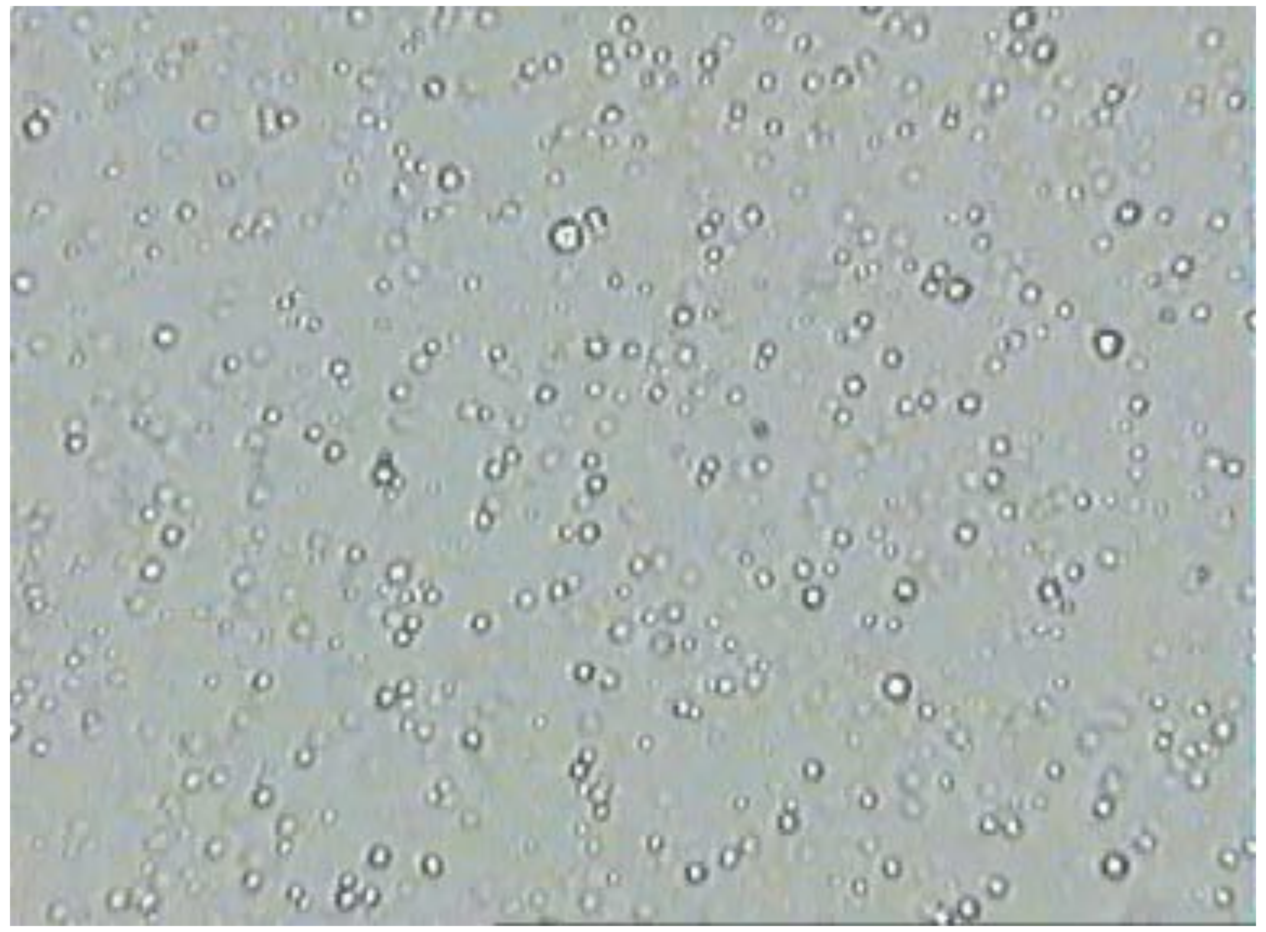


http://micro-universe.tumblr.com

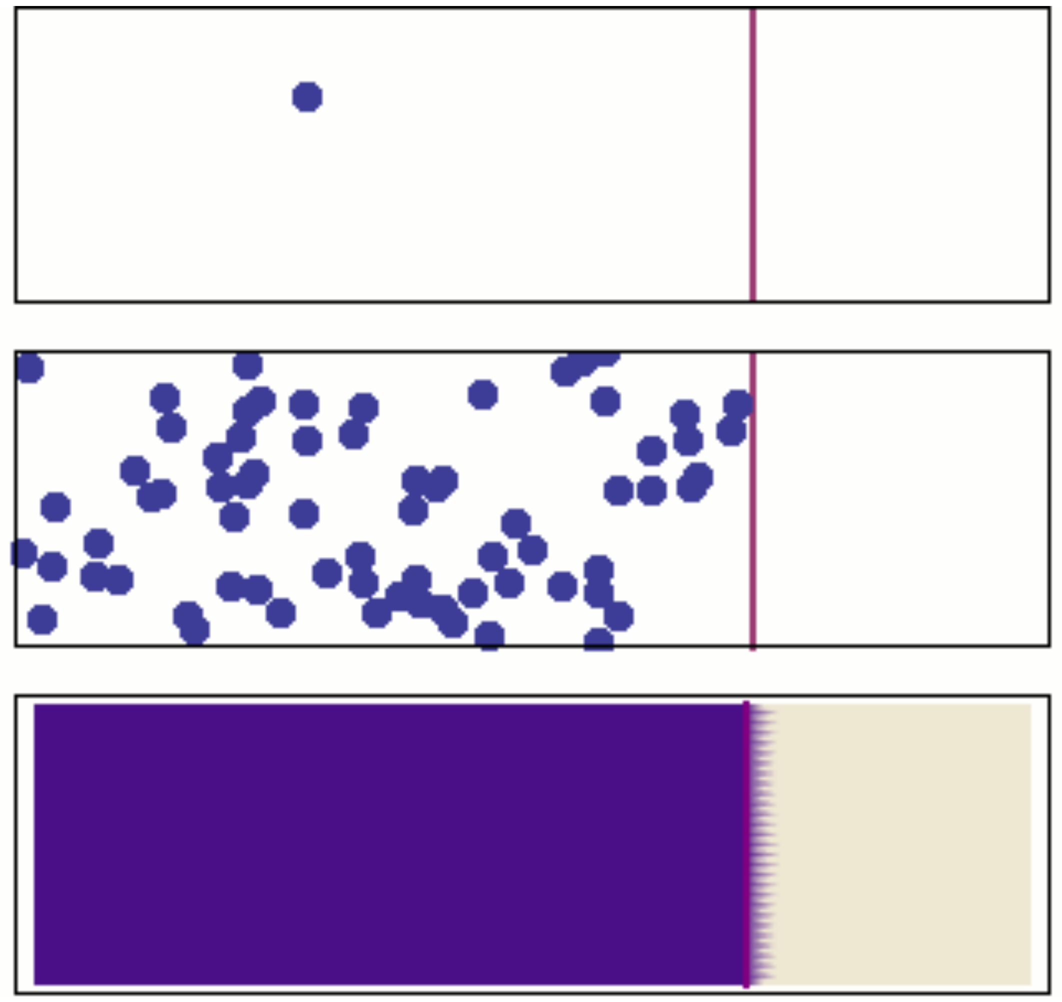
Physics at small scales

Viscosity

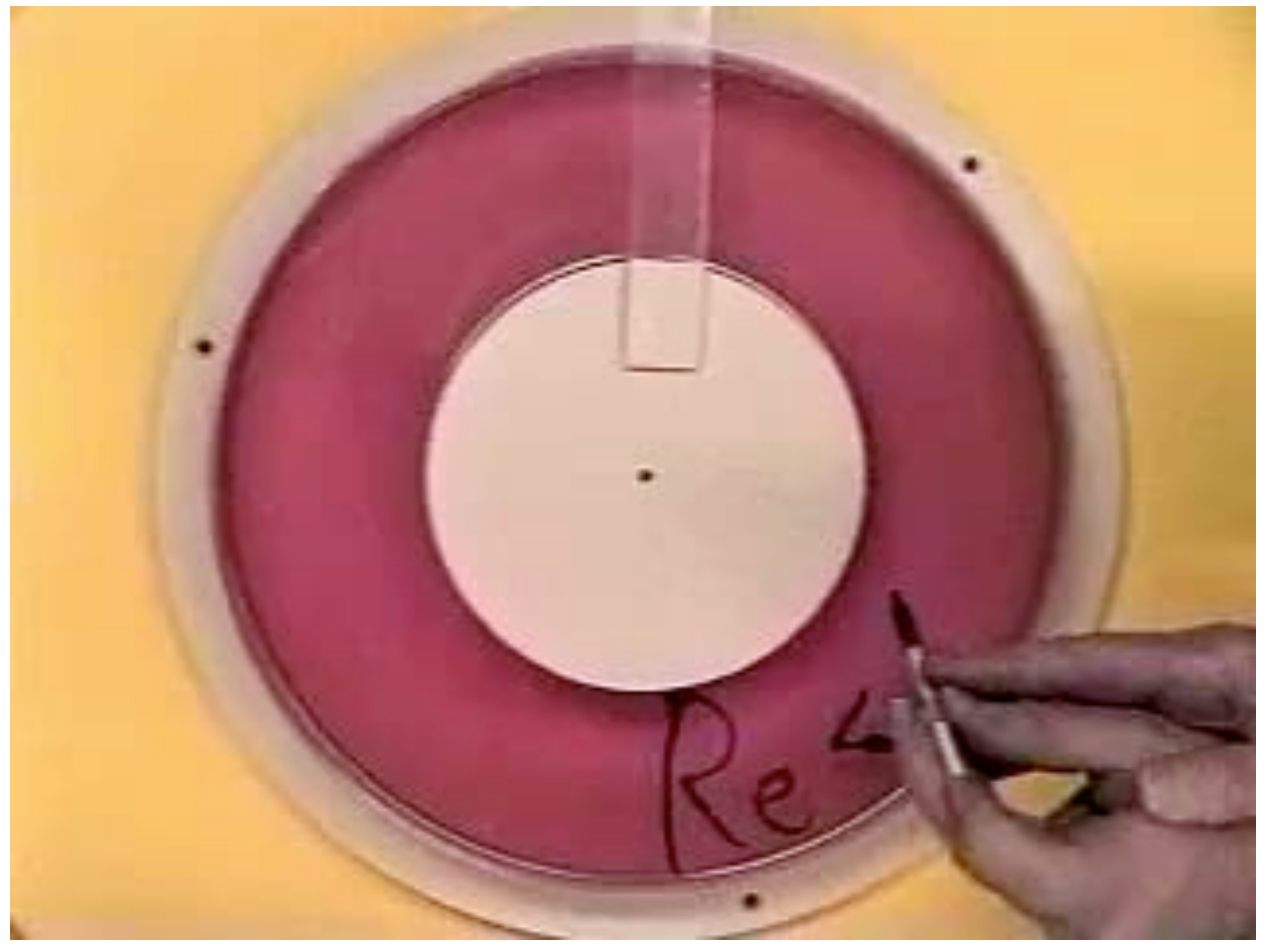
Brownian motion

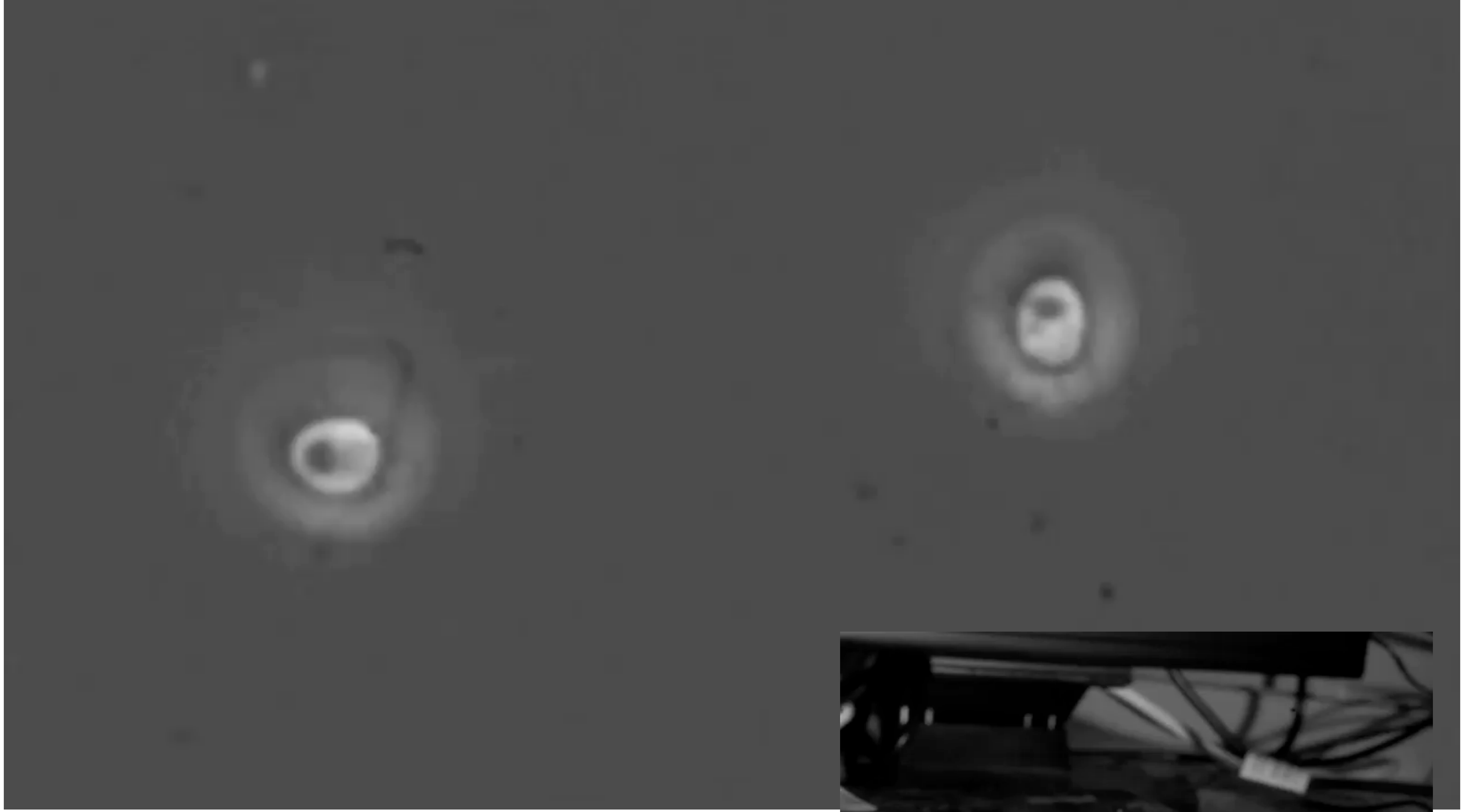


Molecular diffusion

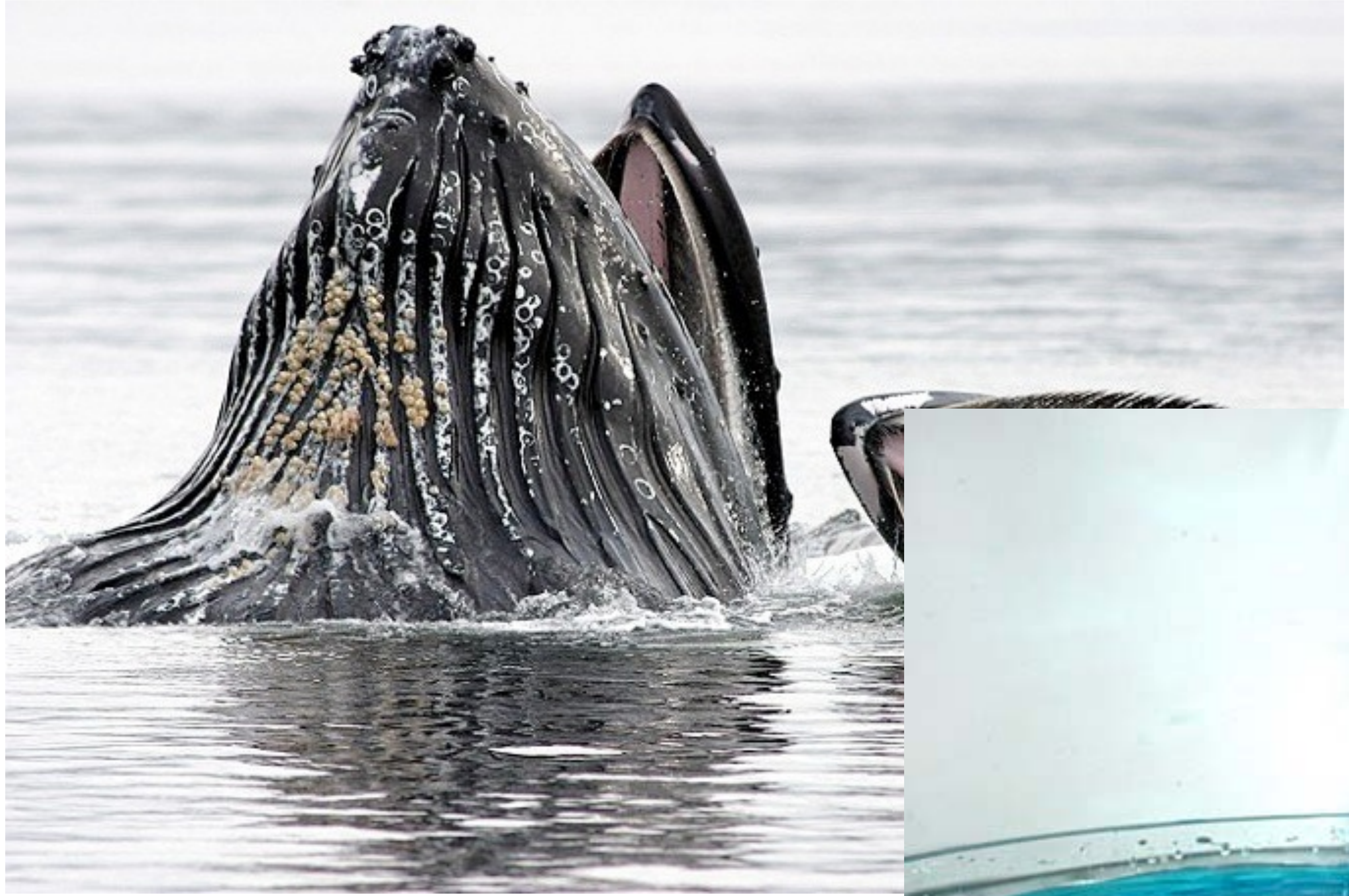


Kinematic reversibility






Viscosity



Animal images © Y. Tsukii (Protist Information Server, URL: http://protist.i.hosei.ac.jp/) & D. Davies

Viscosity

