Scaling in the *Physarum* Amobae during locomotion: size vs shape, speed, rhythm

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Nov 28, 2014

Outline

- **Backgournd**
  - Self-organized Phenomena as Directional locomotion of Amoeba cell
  - Various size in Physarum amoebae
- **Experimental**
  - Methods
  - Results
- **A Math. Model**
  - Amoeba locomotion with large fluctuated speed as Traveling wave-like solution in non-autonomous R-D systems

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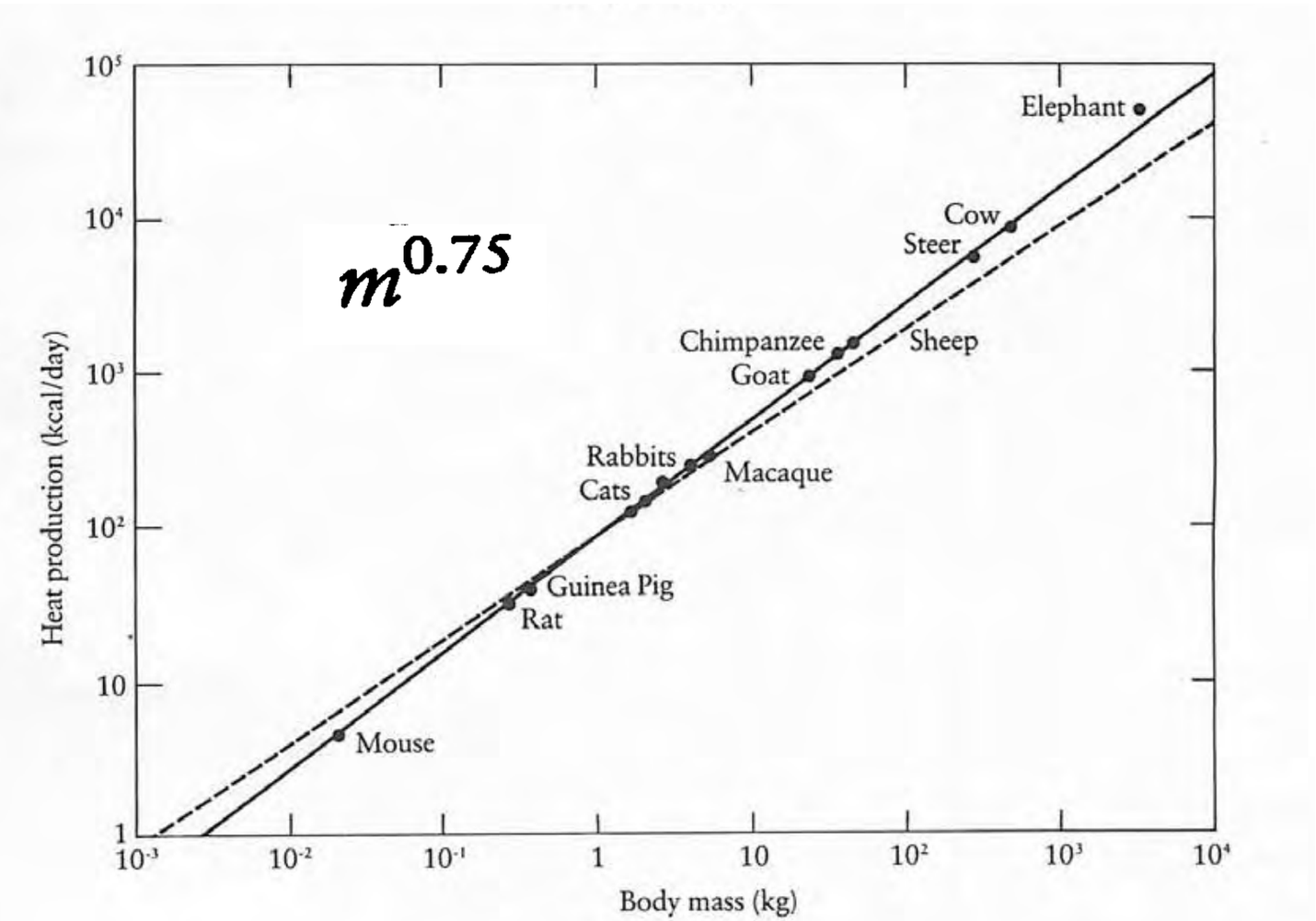
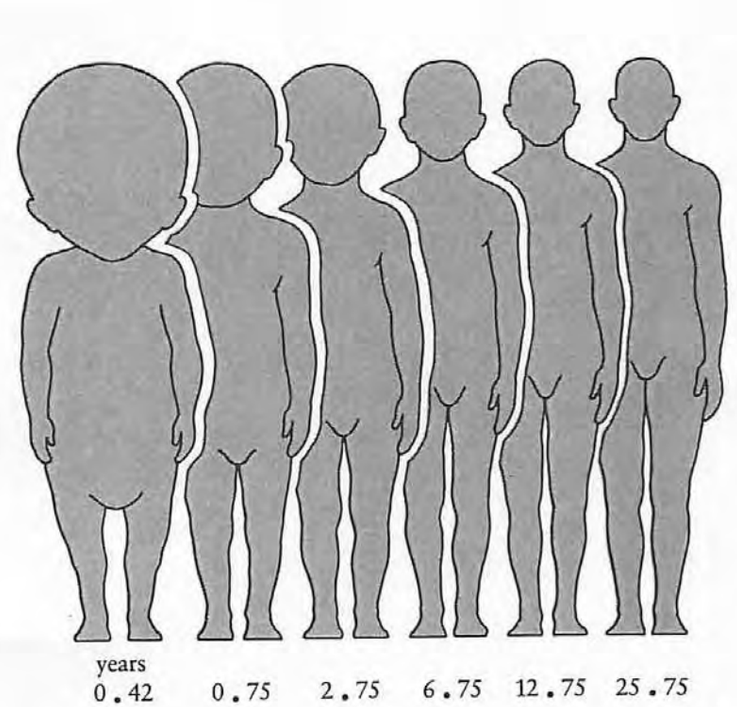
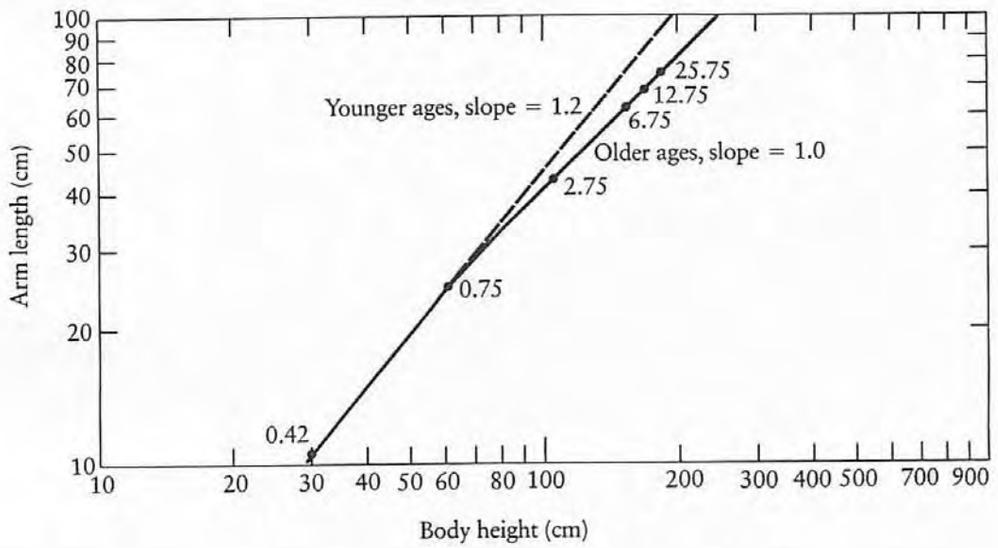
Biological scaling (*allometry*)

- The study of the relationship of <u>body size</u> to the other characteristics (ex) basal metabolic rate, cardiac rate, size of body parts, speed, shape, ...).
- referred as *allometry* in zoology.







