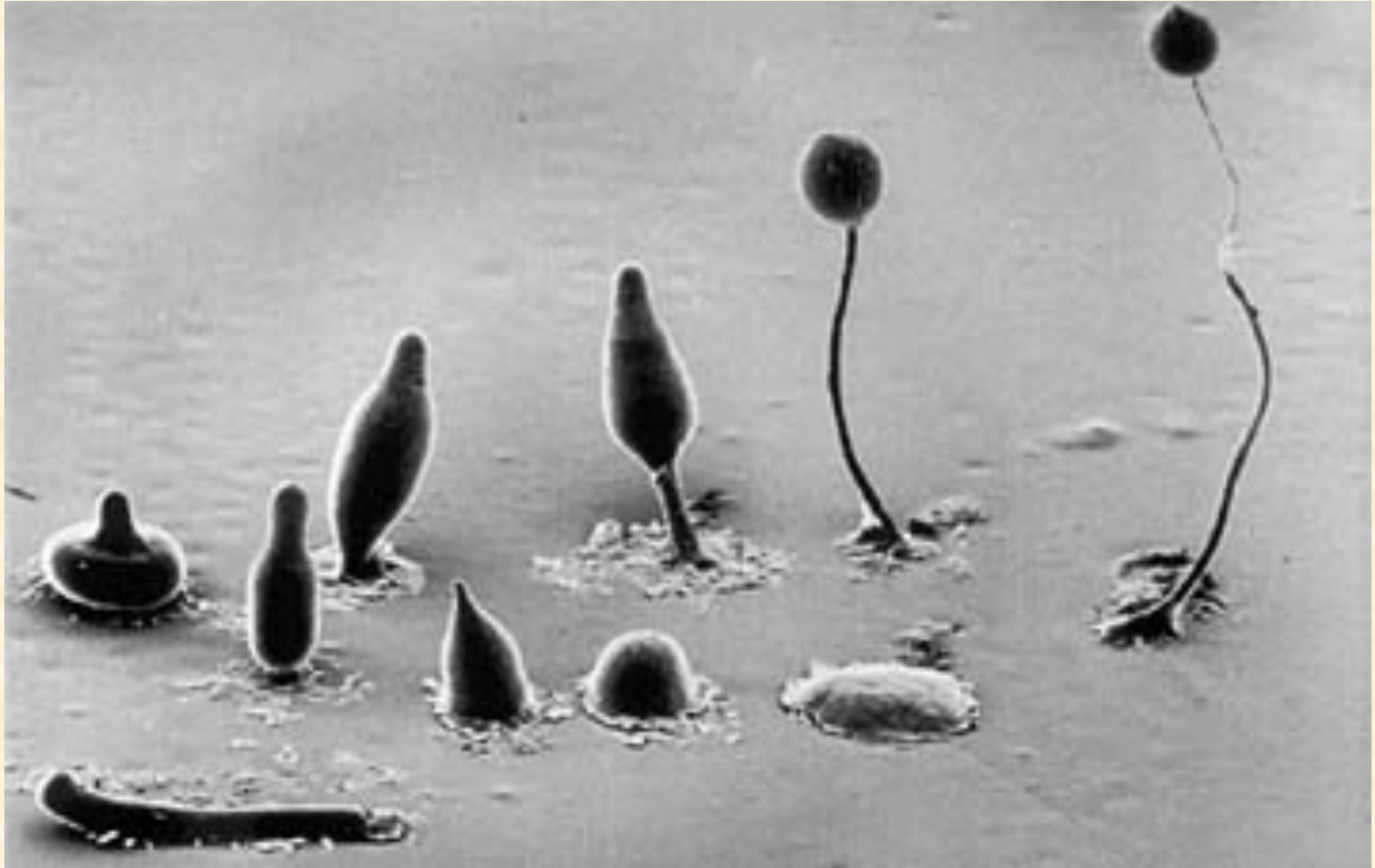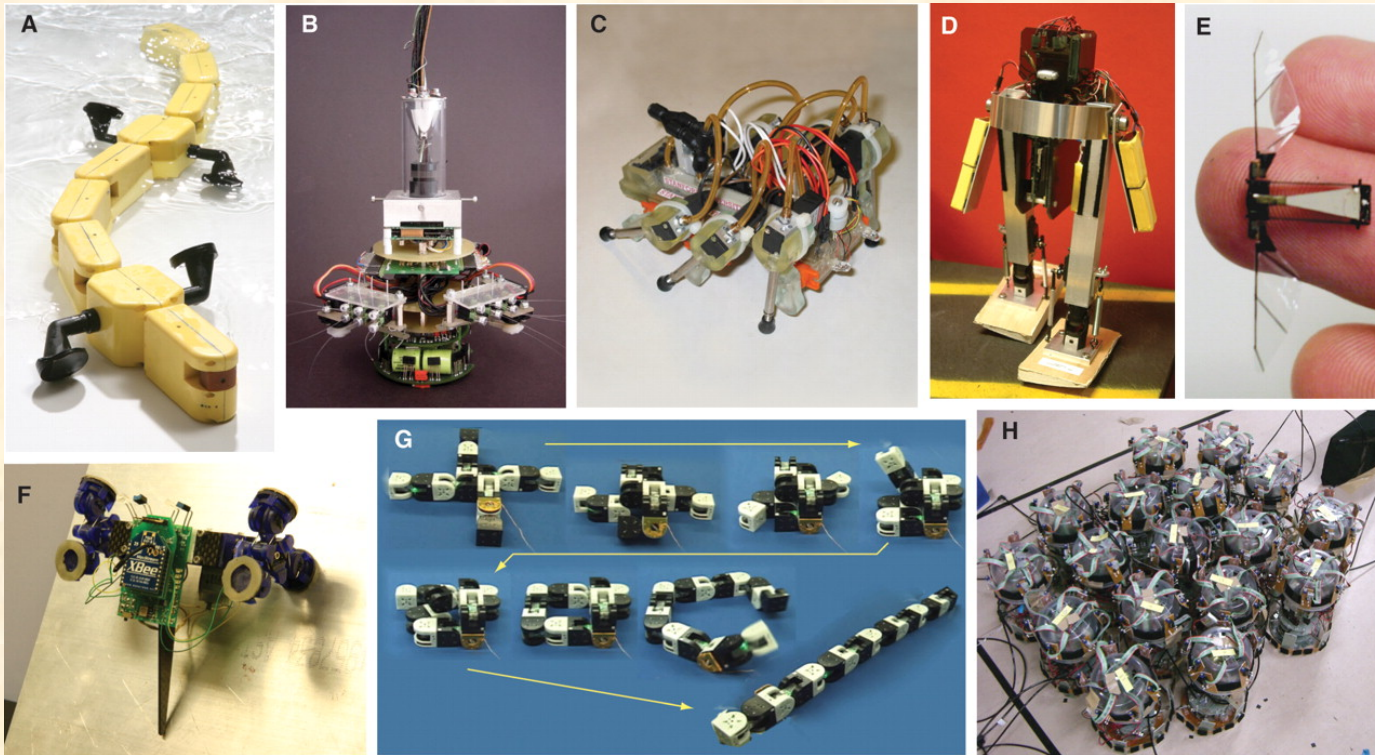# C.
Slime Mold