Animal images © Y. Tsukii (Protist Information Server, URL: http://protist.i.hosei.ac.jp/) & D. Davies

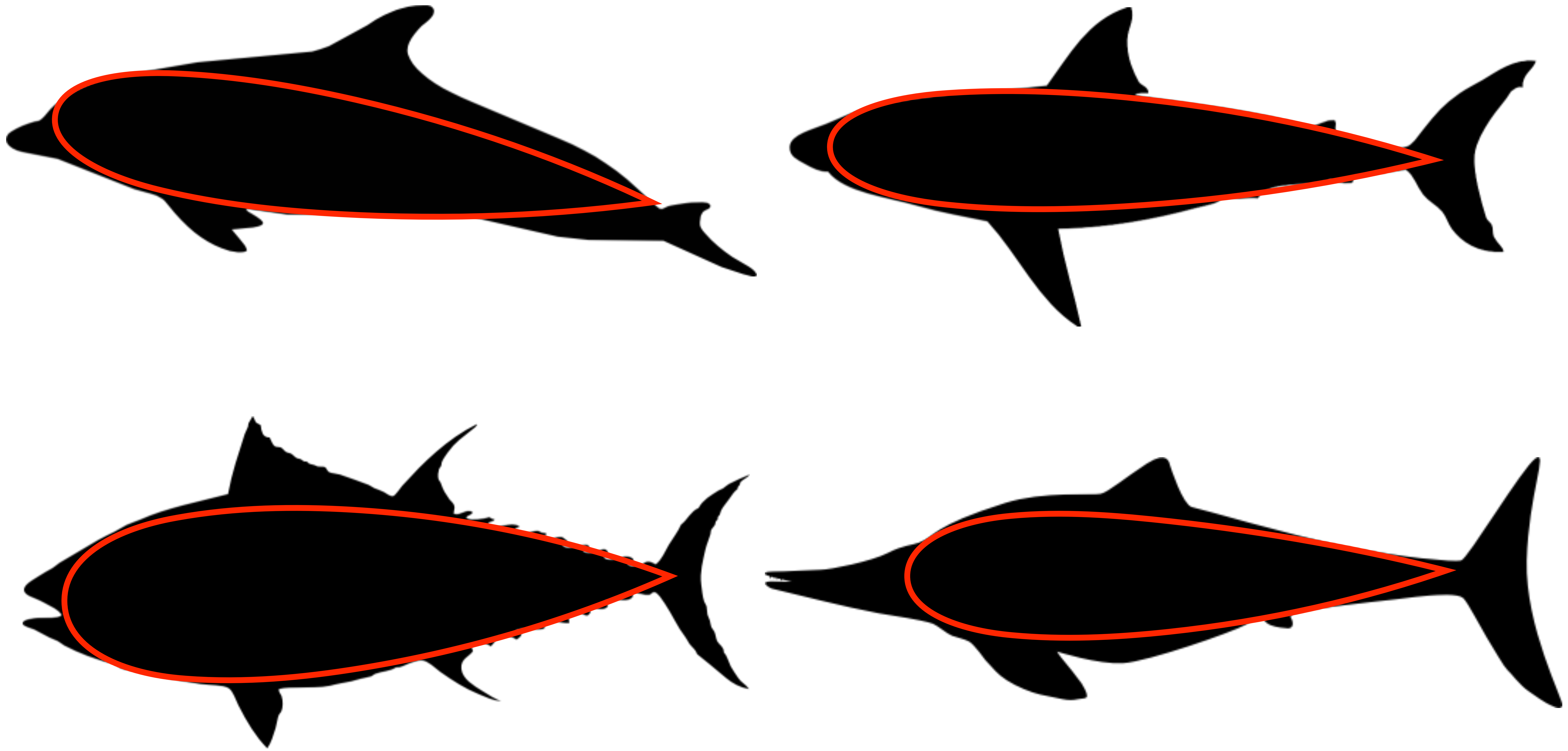
Viscosity

Animal images © Y. Tsukii (Protist Information Server, URL: http://protist.i.hosei.ac.jp/) & D. Davies

Momentum and inertia

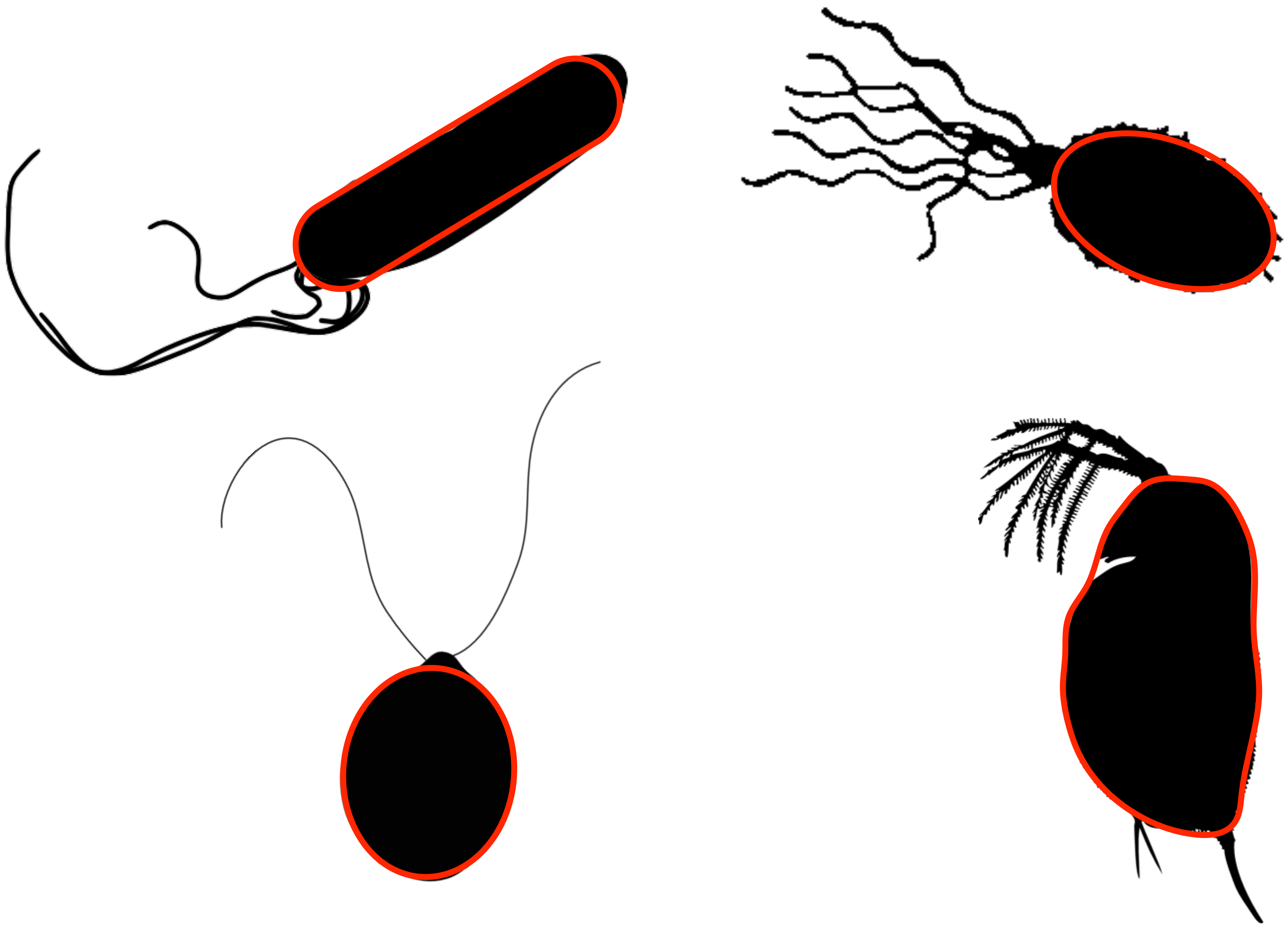
Momentum and inertia

Convergent evolution



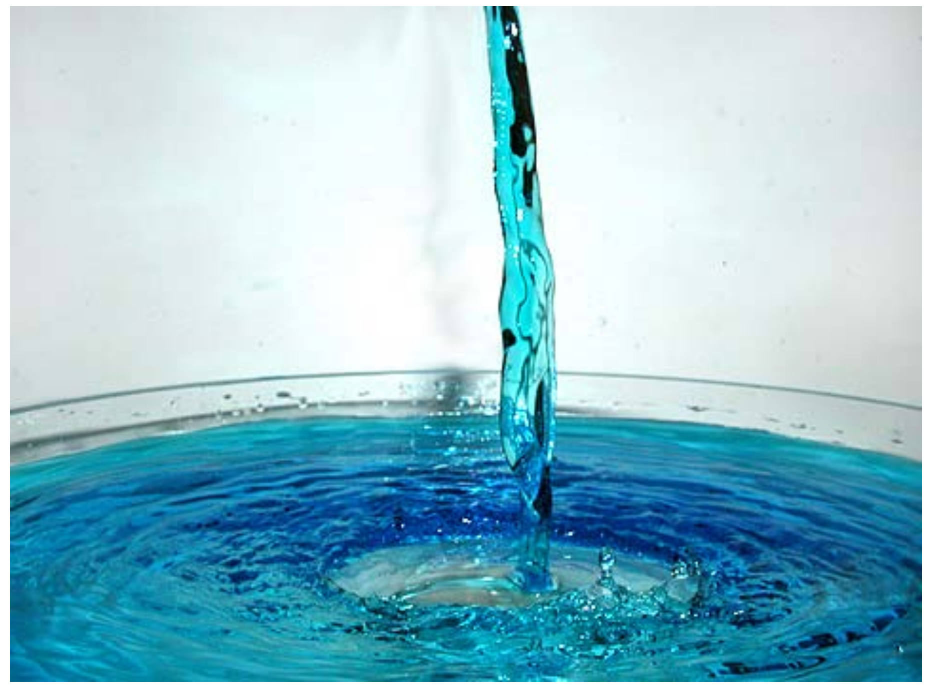
Images from Phylopic: Opthalmosaurus - Gareth Monger; Tursiops - Chris Huh