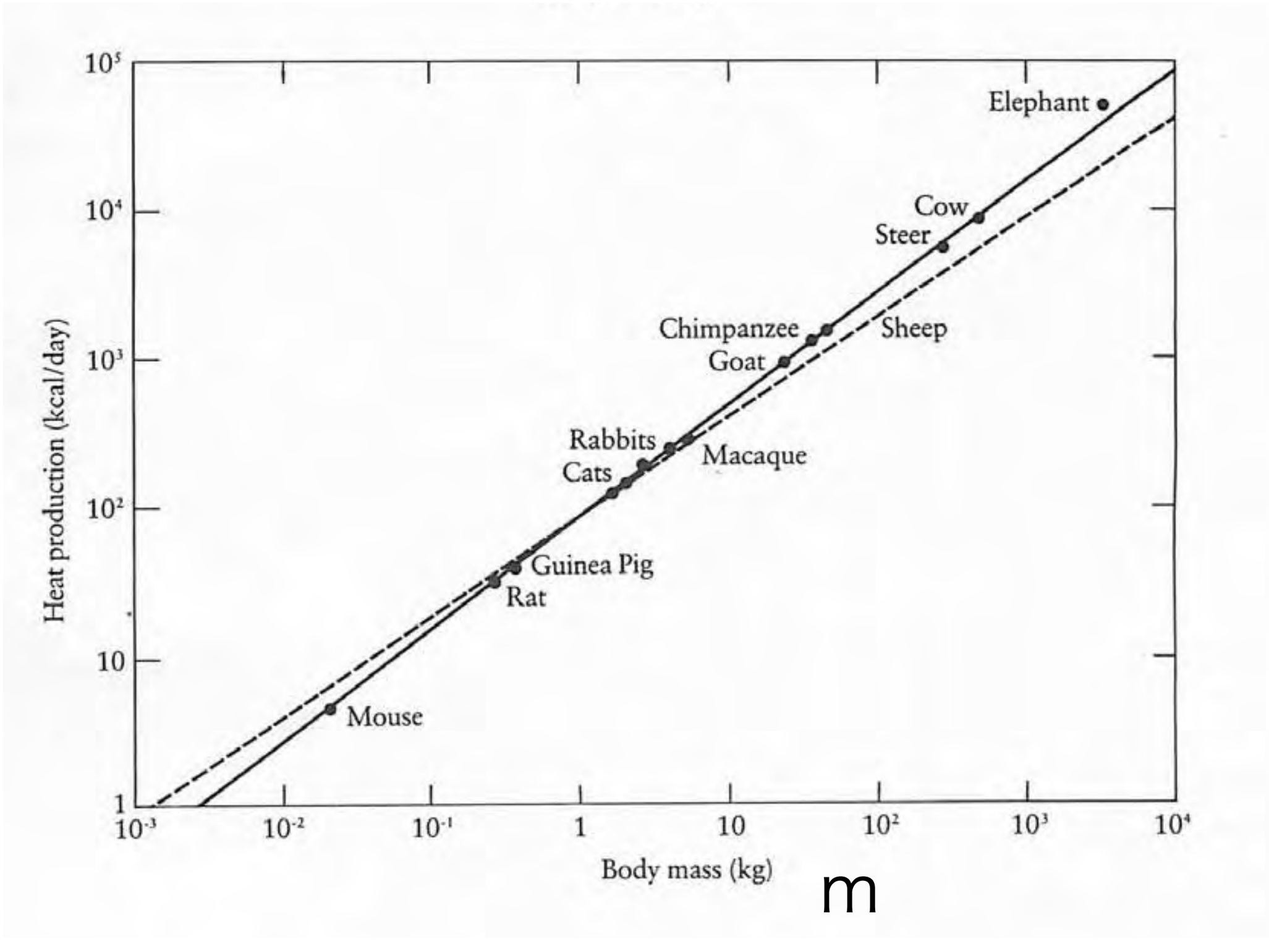
Why are the scalable properties important?

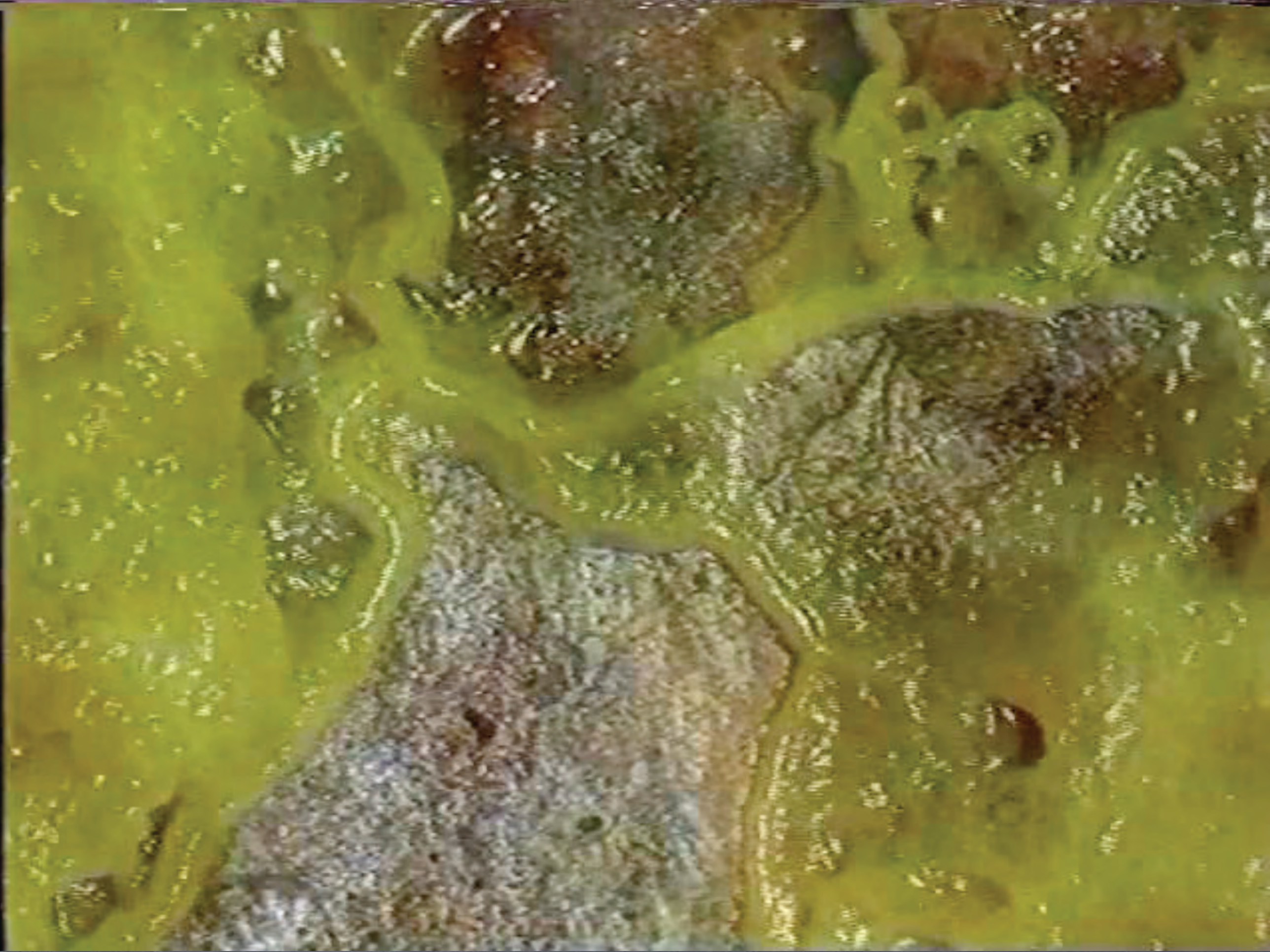
It does not involve chance but instead tells us about the physical laws behind biological behaviour.

In particular,

the observation of scaling laws that hold across size differences of several orders of magnitude may lead to substantial revisions in the understanding of not only the field of interest but also in many other fields of study.

metabolic rate $\propto m^{3/4}$

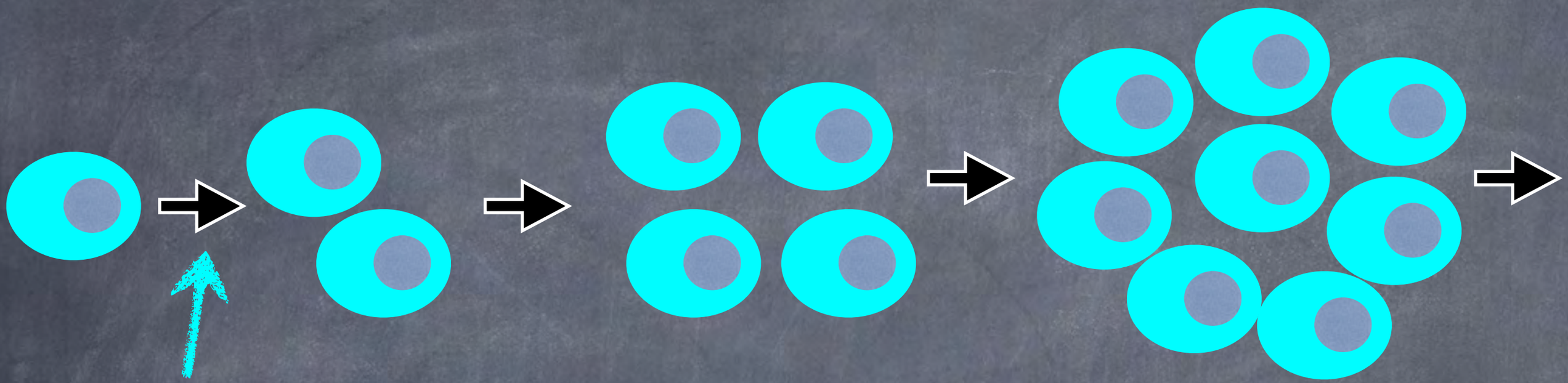




Slime mould (*Physarum* Policepharum)

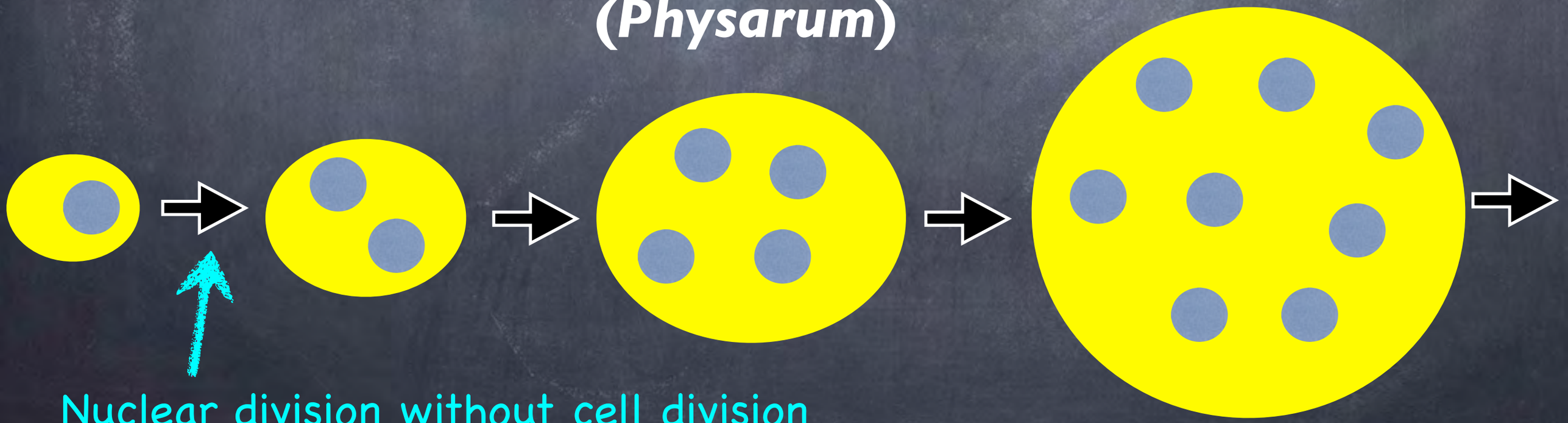
- Multinucleus single-cell organism with amoeboid movement
- Nuclear division without cell division occur per 10 hour
- Large variation of cell size: 10^{-5}m ~ 1m
- Experimental convenience of size manupulation: fuse and cut