(Dictyostelium discoideum)

"Dicty"

Complete Life Cycle

Self-organization in Bio-inspired Robotics

R. Pfeifer et al., Science 318, 1088 -1093 (2007)

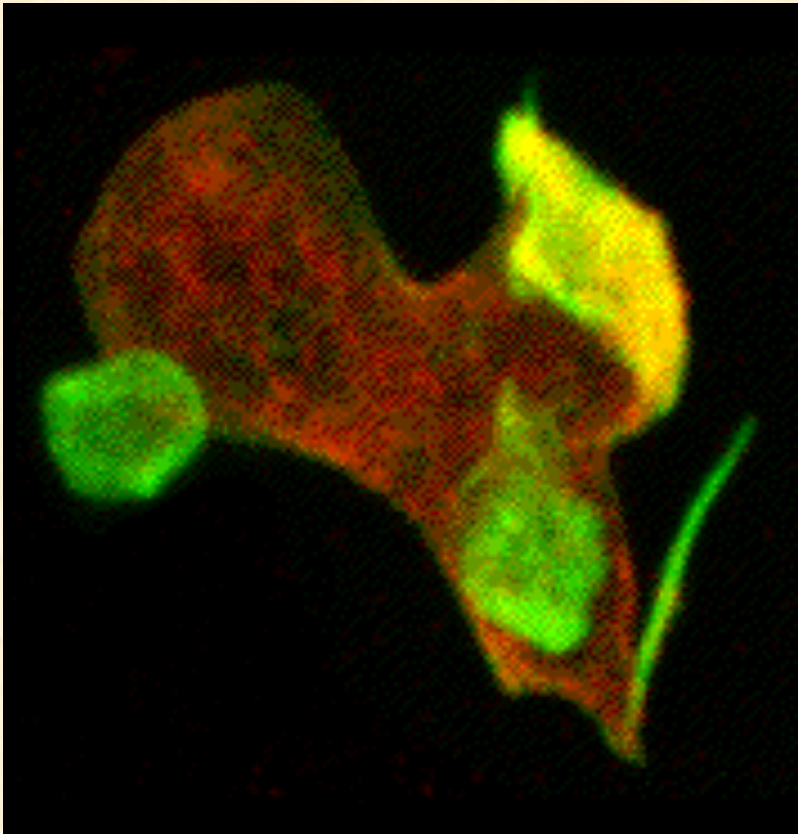# Self-copying Robot (2005)