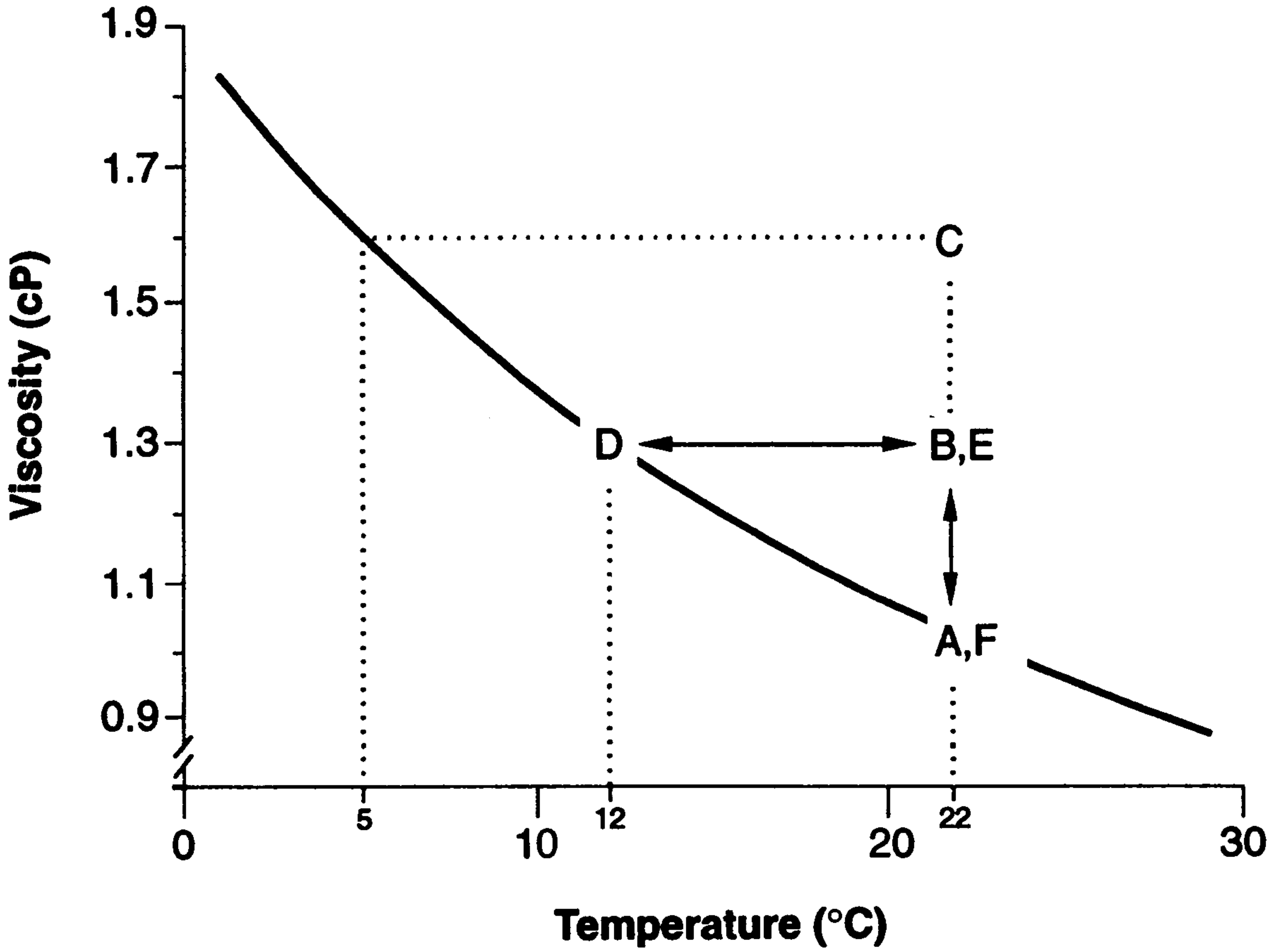
Release from selection



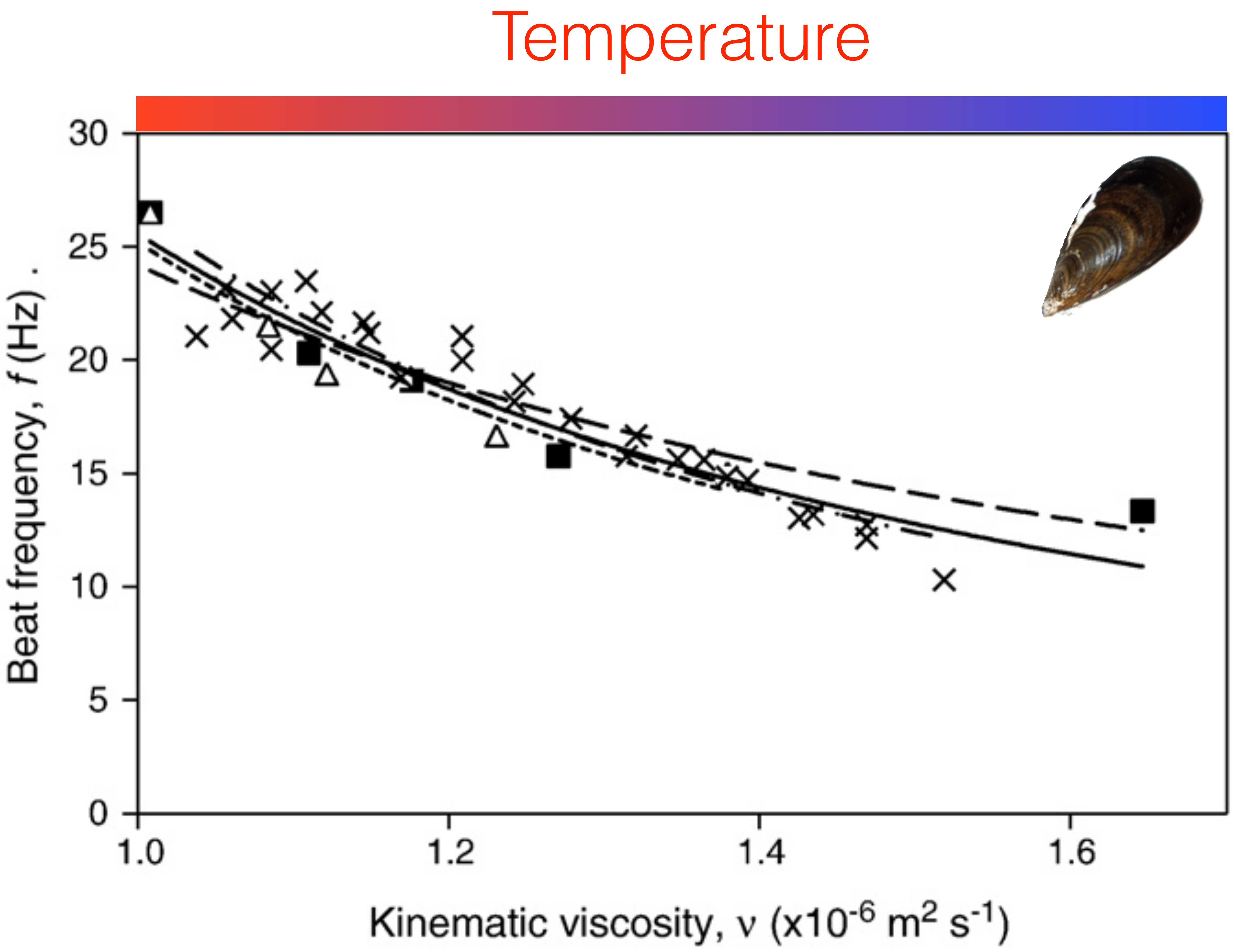
Images from phylopic: Chlorphyceae - Sergio A. Muñoz-Gómez