Growth of single-nucelus unicelluar organism



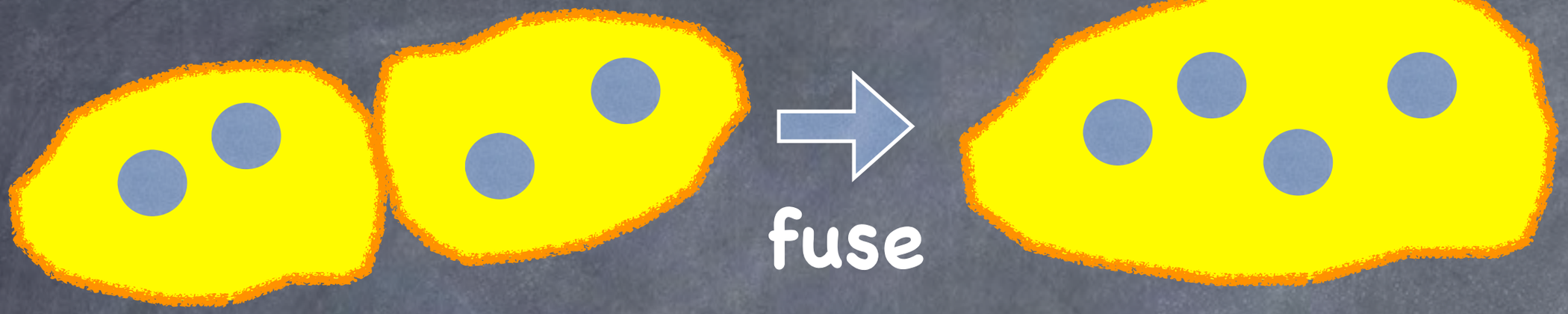
Nuclear division with cell division

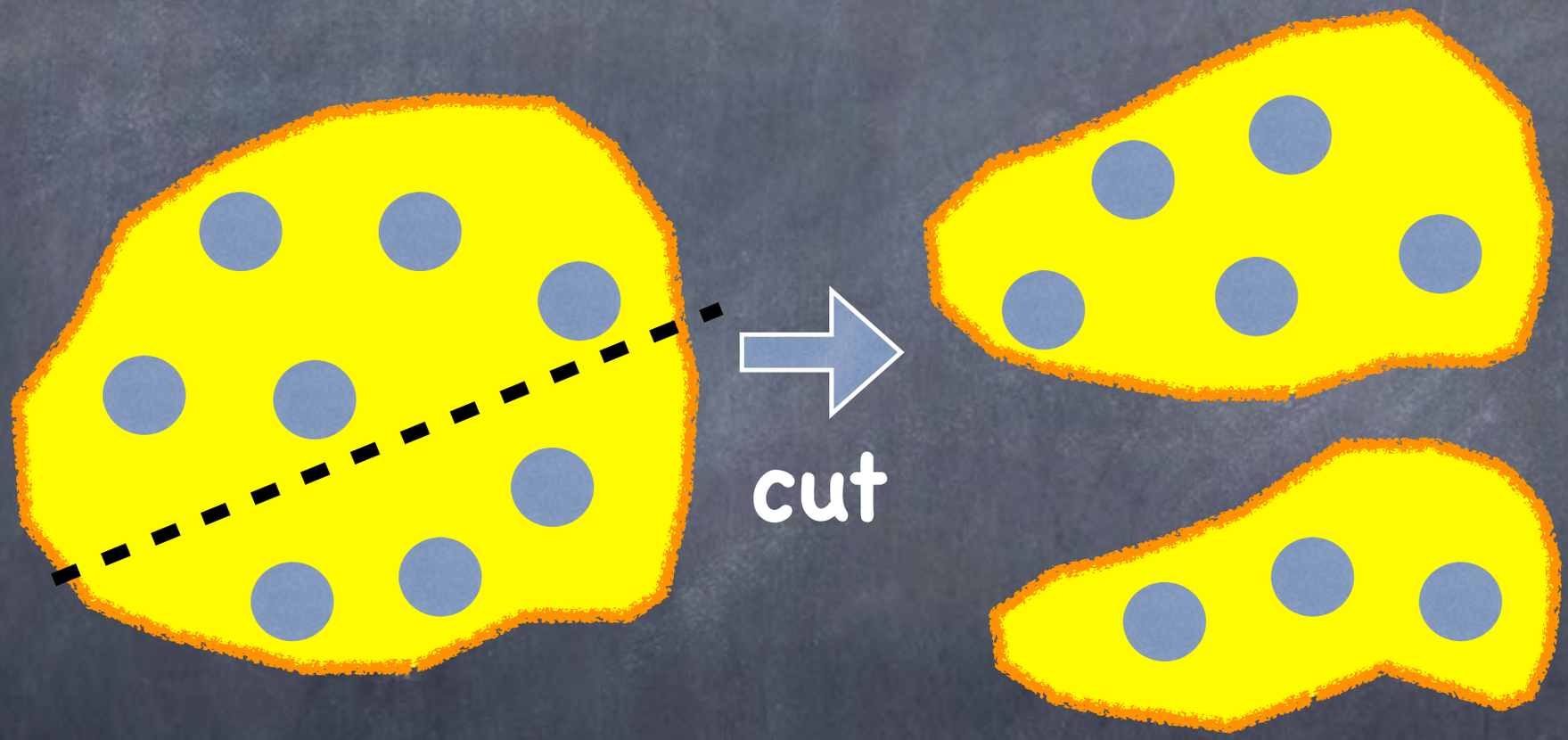
Growth of multinucleus unicelluar organism (*Physarum*)



Nuclear division without cell division

Experimental convenience of size manupulation:





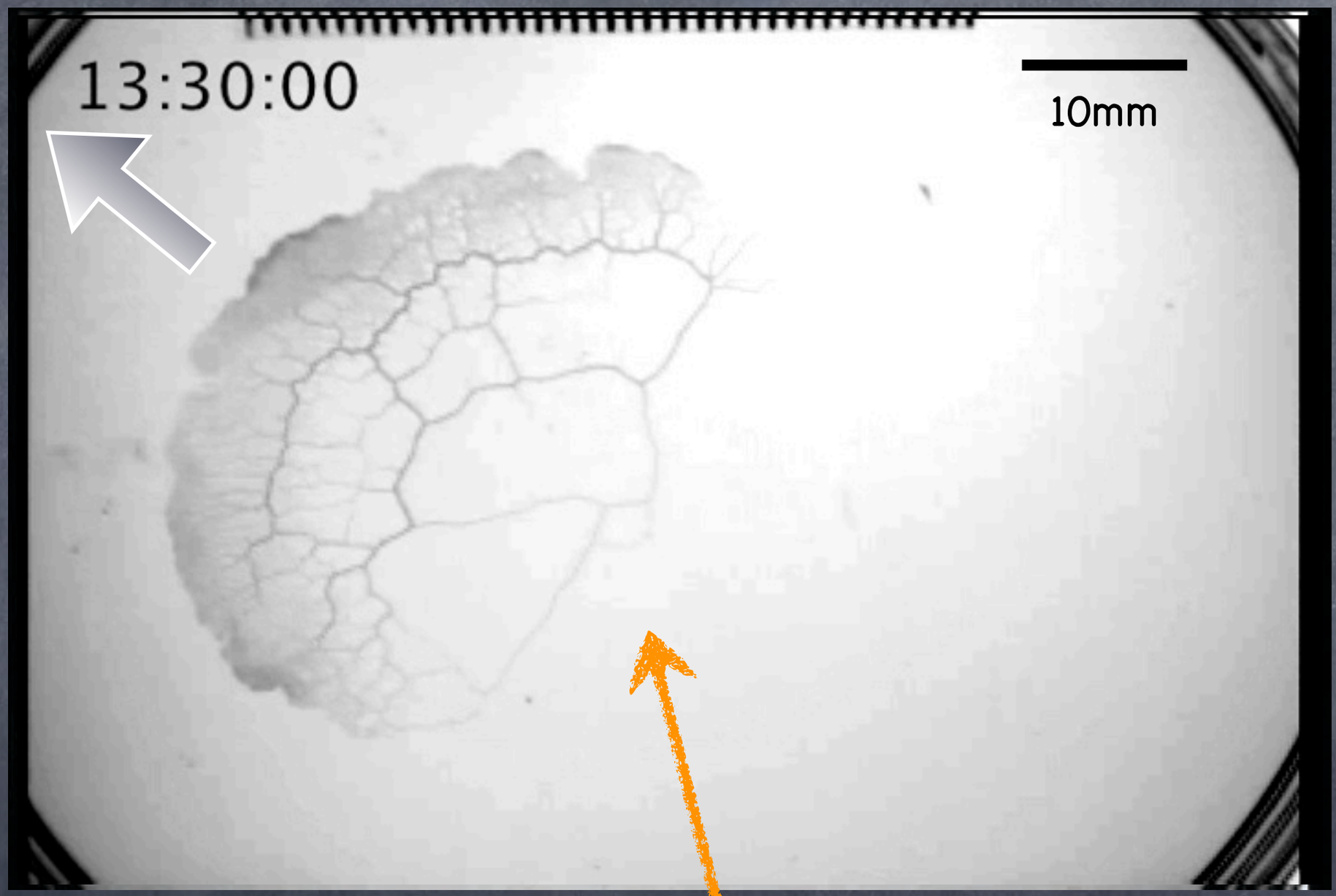
⇒ Body size can thus be regarded as a system parameter !