- Hod Lipson, Cornell
- Programmable blocks
- 2 swiveling pyramidal halves
- Magnetic connections
- 10 cm across
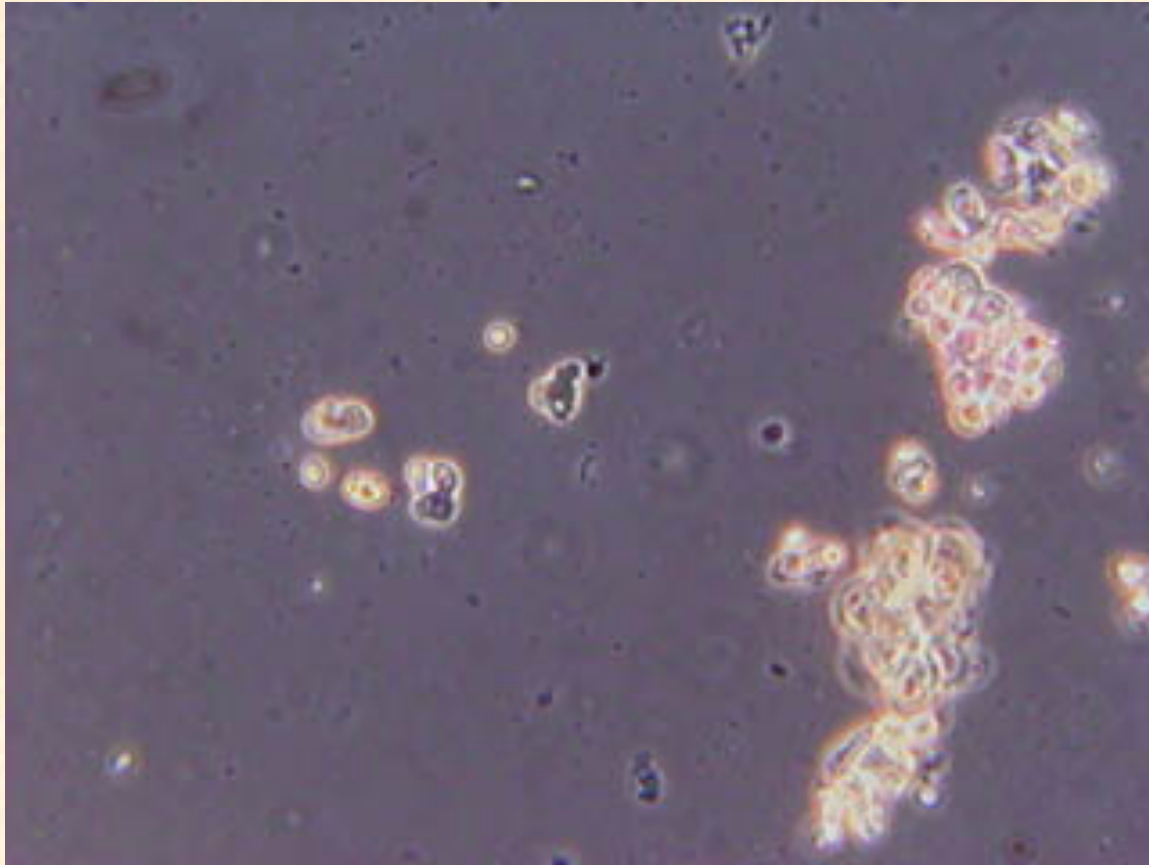- One stack can assemble another

Dicty Videos

- [Bonner's videos](#)