Temperature





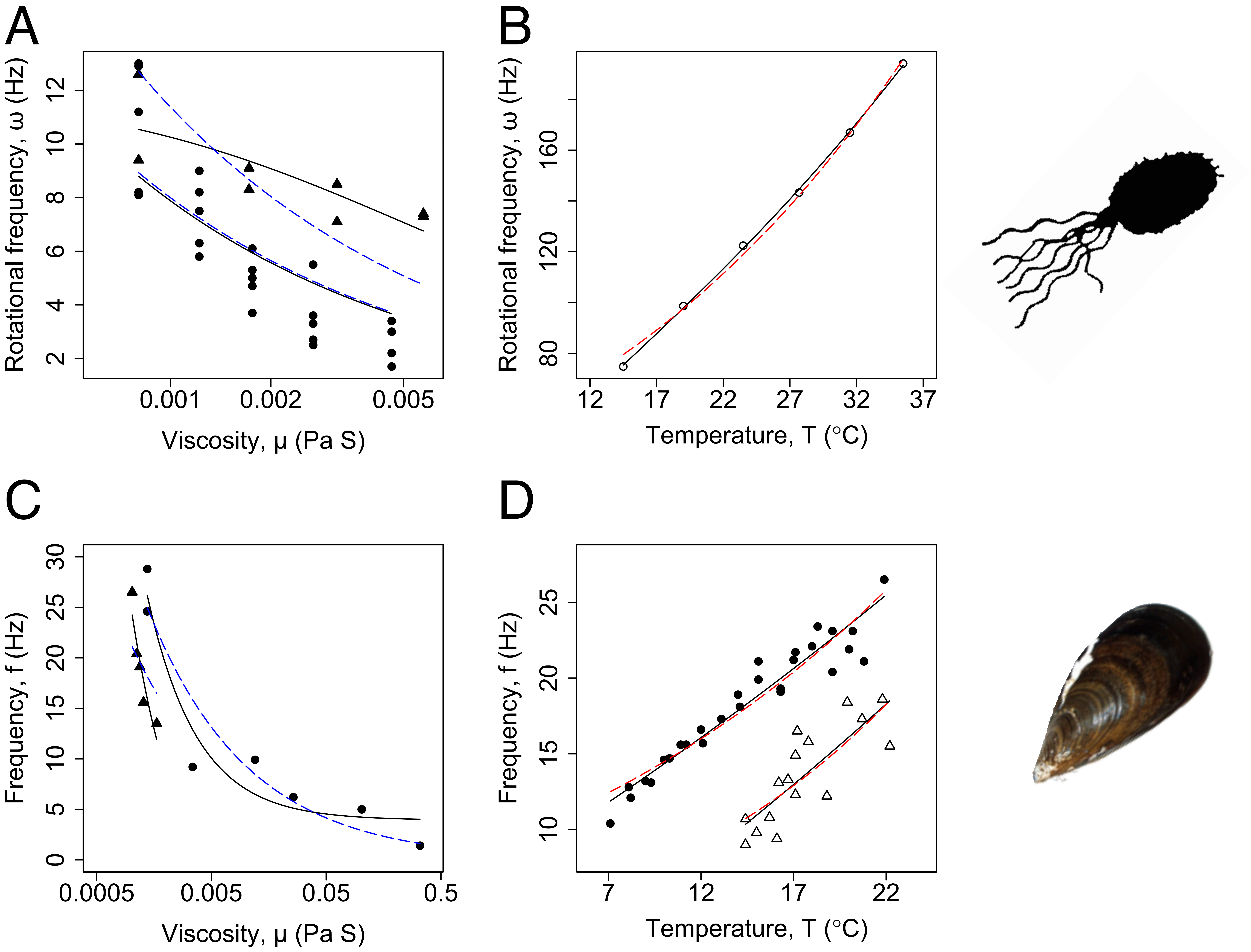
Viscosity

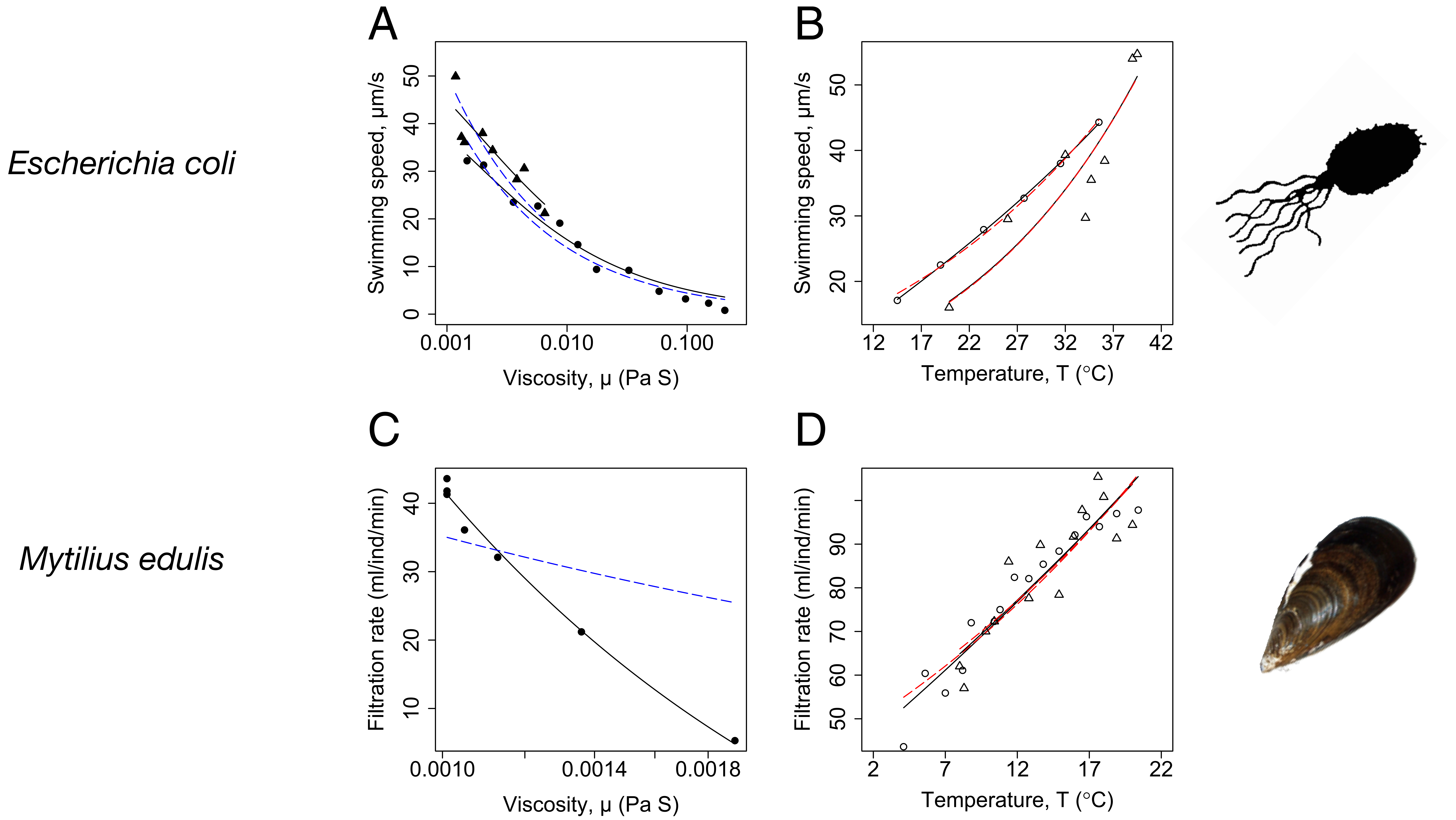


Mytilus cilia: Larsen & Riisgård, 2009

Escherichia coli

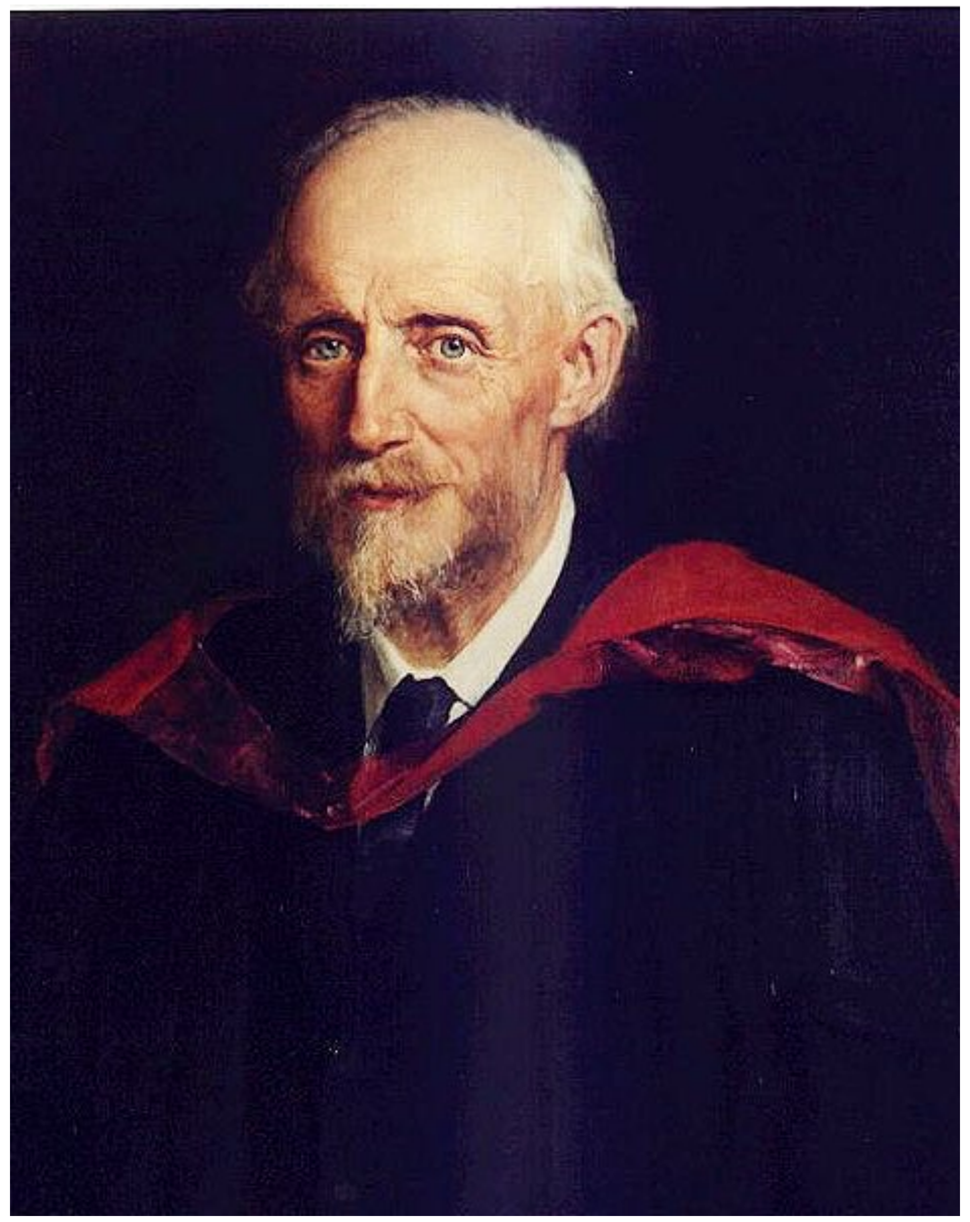
Mytilius edulis



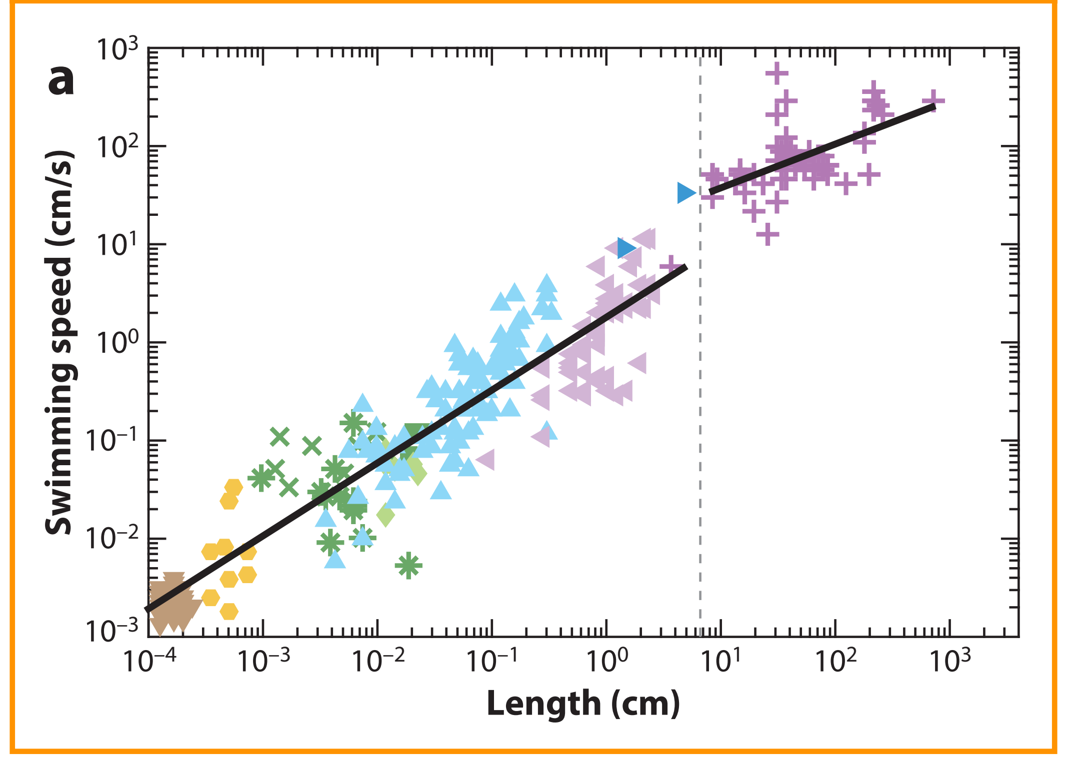


Escherichia coli
Mytilius edulis
A
Swimming speed, µm/s
0
10
20
30
40
50
0.001
0.010
0.100
Viscosity, µ (Pa S)
B
Swimming speed, µm/s
20
30
40
50
12
17
22
27
32
37
42
Temperature, T (°C)
C
Filtration rate (ml/ind/min)
10
20
30
40
0.0010
0.0014
0.0018
Viscosity, µ (Pa S)
D
Filtration rate (ml/ind/min)
50
60
70
80
90
2
7
12
17
22
Temperature, T (°C)

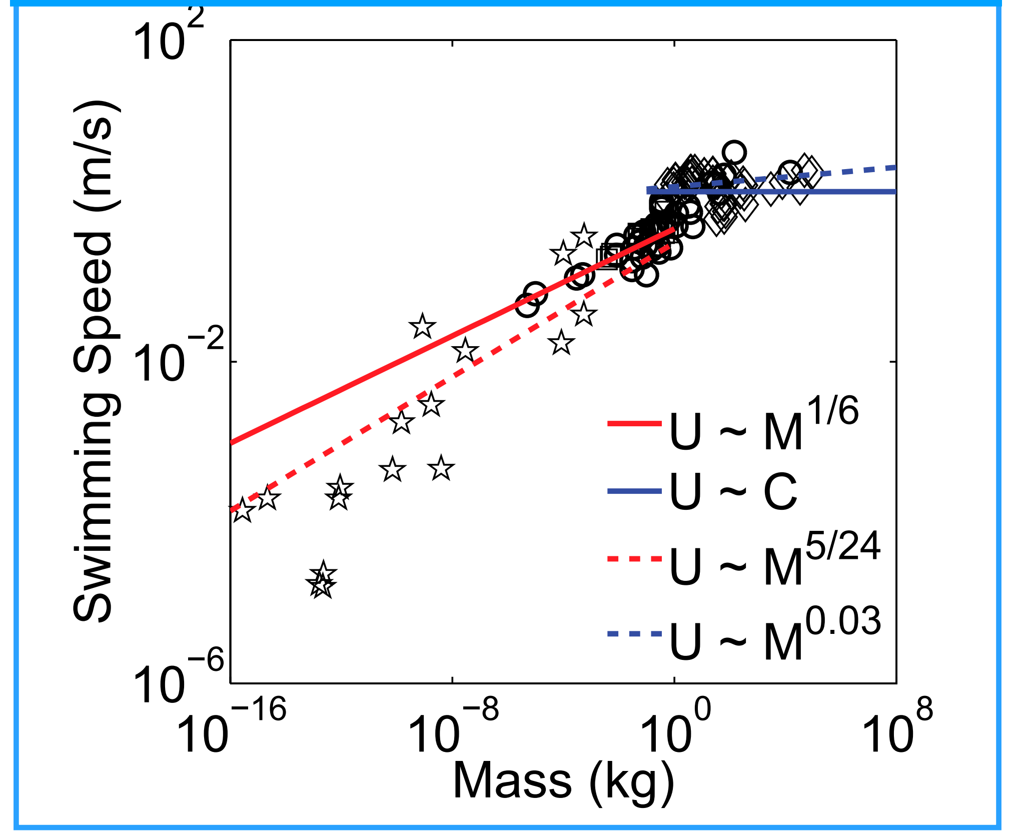
Reynolds number



Characteristic length



Velocity

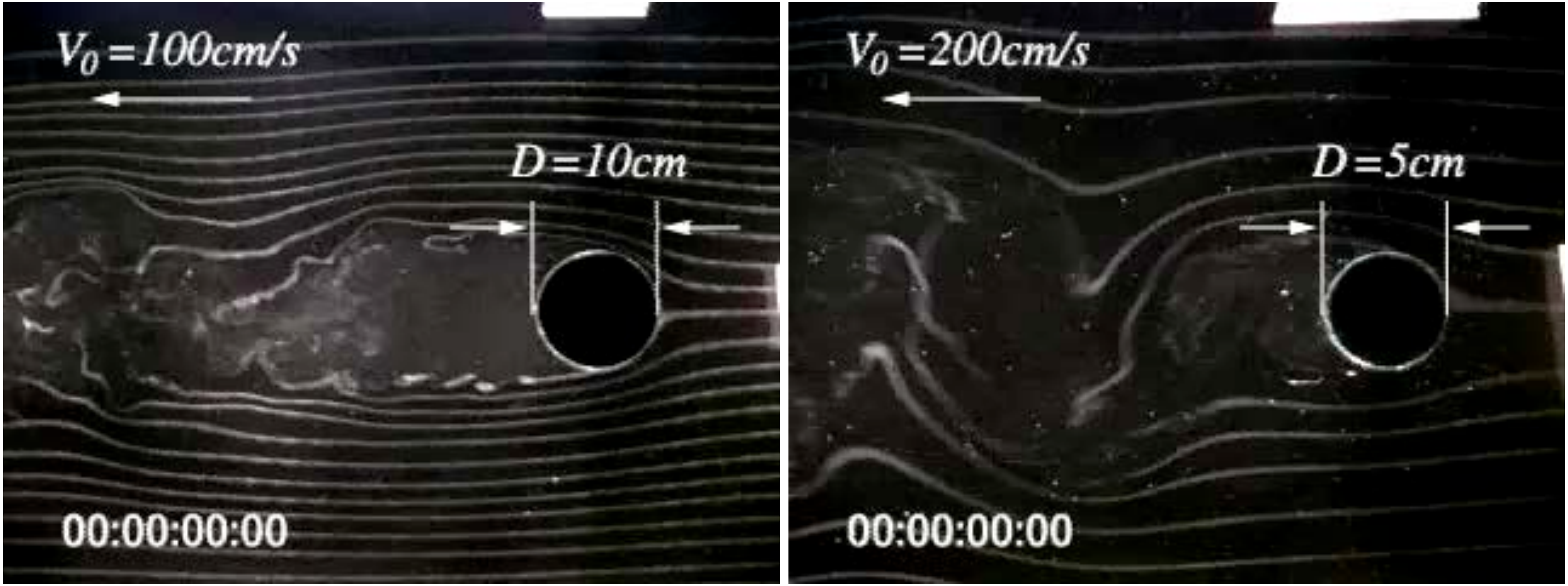


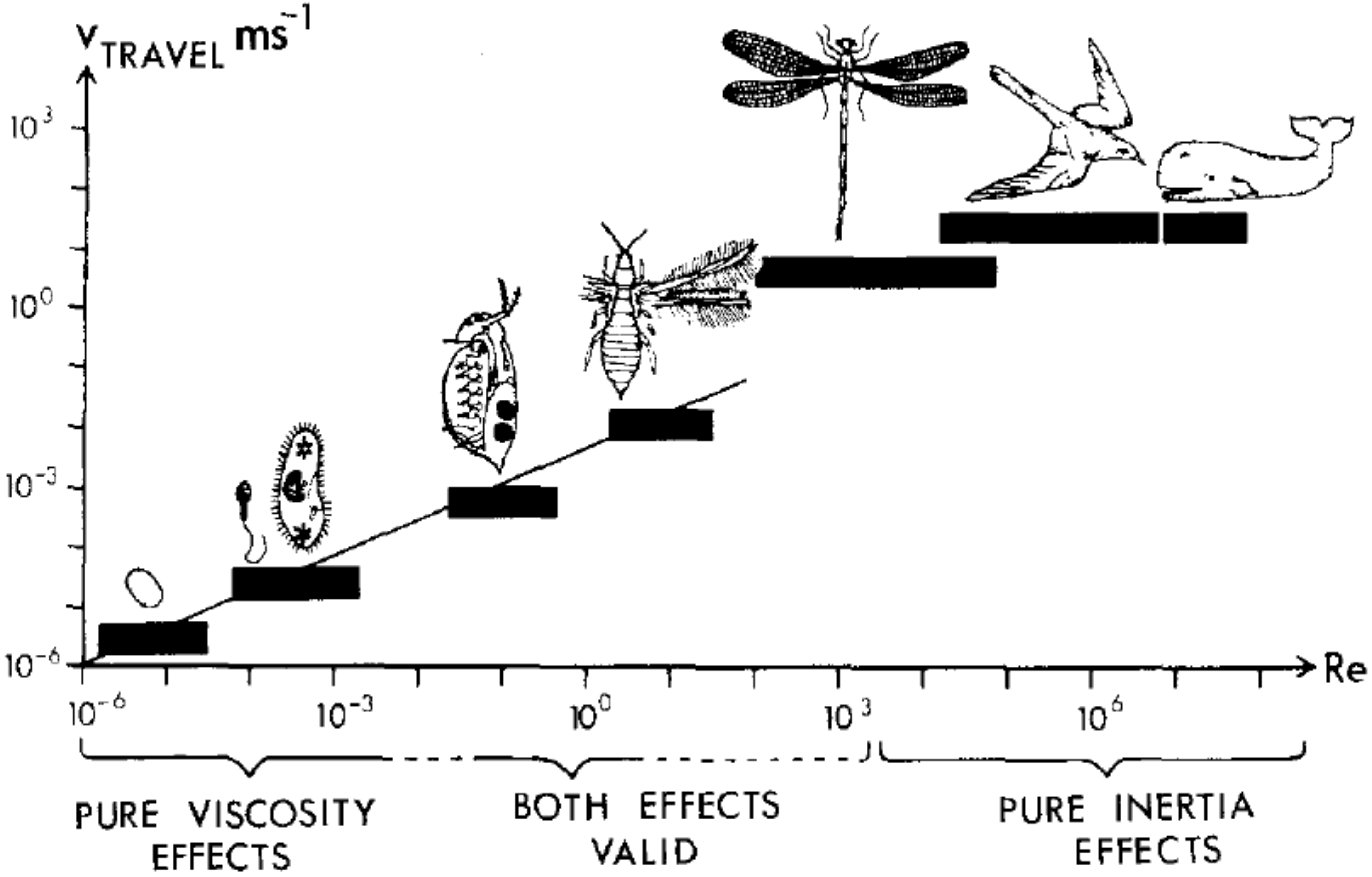
$$\mathrm{Re} = \frac{\rho l U}{\mu} = \frac{lU}{\nu}$$

kinematic viscosity

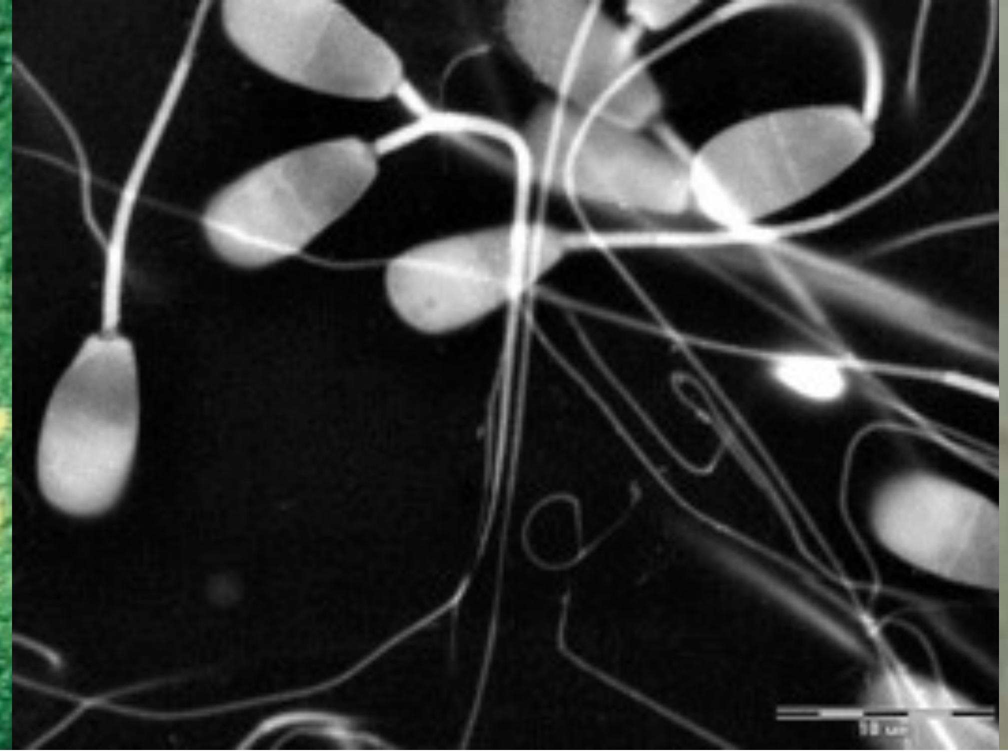
For similar geometries, similar *Re* indicates similar flows