Directional movement of the cell as self-organized phenomenon

Plasmodium of
True slime mould

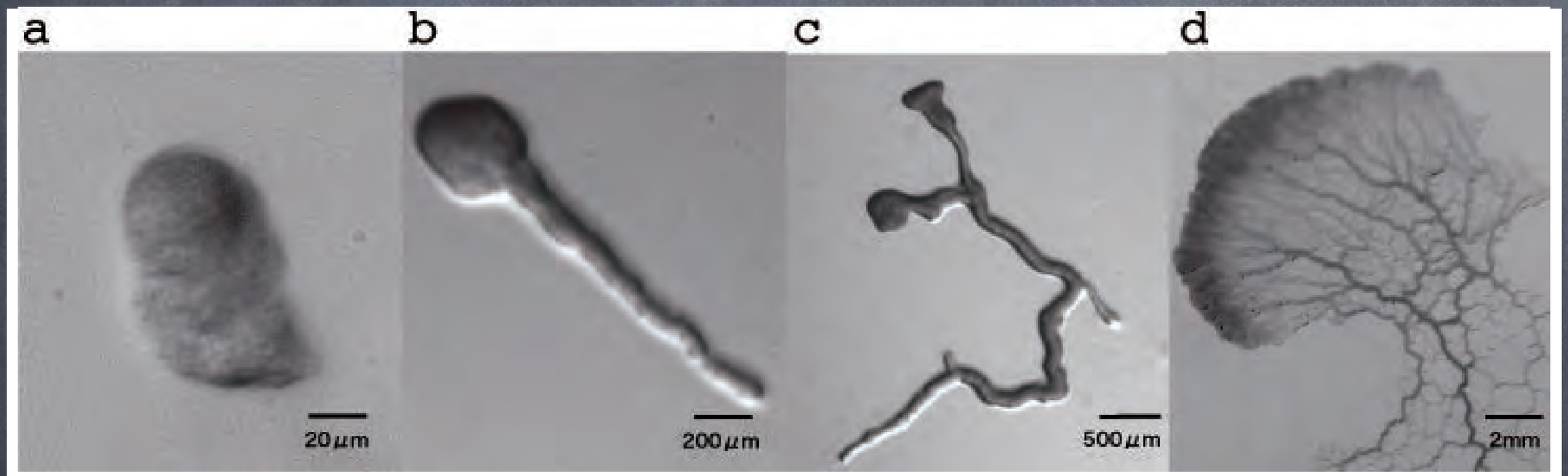
Note. In our body, there are many kinds of cells using amoeboid motion.
(ex) White blood cell (leukocyte), Epithelial cell, Cancer

speed x 3600



Small piece taken from a large *Physarum* amoeba

Slime mould with various size during locomotion

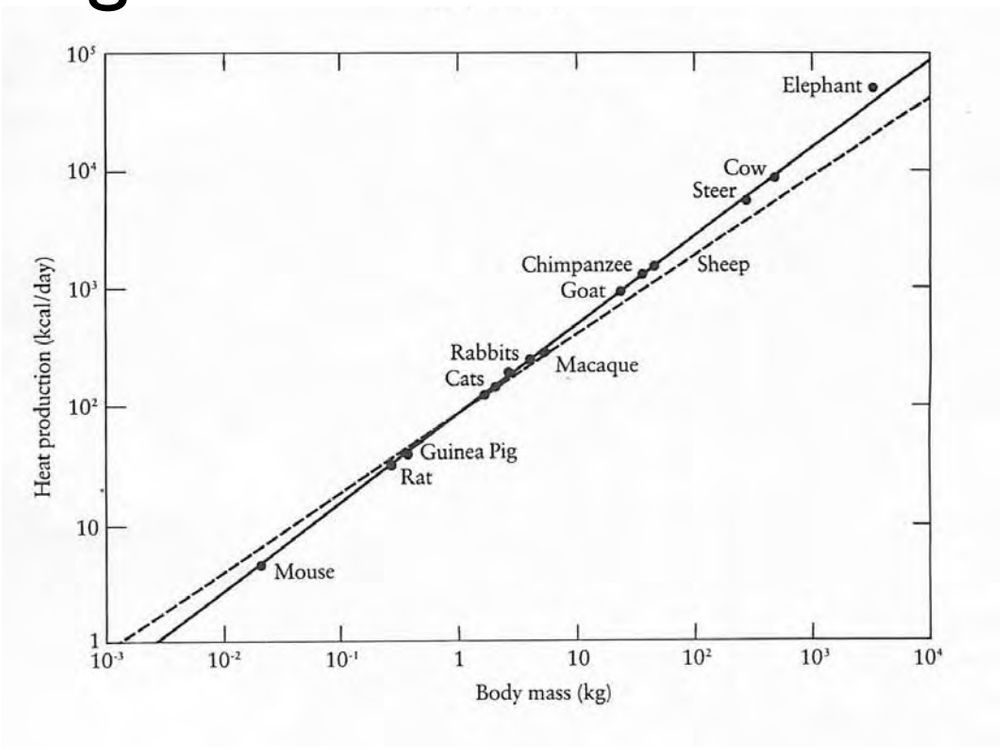


100 μm 500mm 1mm 1cm body length

⇒ Scaling study of cell movement using Slime mould

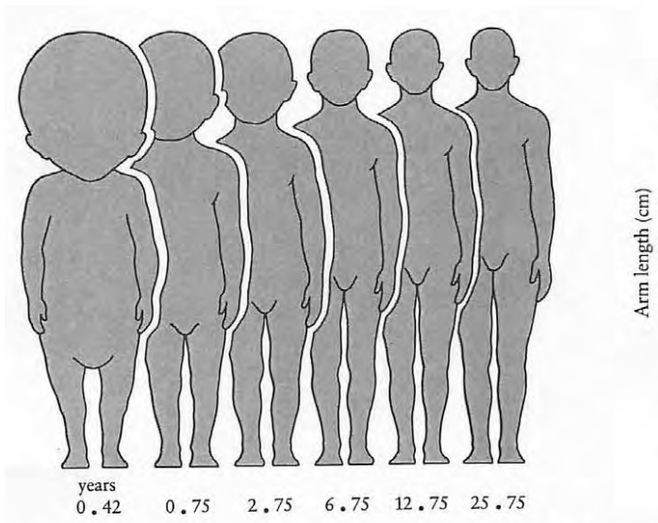
- **Static allometry**

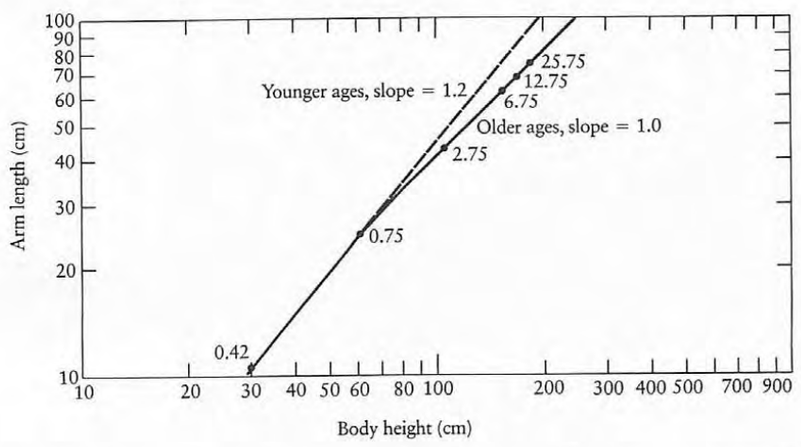
  the size dependency of the time-averaged characteristics