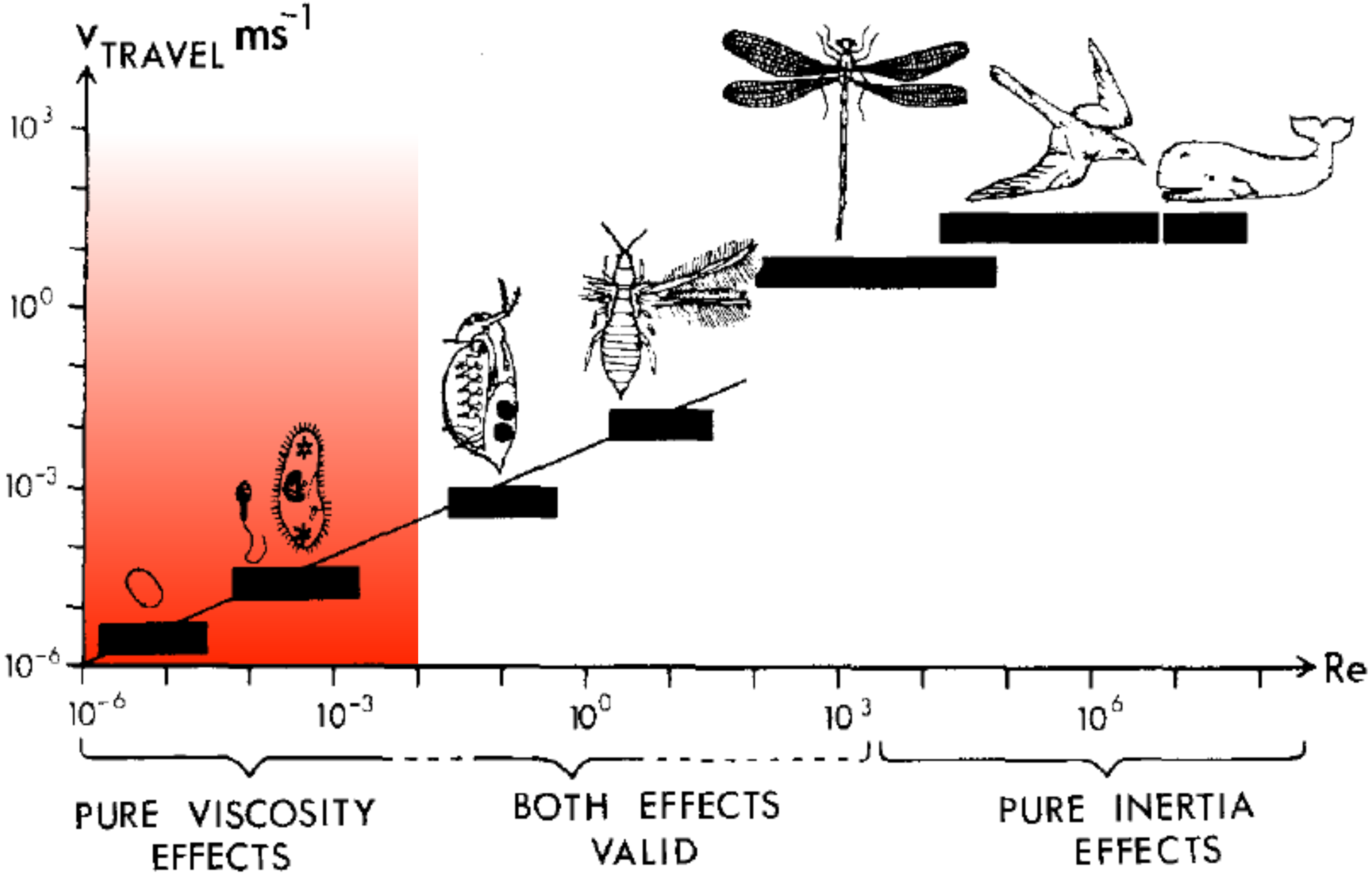
Re = 100,000





v_{TRAVEL} ms^{-1}
10^3
10^0
10^{-3}
10^{-6}
Re
10^{-6}
10^{-3}
10^0
10^3
10^6
PURE VISCOSITY EFFECTS
BOTH EFFECTS VALID
PURE INERTIA EFFECTS

v_{TRAVEL} ms^{-1}
10^3
10^0
10^{-3}
10^{-6}
Re
10^{-6}
10^{-3}
10^0
10^3
10^6
PURE VISCOSITY EFFECTS
BOTH EFFECTS VALID
PURE INERTIA EFFECTS

Laminar

Turbulent

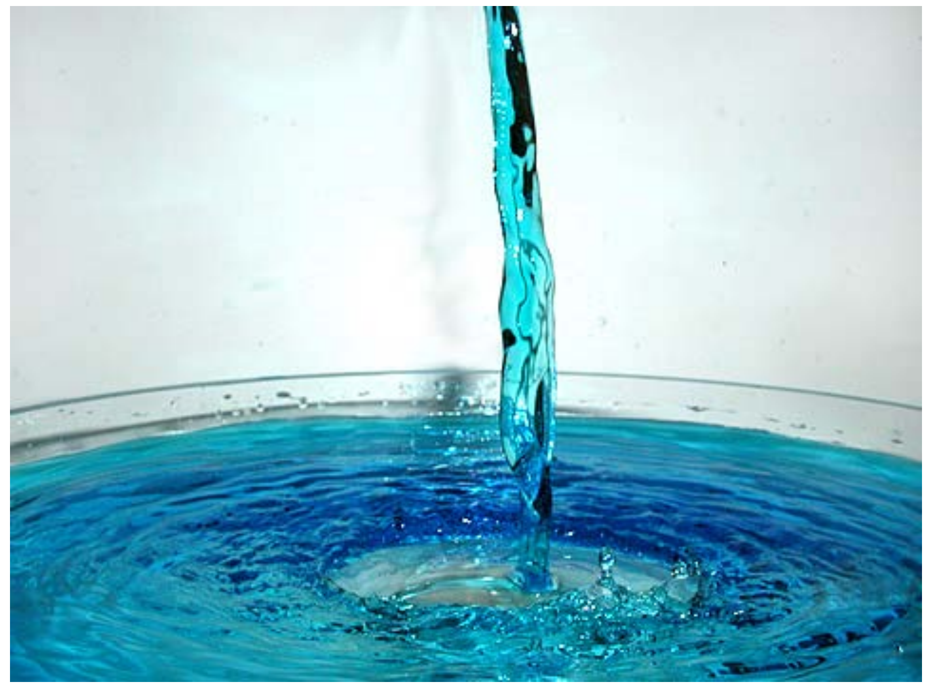
Characteristics of Low *Re* regimes

- Non-intuitive
- Inertia is negligible
- Flows are reversible
- Drag depends on surface
  - friction drag dominates
  - streamlining impossible (pressure drag negligible)
  - shape and orientation can help

Drag

$$\mathrm{Re} = \frac{lU}{\nu}$$

High *Re*

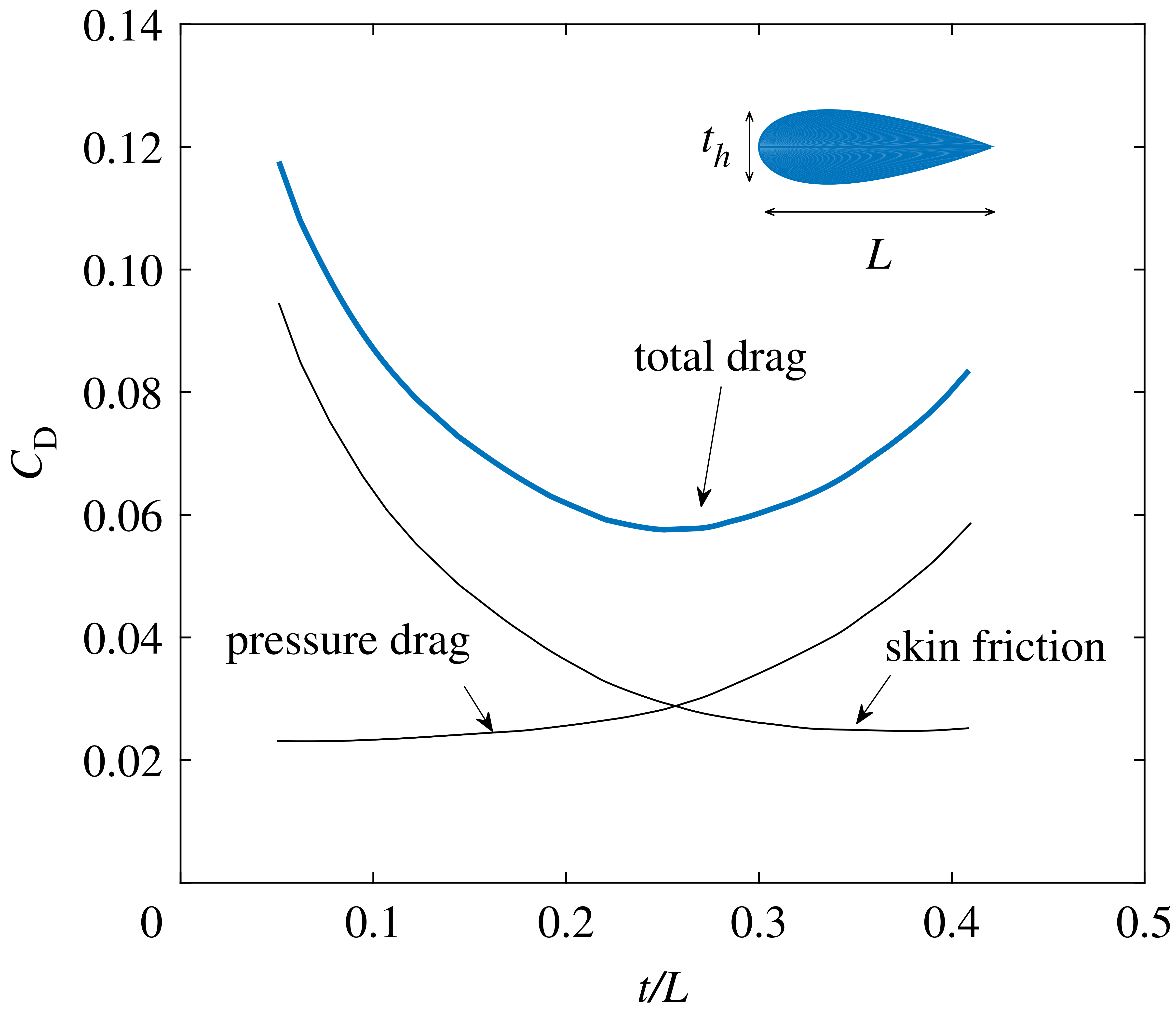


$$Drag \propto U^2$$

Low *Re*

$$Drag \propto U$$

Drag

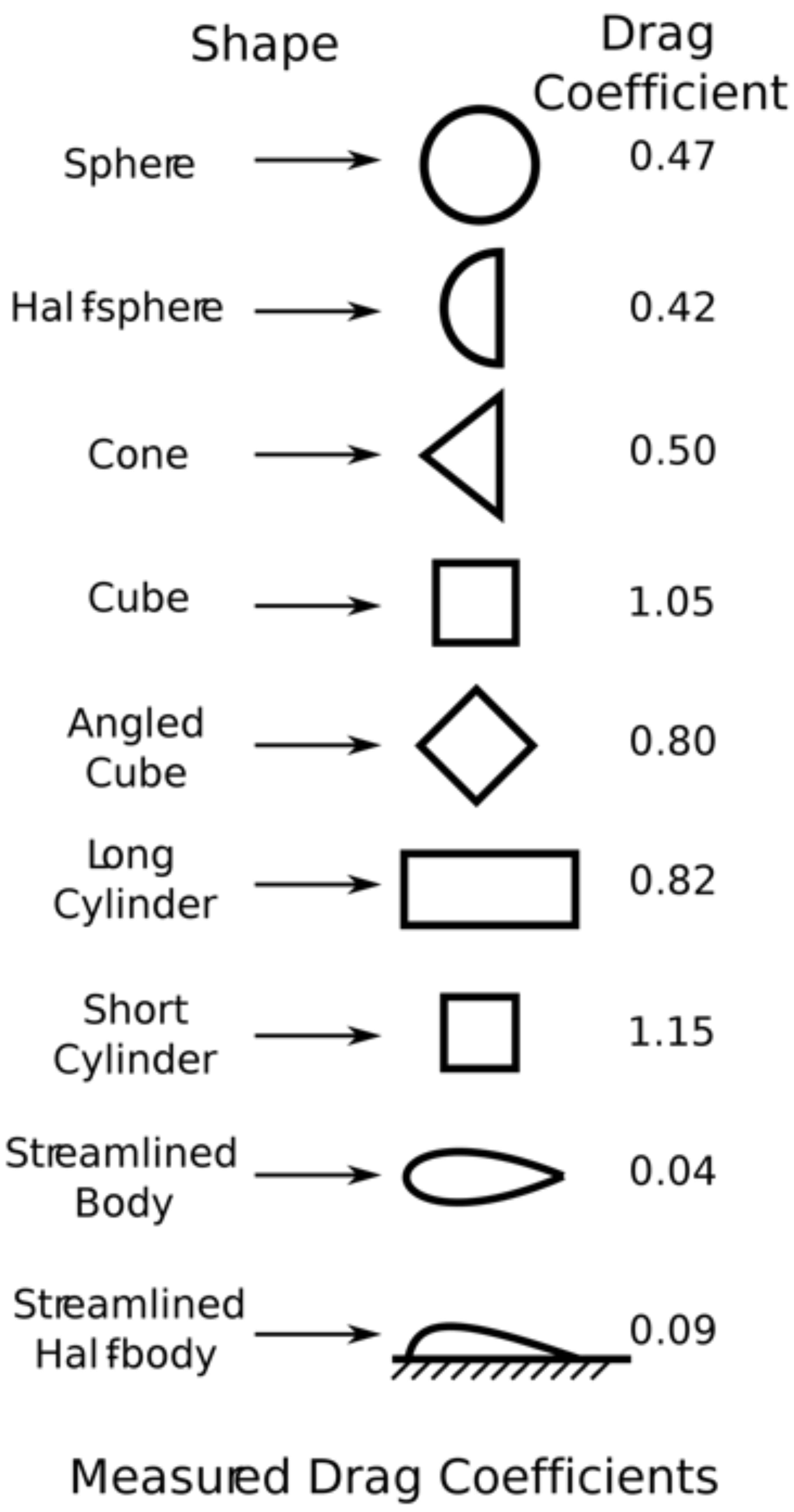


Godoy-Diana, R. & Thiria, B., 2018. On the diverse roles of fluid dynamic drag in animal swimming and flying. Journal of the Royal Society, Interface 15(139), p.20170715.

Drag

Fluid dynamicists describe effect of shape through empirically derived “fudge factor”

Drag coefficient, C_d



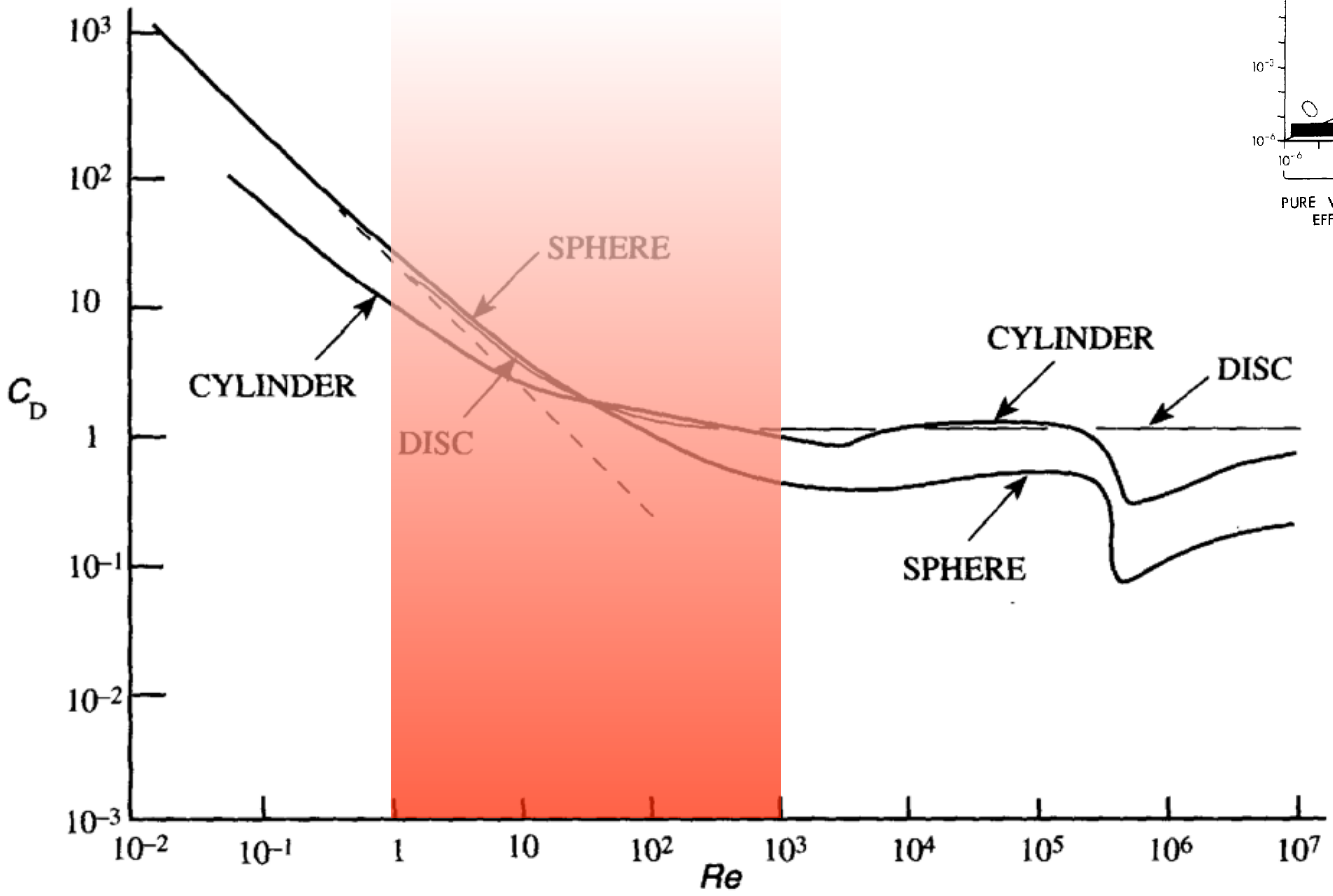
Drag

C_d not necessarily constant, varies with…

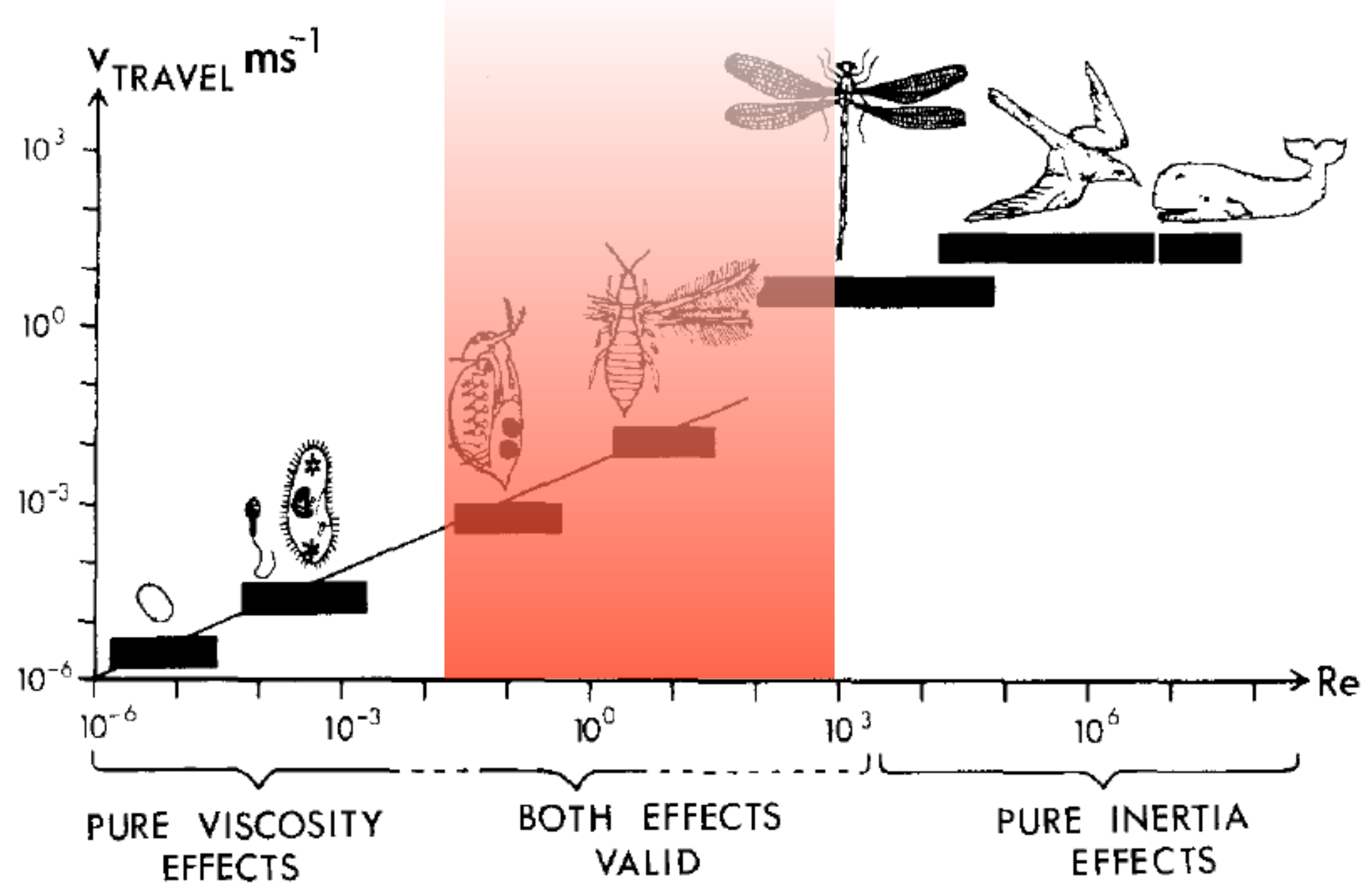
- velocity
- object size
- density/viscosity ratio

$$\mathrm{Re} = \frac{\rho l U}{\mu} = \frac{lU}{\nu}$$

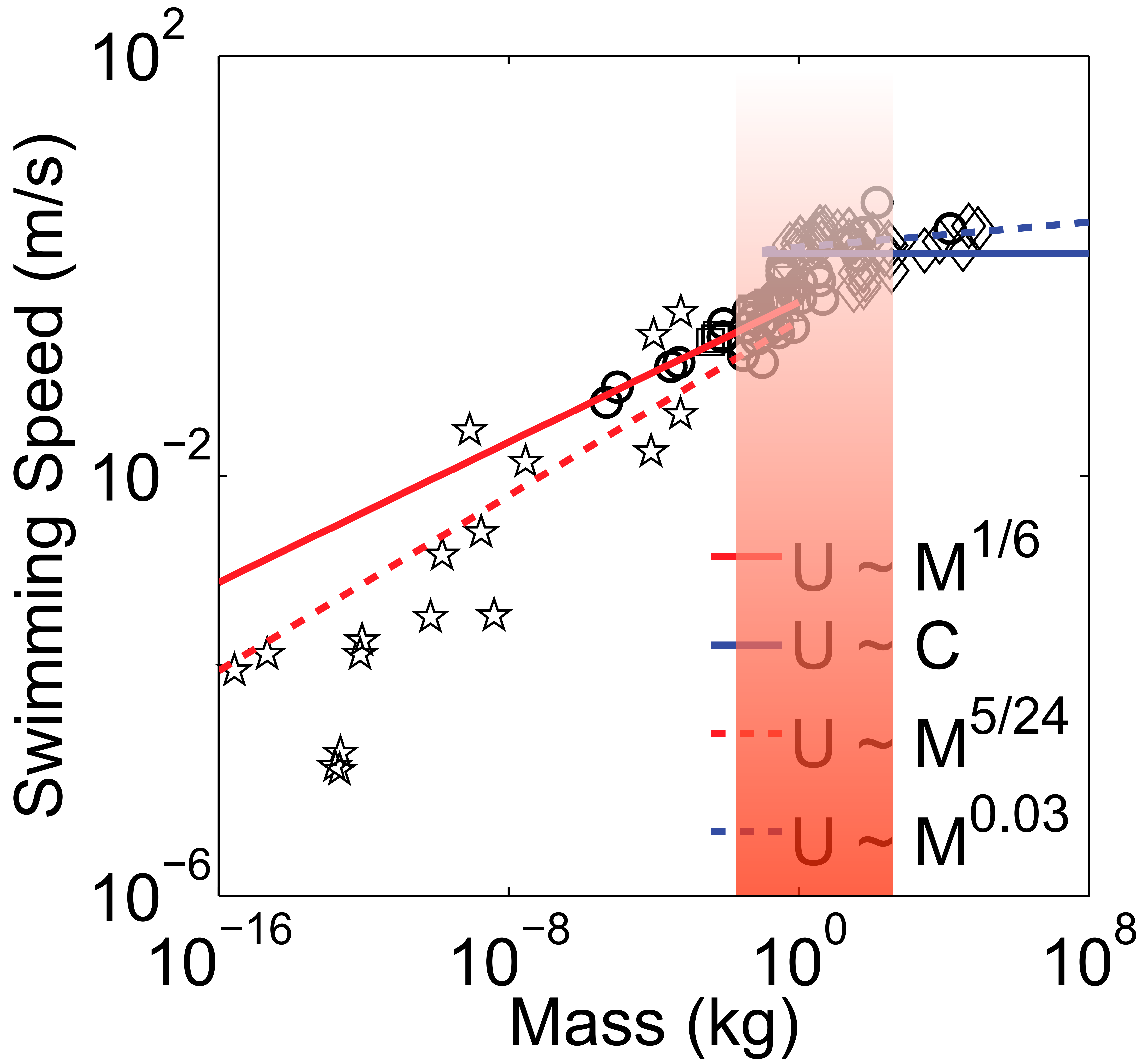
Drag



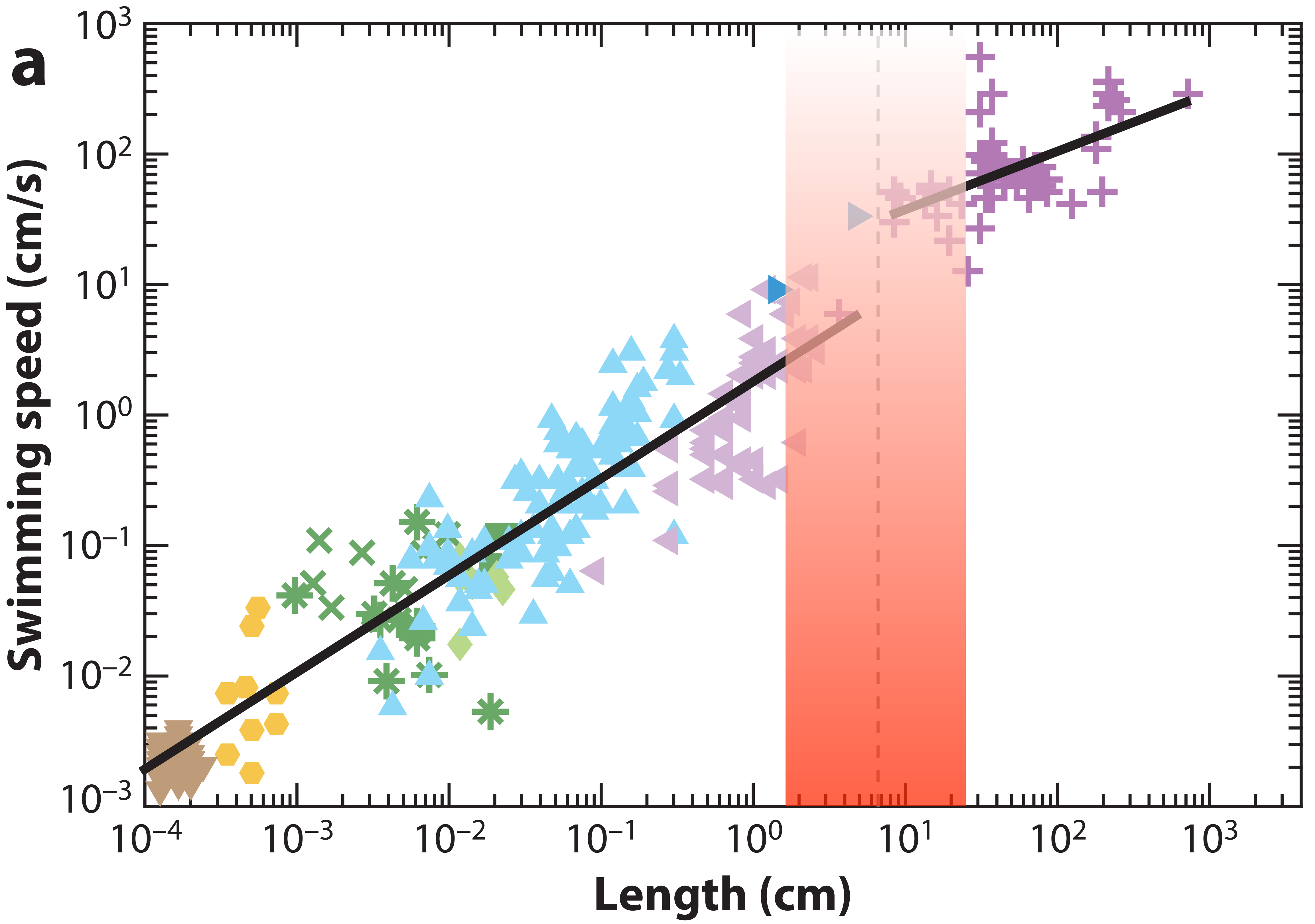
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
C_D
CYLINDER
SPHERE
DISC
CYLINDER
DISC
SPHERE
10⁻²
10⁻¹
1
10
10²
10³
10⁴
10⁵
10⁶
10⁷
Re



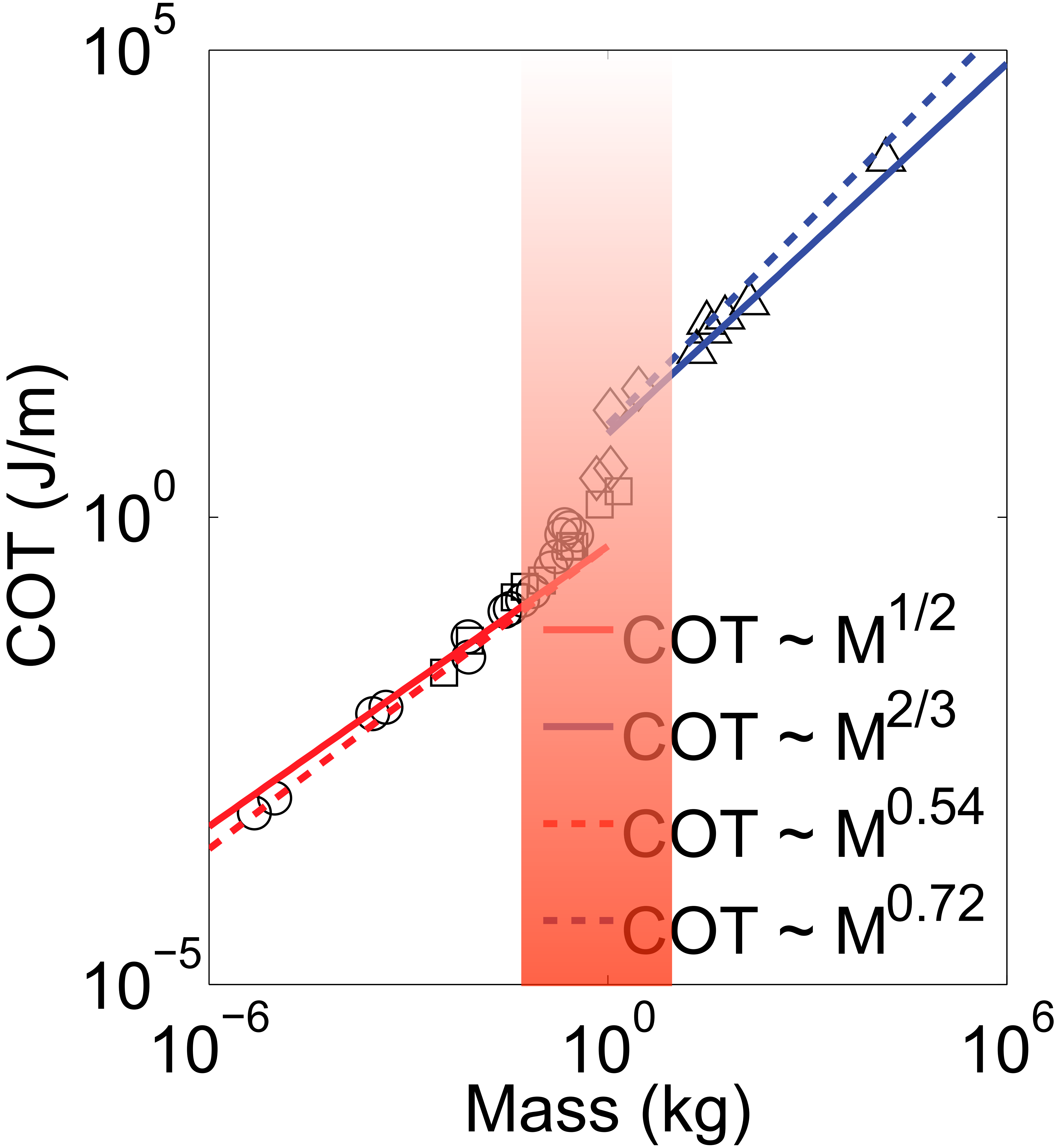
v_{TRAVEL} ms^{-1}
10³
10⁰
10⁻³
10⁻⁶
Re
10⁻⁶
10⁻³
10⁰
10³
10⁶
PURE VISCOSITY EFFECTS
BOTH EFFECTS VALID
PURE INERTIA EFFECTS