- **Ontogenetic allometry**

  the characteristics changes throughout its development





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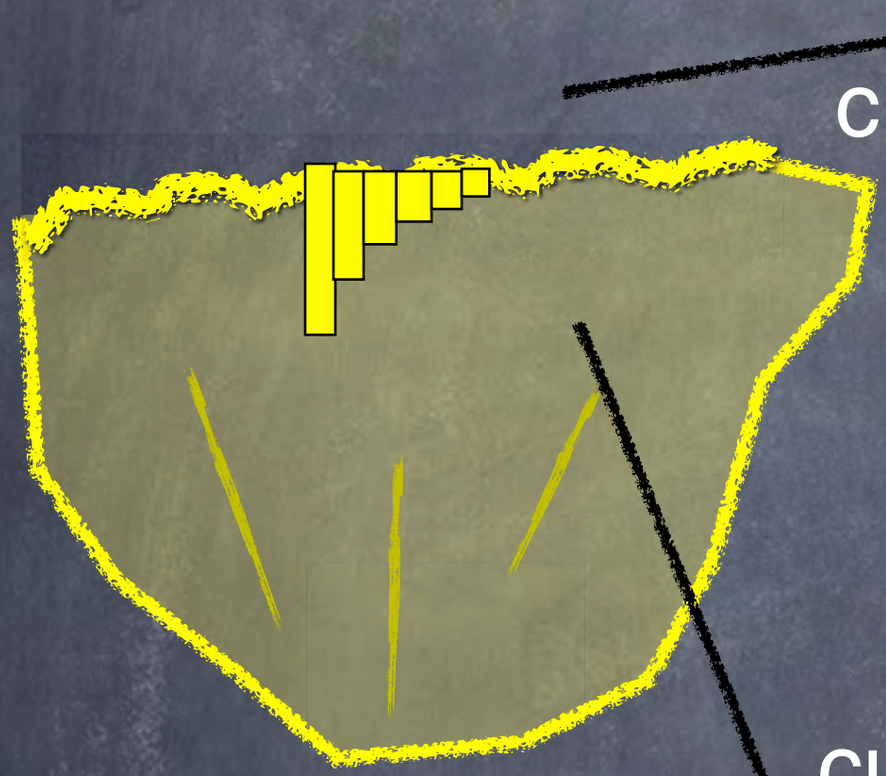
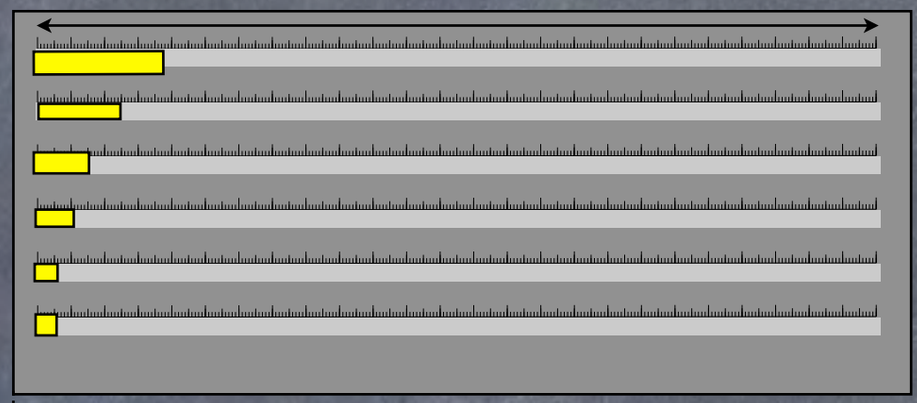
- **Experimental environment**
  - 1 w%agar, room temp. 24±1℃, the humidity inside the apparatus 90%RH
  - more than six hour measurement of one directional locomotion
- Smaller slime moulds (< 0.1 μL (n=13))
  - allowed to move freely on agar plate (ϕ =9cm)
- Larger slime moulds (> 0.1 μL (n=37))
  - placed on narrow agar lanes (width 0.5, 1, 2, 4, or 8 mm) in order to limit the num of advancing front to one or to confine locomotion to 1-dim.

Systematic preparation of cells with different sizes from a giant cell

For medium and larger size (> 0.1μL)



cut

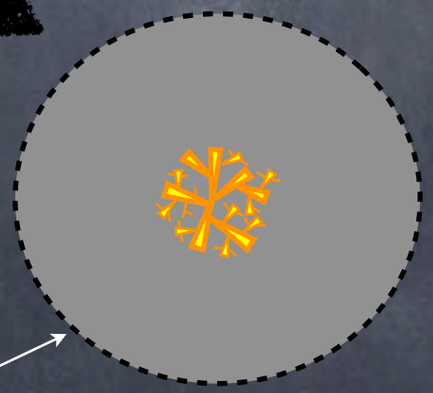


PET film

agar (1w%)

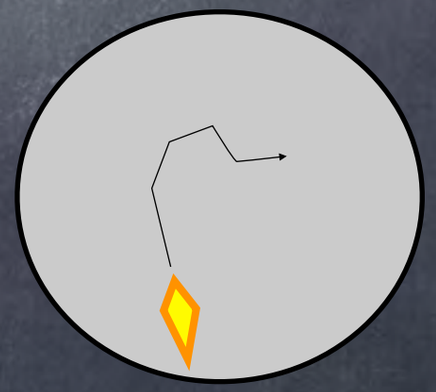
width of each lane lw = 1, 2, 4 or 8 [mm]

cut



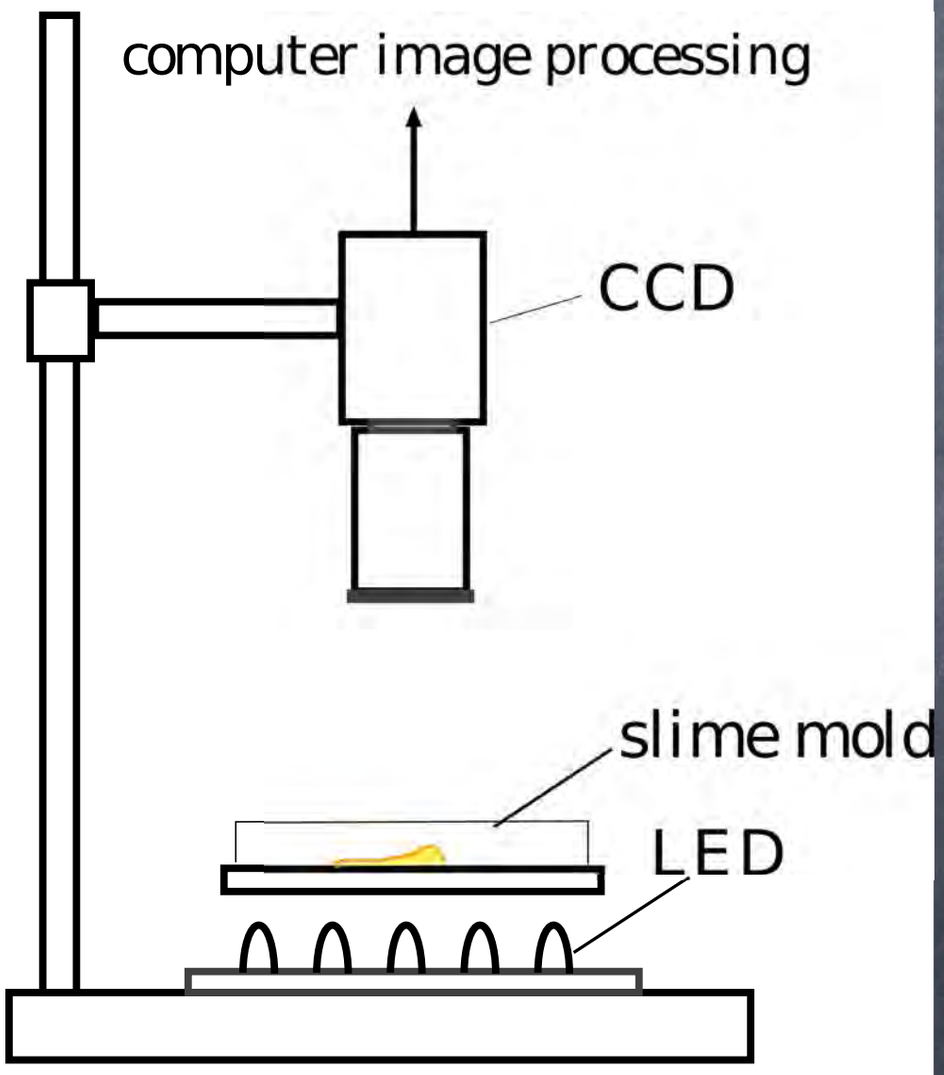
wet cellophane

cut

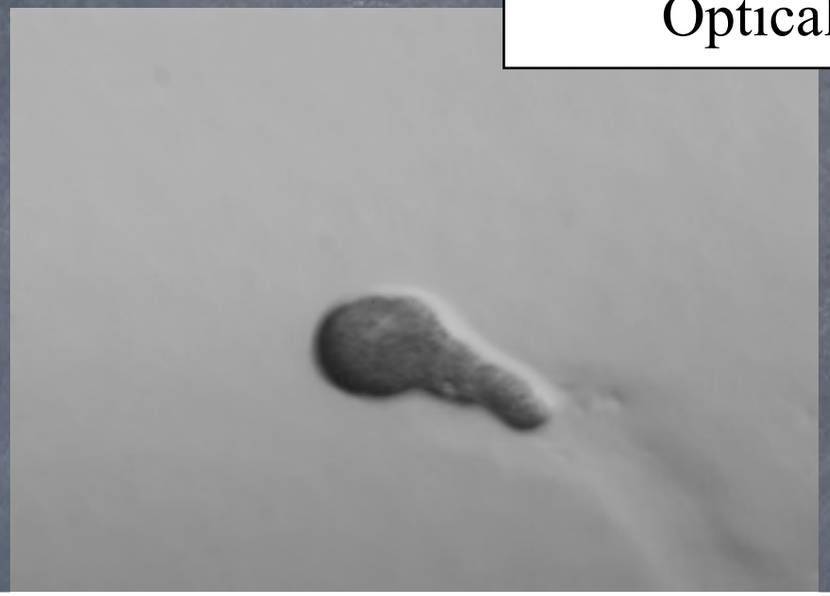


For smaller size(< 0.1μL)