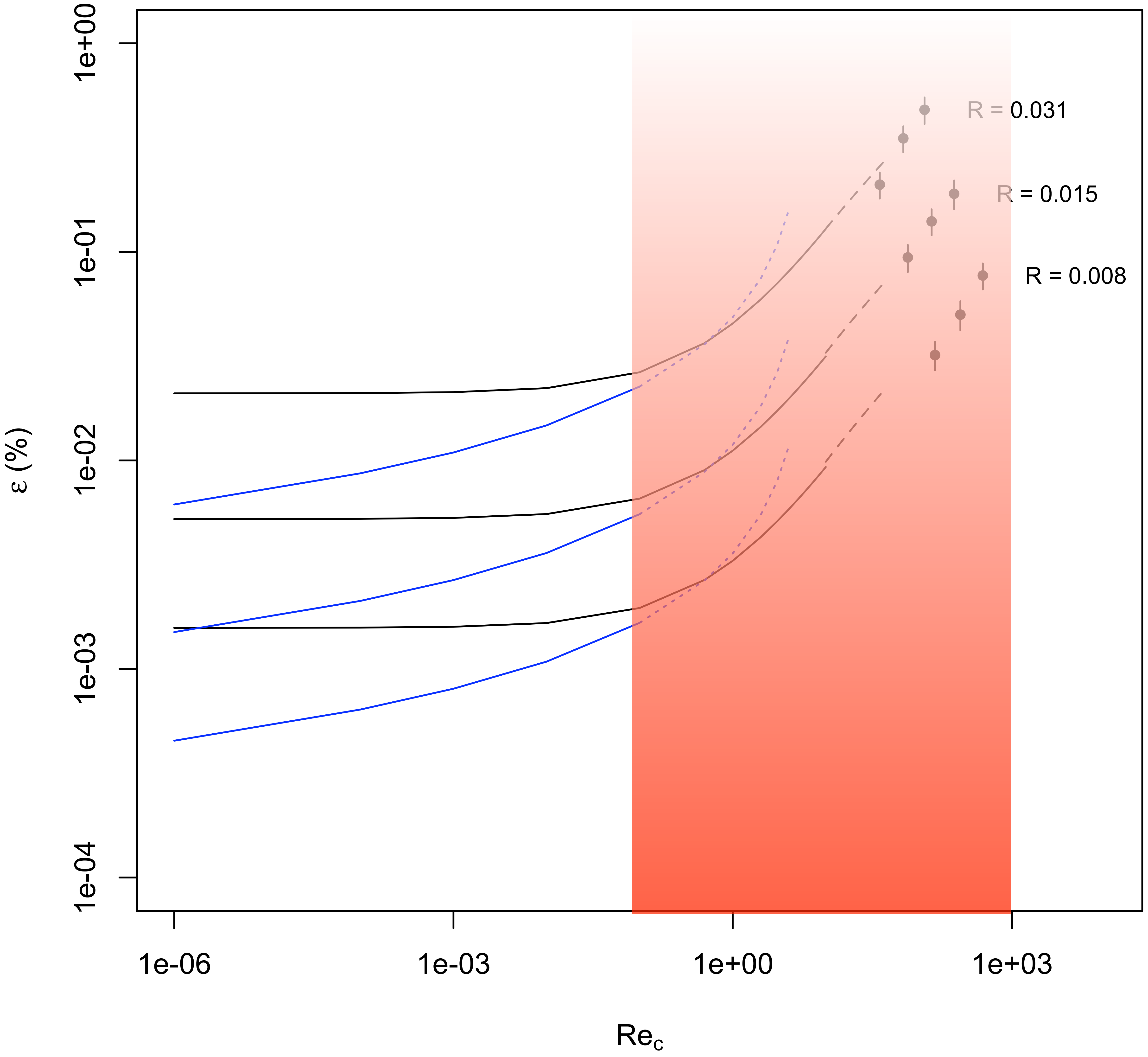
Bale, R. et al., 2014. PNAS, 111(21), pp.7517–7521.



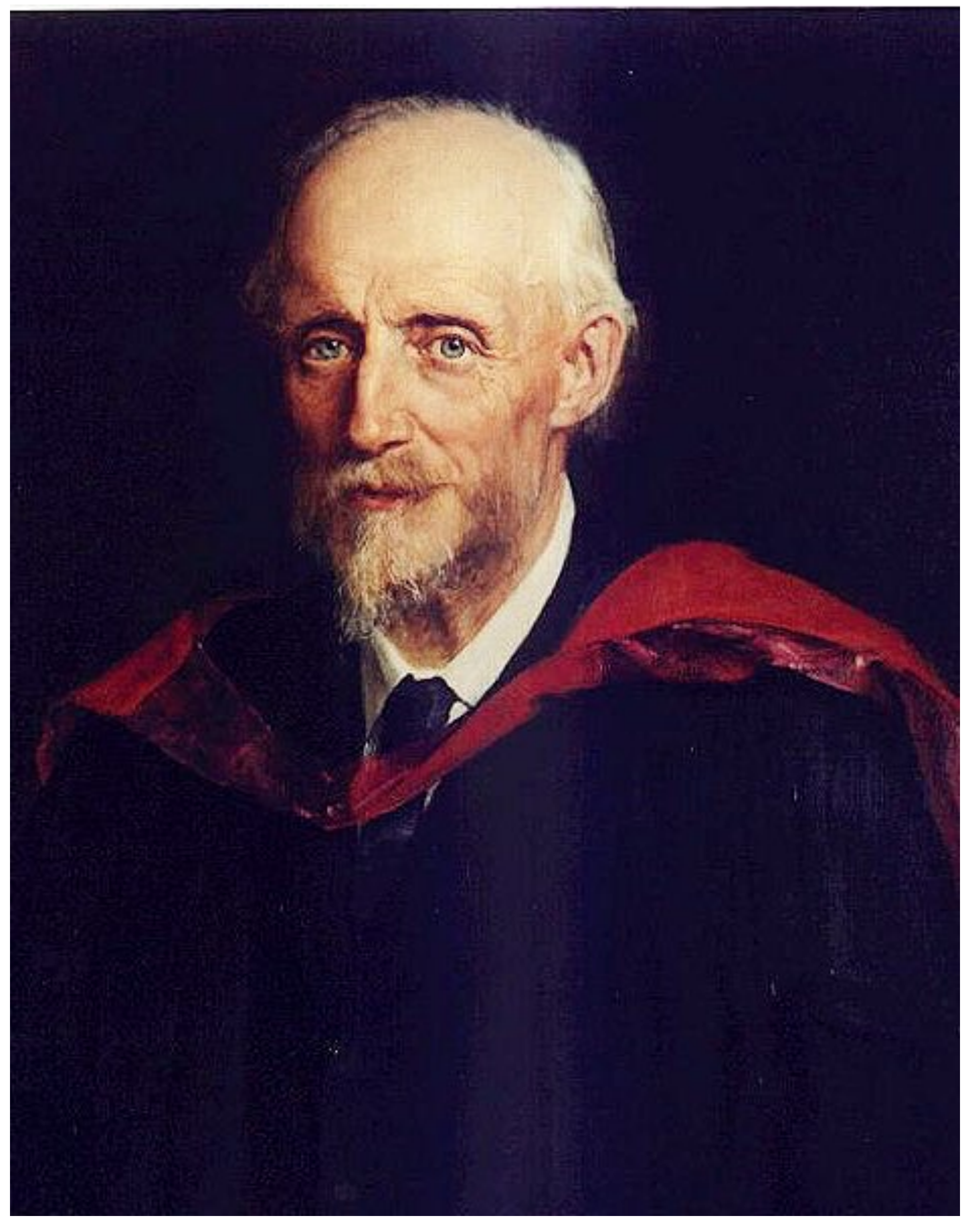
Andersen, K.H. et al., 2015. Annual Review of Materials Science, 8(1), pp. 150710224004001–241.



Bale, R. et al., 2014. PNAS, 111(21), pp.7517–7521.

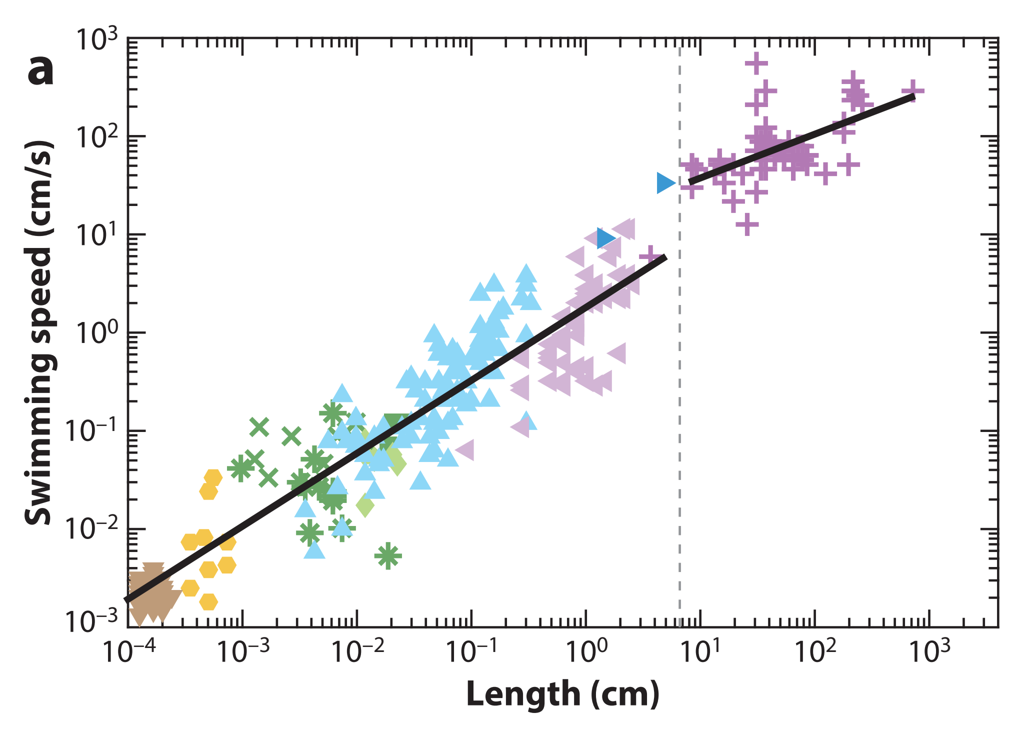


Humphries, S., 2013. PNAS, 110(36), pp.14693–14698.