Measurement of thickness

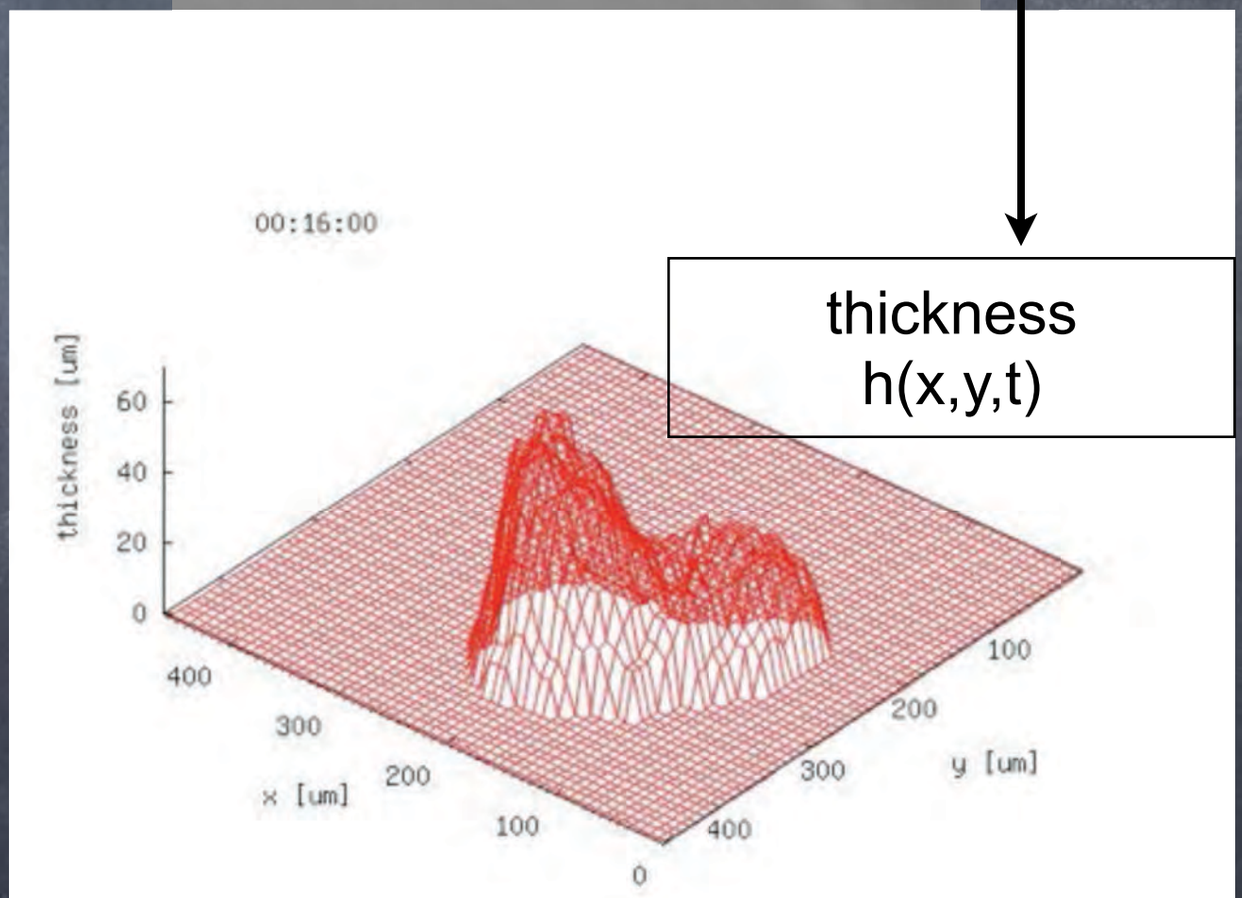


Optical density (x,t)

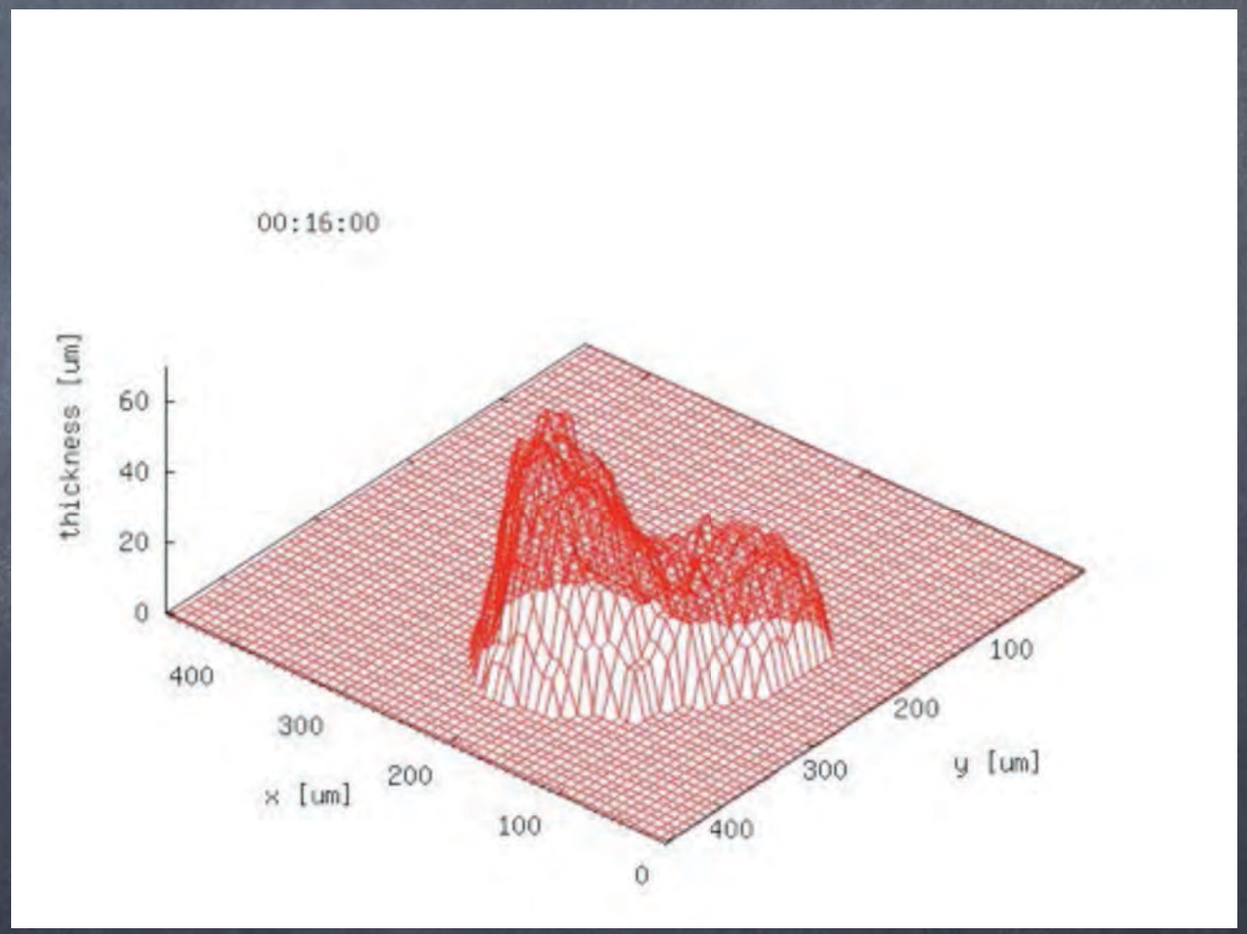


Caribulation

thickness
h(x,y,t)



- Smaller slime moulds (< 0.1 μL (n=13))
  - allowed to move freely on agar plate (ϕ =9cm)



Coordinate system and longitudinal shape

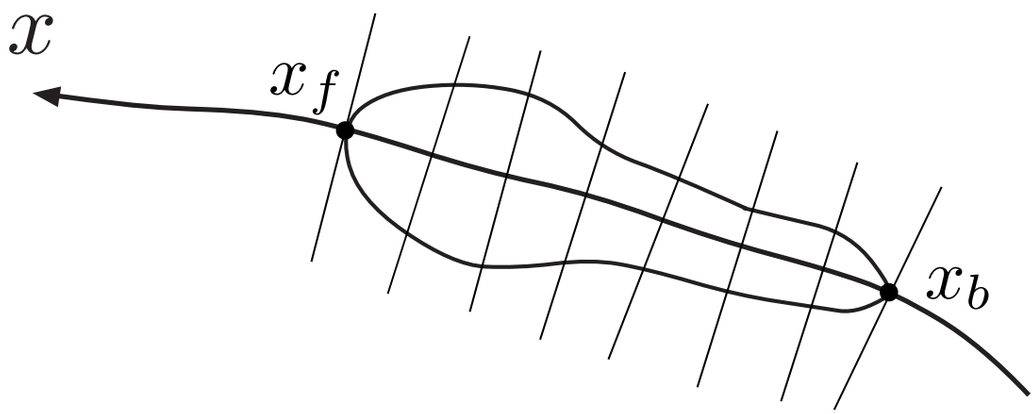
h_{max} : the max thickness of frontal part

x_L : body length

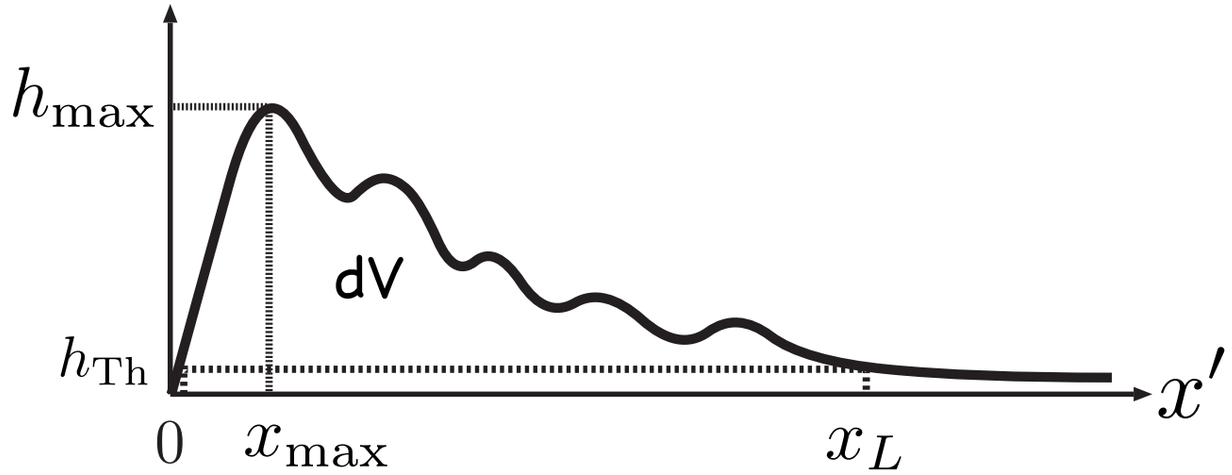
x_{max} : length of very frontal tip

dV :

$h'(x, t)$



Longitudinal coordinate and
its perpendicular axis.



Characterisation of longitudinal shape

$h'(x, t) = \max_{y \in l(x,t)} h(y, t)$

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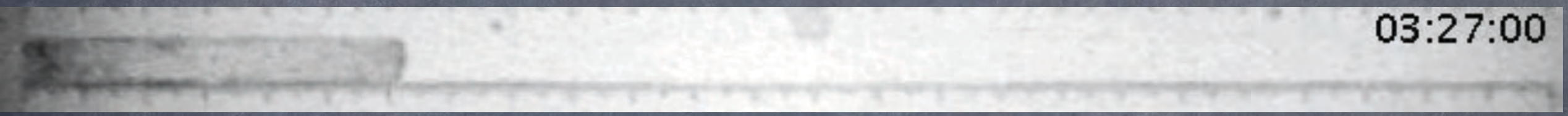
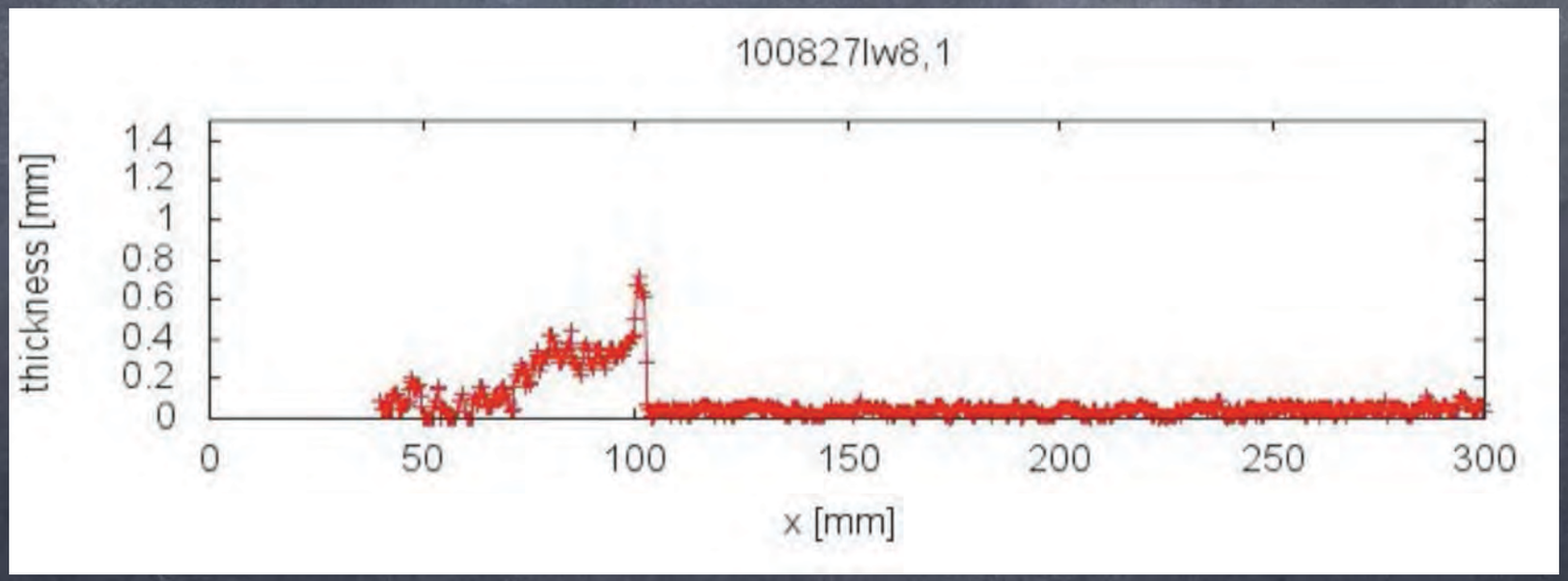
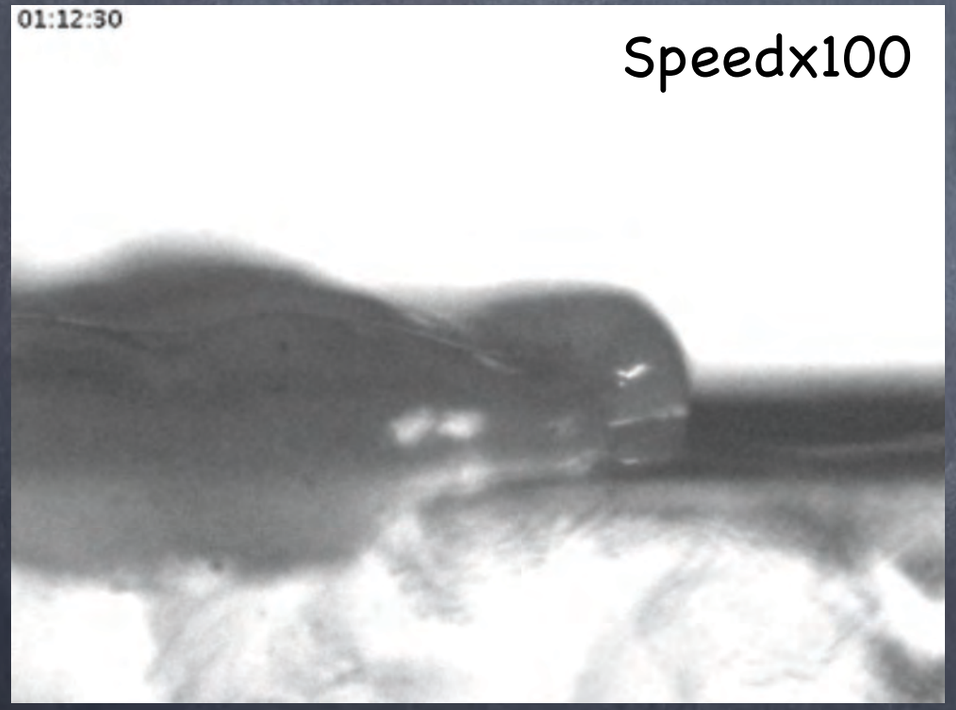
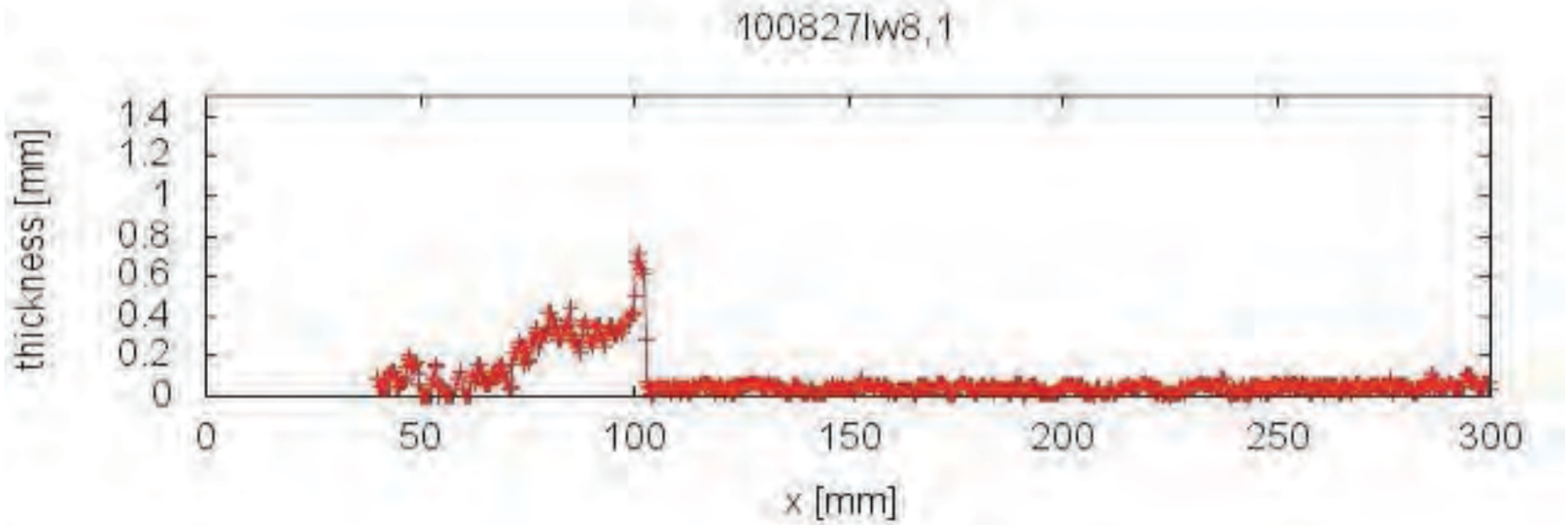