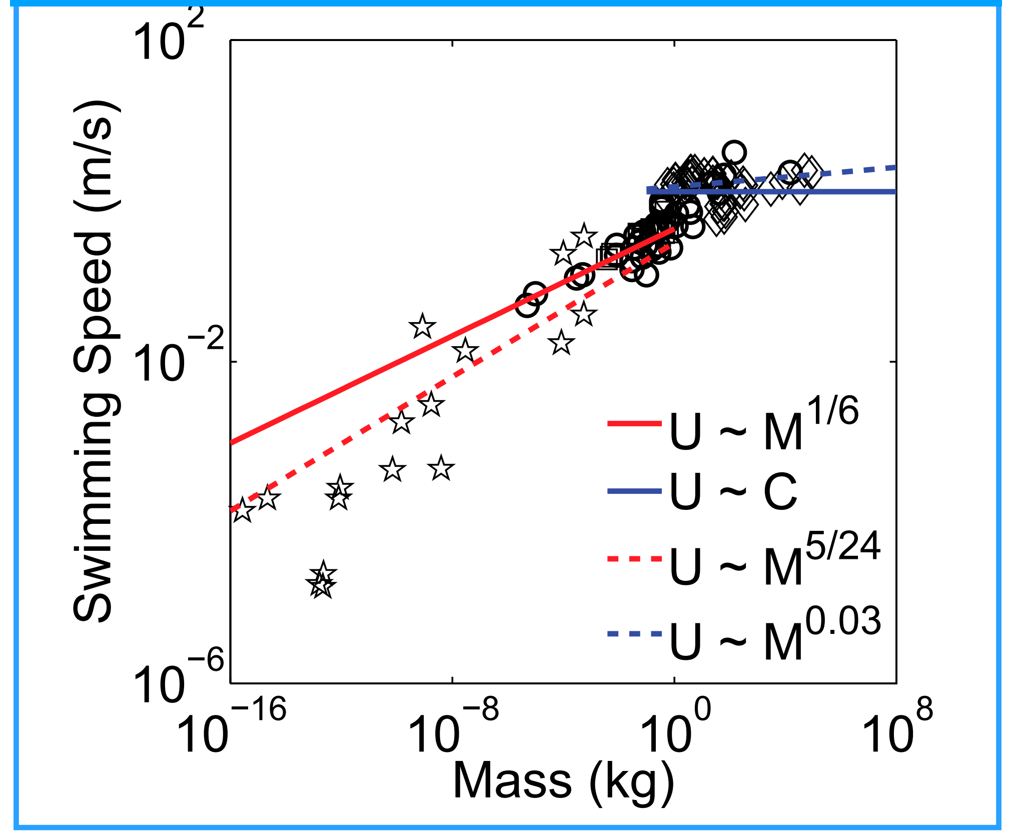


Reynolds number

Characteristic length



Velocity

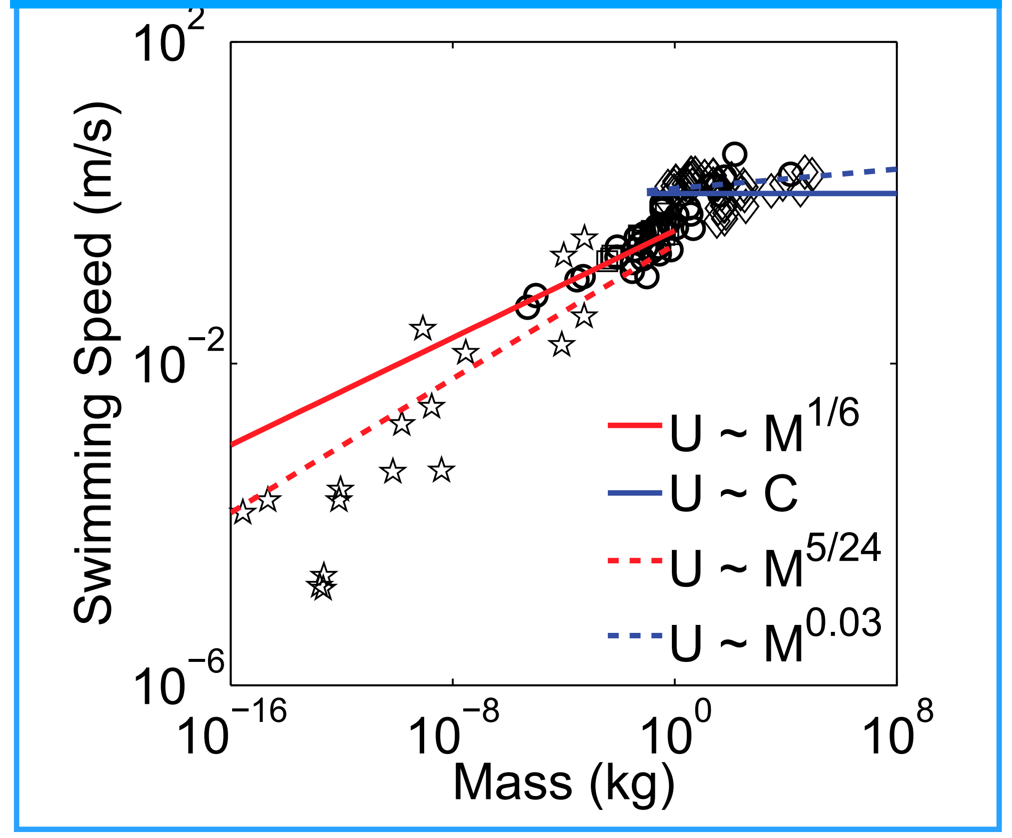


$$\mathrm{Re} = \frac{\rho l U}{\mu} = \frac{lU}{\nu}$$

kinematic viscosity

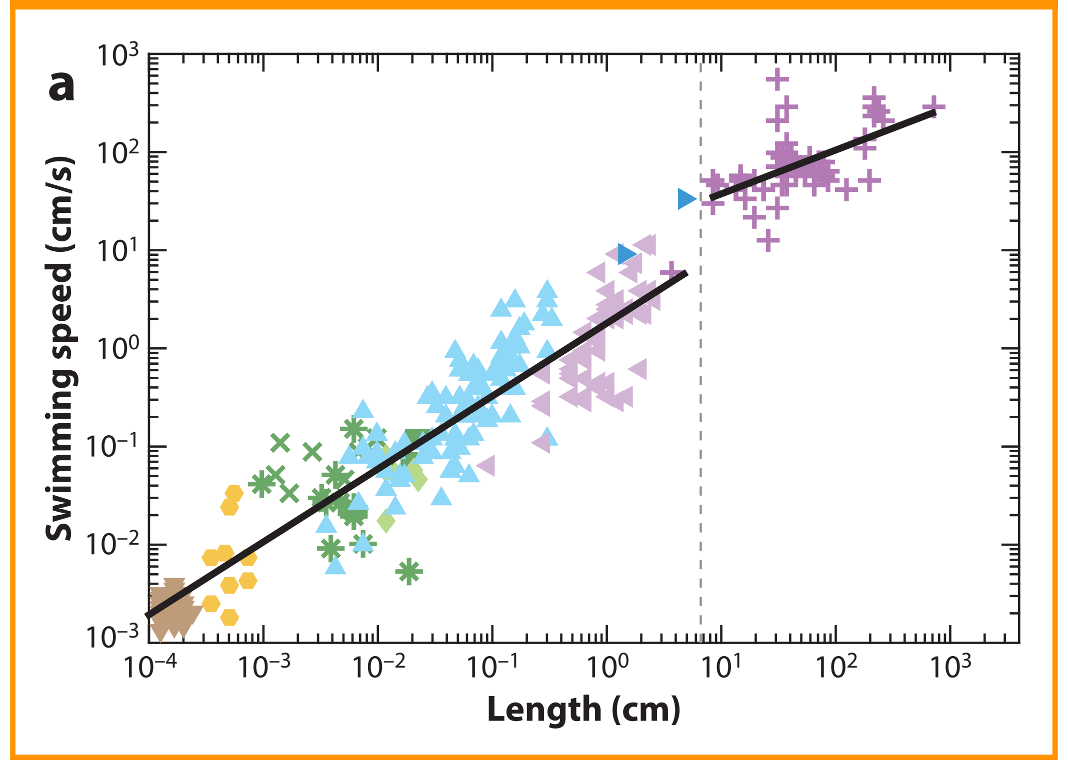
Froude number

Velocity

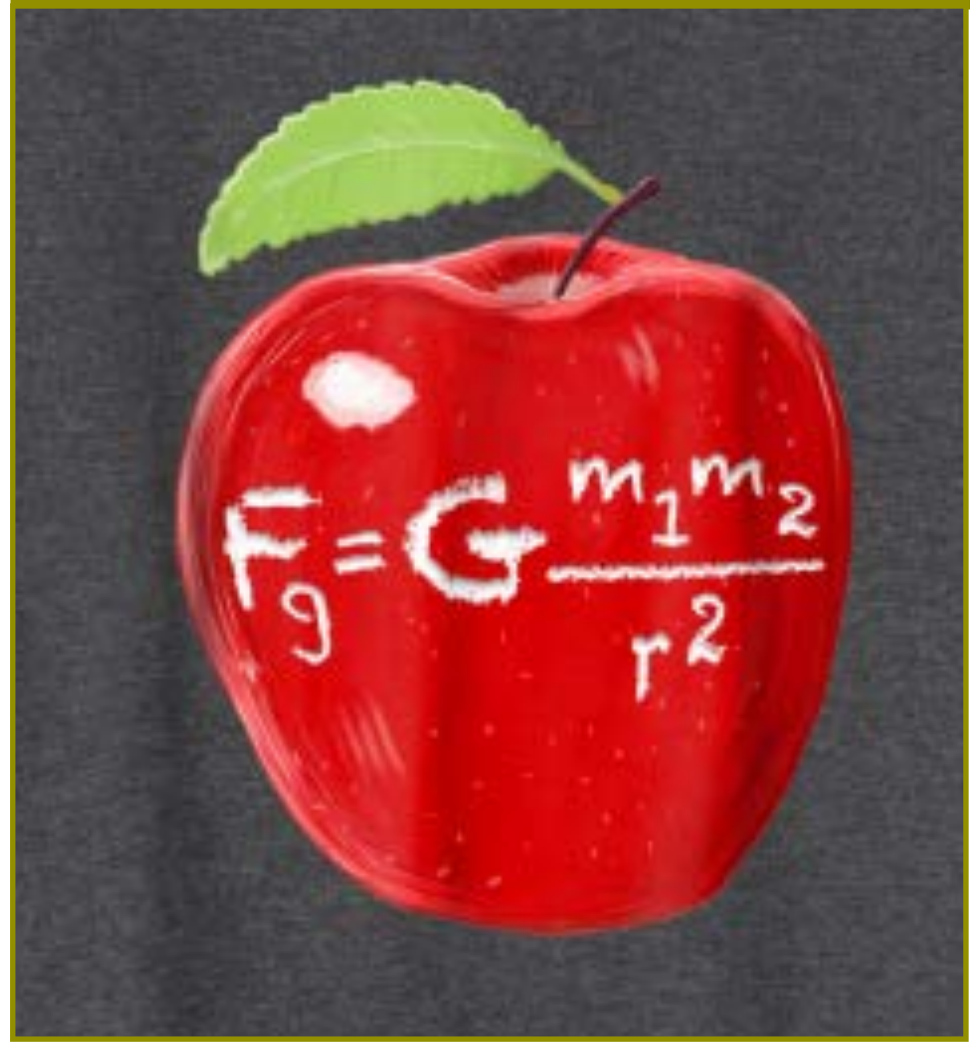


$$Fr = \frac{U}{\sqrt{gl}}$$

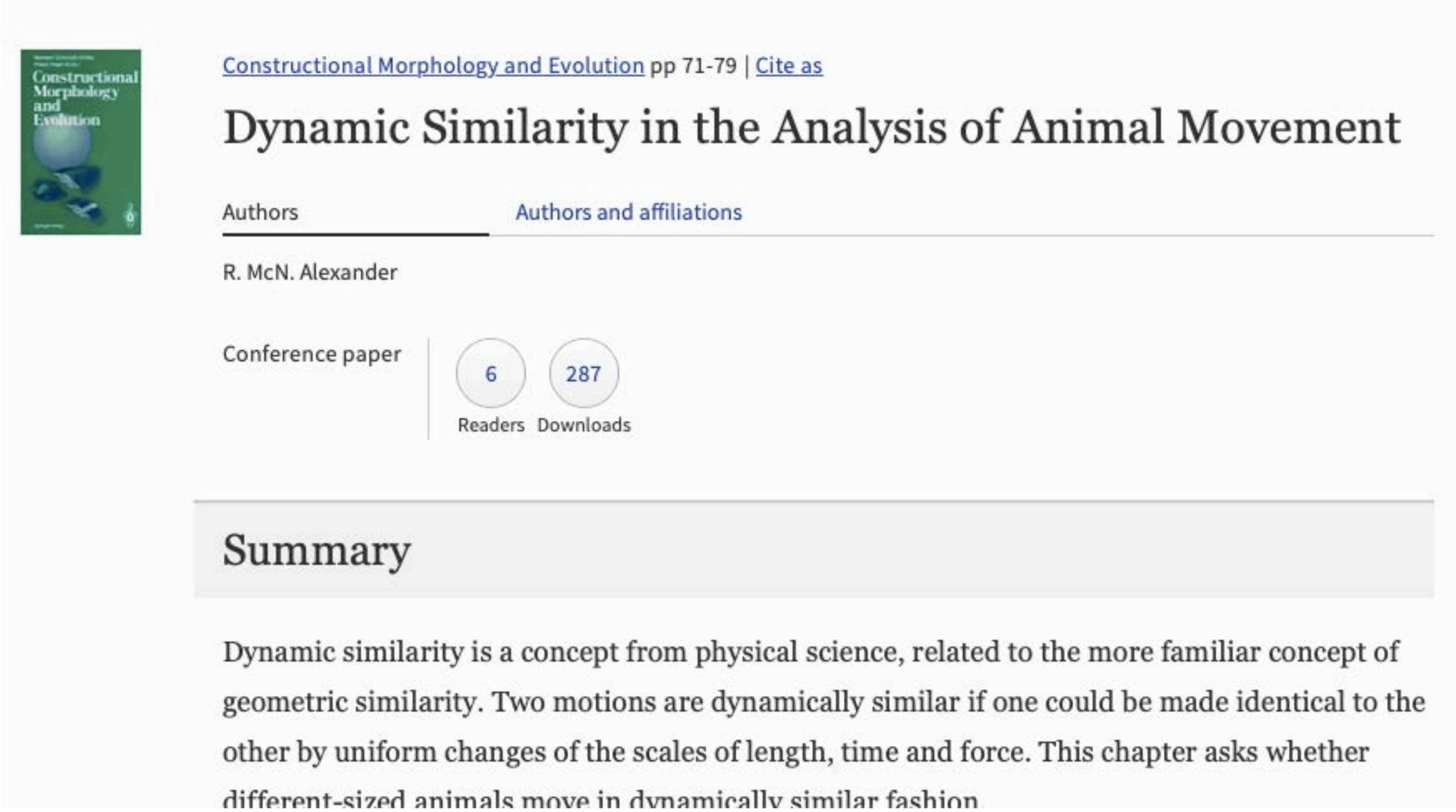
Characteristic length



Gravity



Froude number


Constructional Morphology and Evolution pp 71-79 | Cite as

Dynamic Similarity in the Analysis of Animal Movement

Authors | Authors and affiliations

R. McN. Alexander

Summary

Dynamic similarity is a concept from physical science, related to the more familiar concept of geometric similarity. Two motions are dynamically similar if one could be made identical to the other by uniform changes of the scales of length, time and force. This chapter asks whether different-sized animals move in dynamically similar fashion

Figure 1 An Asian elephant marked with dots for gait analysis.

Evolution, R.A.C.M.A.1991, Dynamic similarity in the analysis of animal movement. Springer.

Hutchinson, J.R. et al., 2003. Biomechanics: Are fast-moving elephants really running? Nature, 422(6931), pp.493–494.

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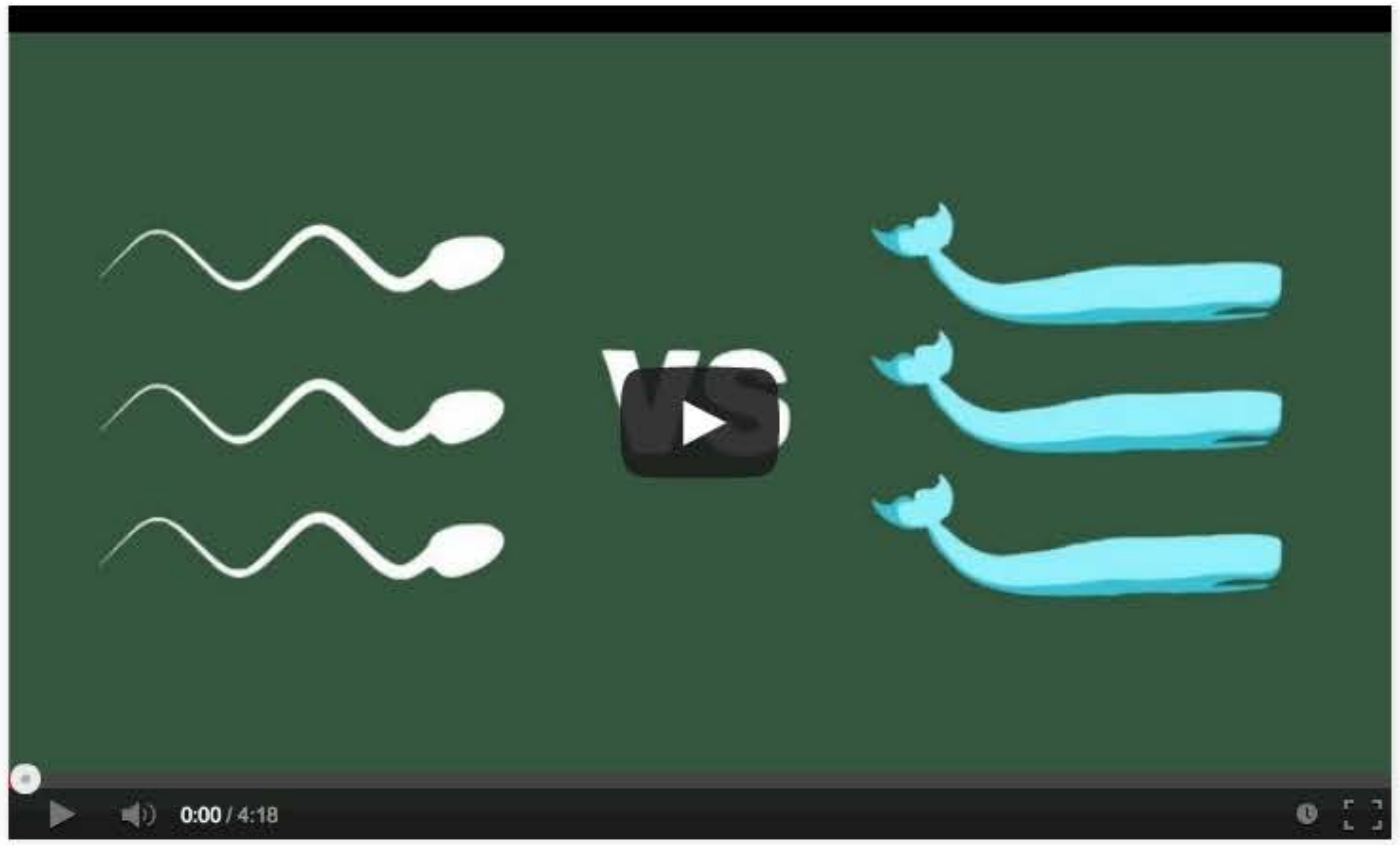
The physics of human sperm vs. the physics of the sperm whale - Aatish Bhatia

LESSON CREATED BY **STUART HUMPHRIES** USING **TED**Ed

VIDEO FROM **TED-Ed** YOUTUBE CHANNEL

Let's Begin…

Traveling is extremely arduous for microscopic organisms -- think of a human trying to swim in a pool made of...other humans. We can compare the journey of a sperm to that of a sperm whale by calculating the Reynolds number, a prediction of how fluid will behave, often fluctuating due to the size of the swimmer. Aatish Bhatia explores the great (albeit tiny) sperm's journey.



Watch

Think

Dig Deeper

…And Finally

Resources: handbook; ed.ted.com/on/KwQTKDKj