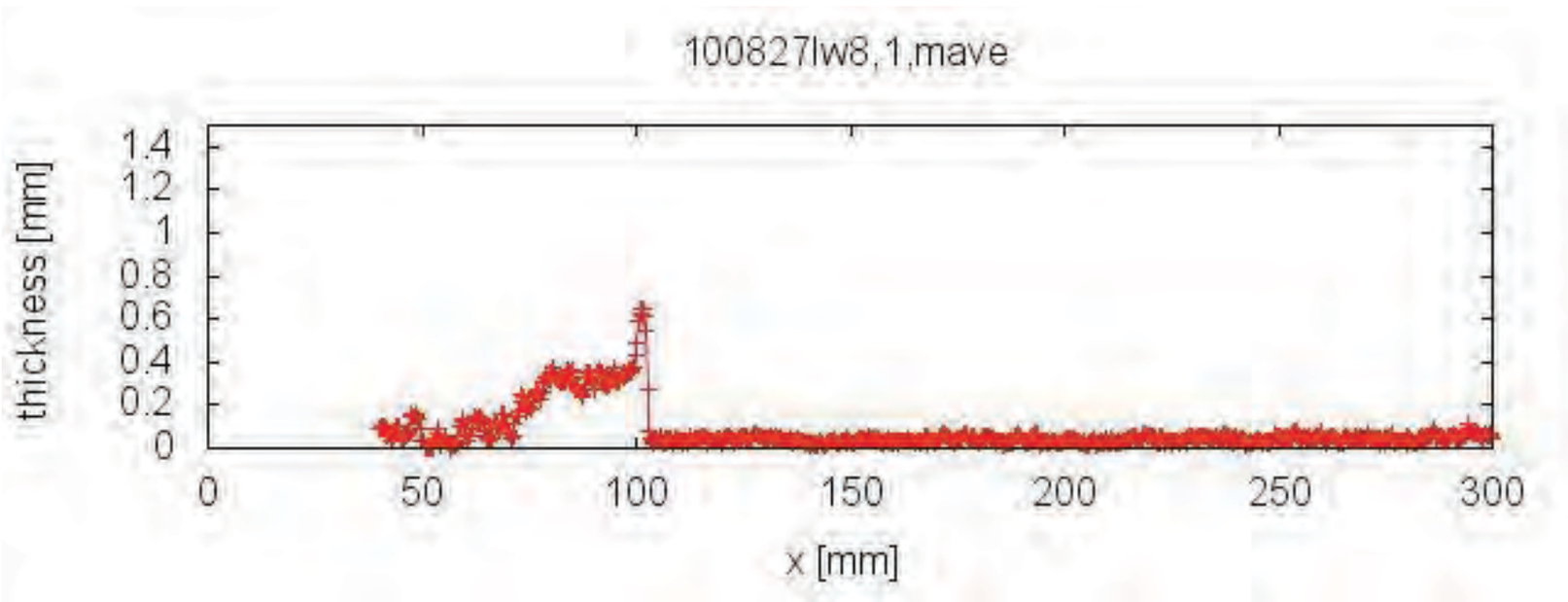
Regular oscillations in thickness with a period of 60- 120s that involves protoplasmic flow inside the body



Averaging of variables over intrinsic period (T_0) of thickness oscillation



Averaging over T_0



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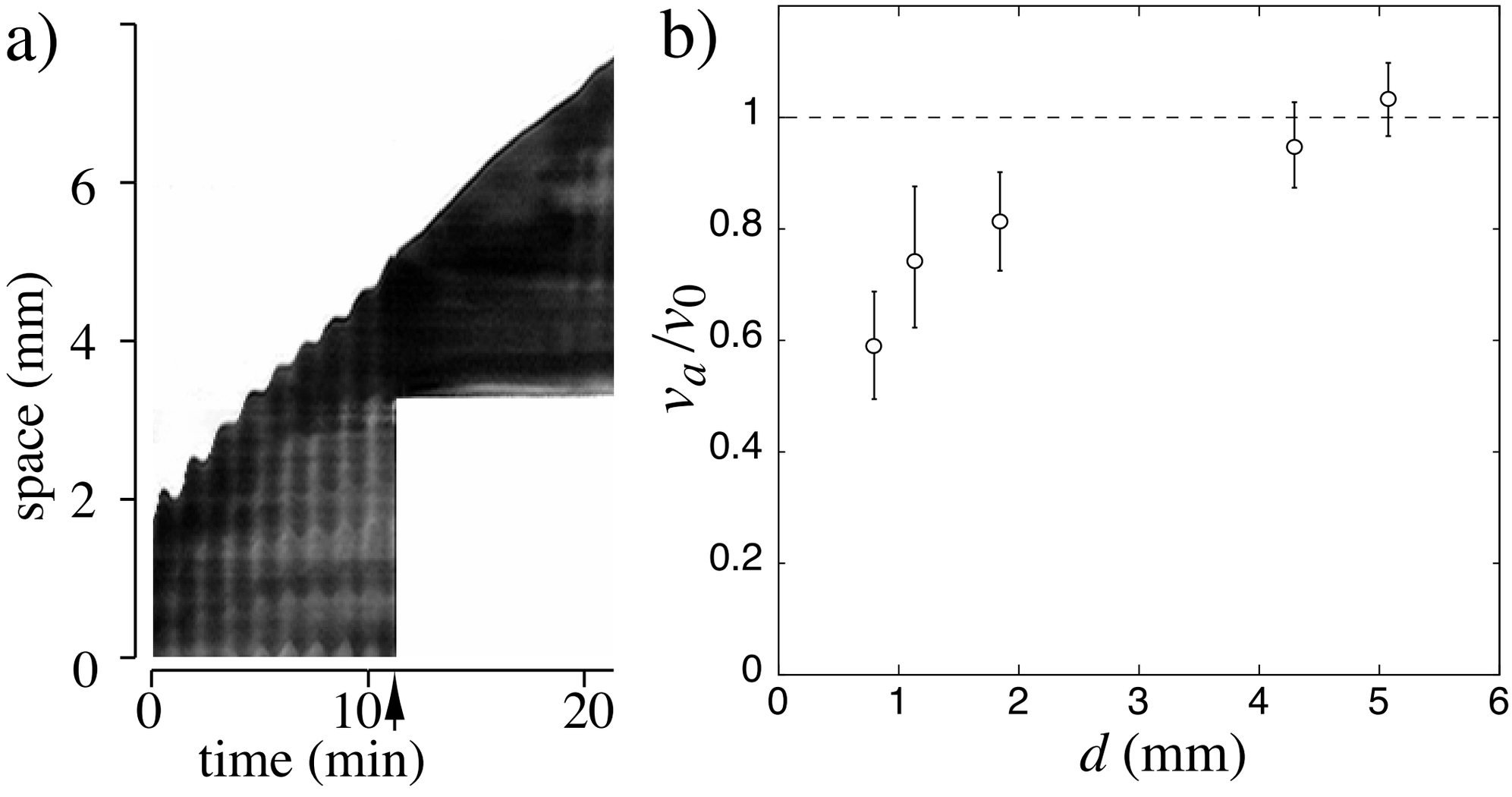
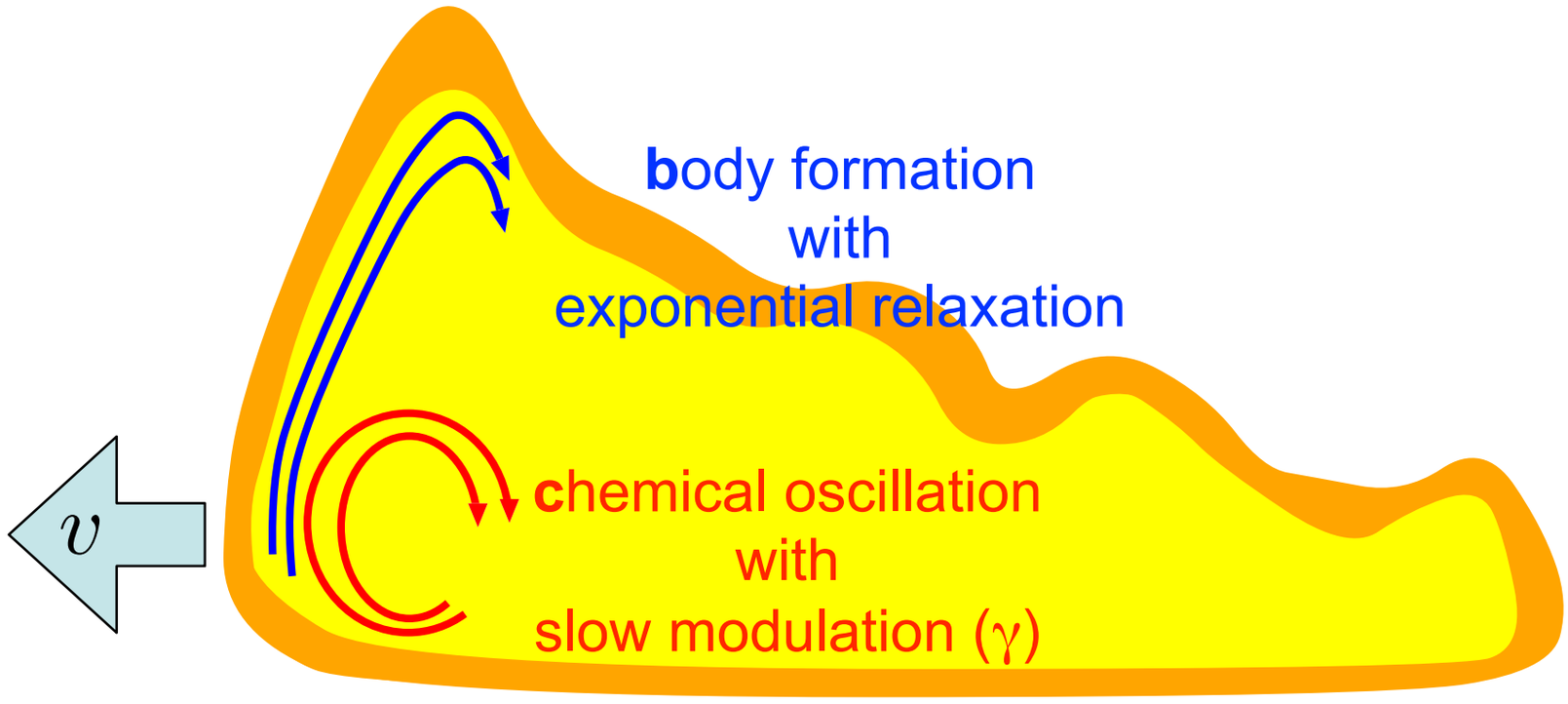
Localization of the locomotion engine in the frontal part



(from Takagi,S. et al 2007)

Traveling wave in reaction diffusion system with slow modulation



Discussion

Scalable vs. Non-scalable properties

What is the origin of the difference between them? One probable reason is that: the size-independent properties result from biochemical processes because chemical reaction speed mainly depends not on the body size itself but on the chemical characteristics of the substances involved.
the size-dependent properties may result from physico-mechanical processes. If so, they are likely to be quite general properties that hold for a wide range of organisms.