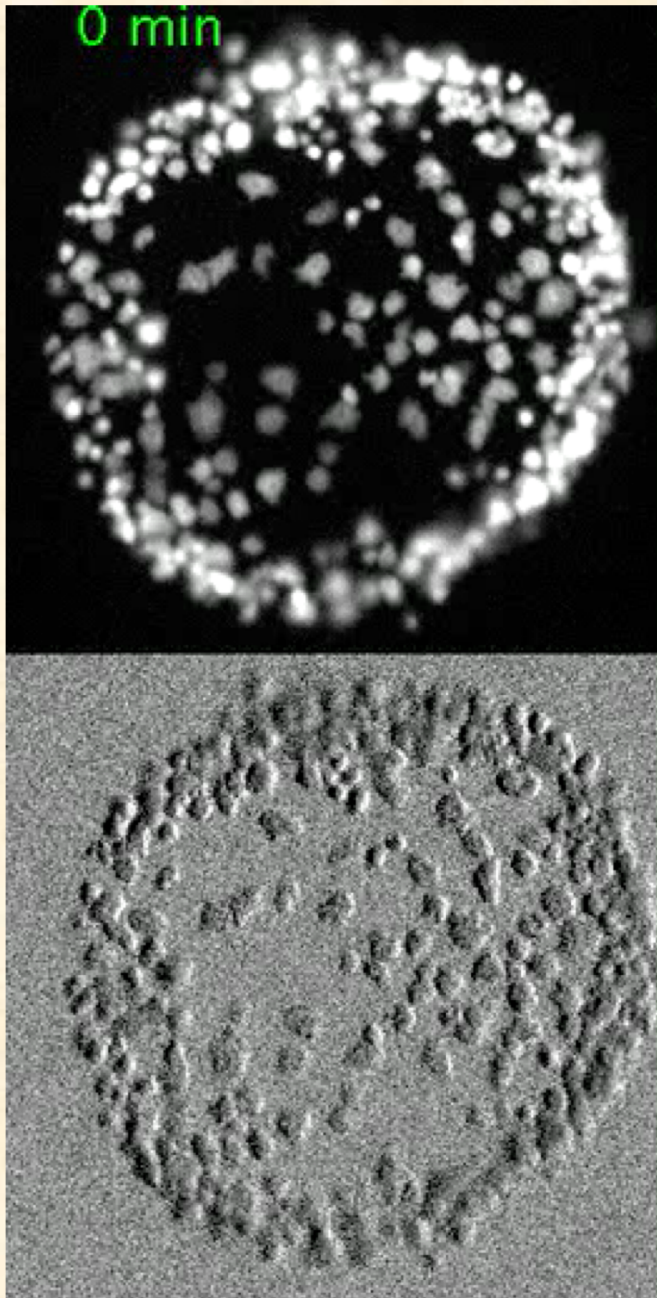- [Aggregation](#)

- [Life cycle](#)

Amoeba Stage

- Single cell
- Lives in soil
- Free moving
- Engulfs food (bacteria)
- Divides asexually

Amoebas

Aggregation Stage

- Triggered by exhaustion of food
- Aggregate by *chemotaxis*
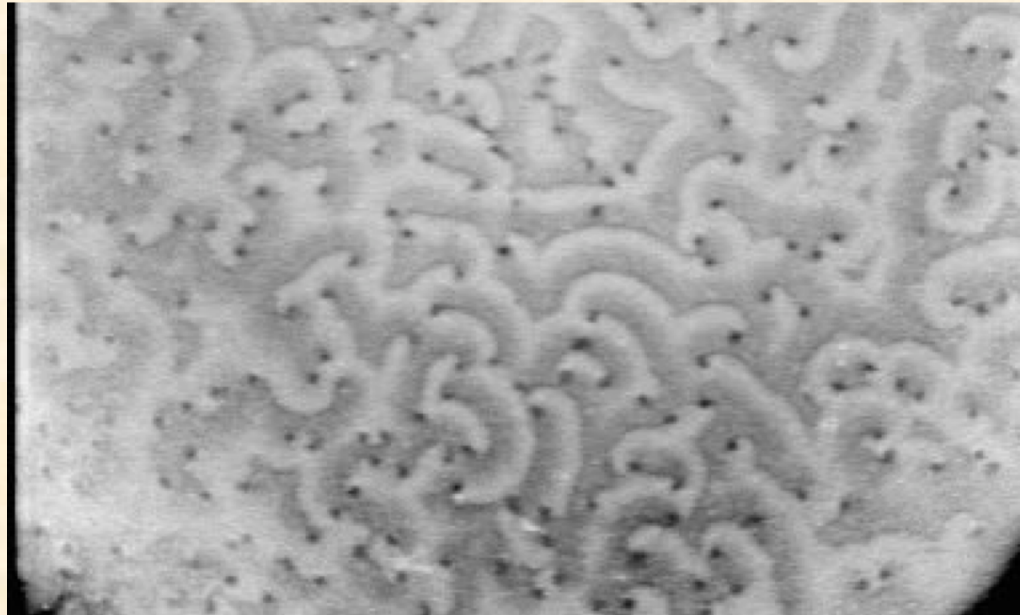- Example: 180 cells
- Time lapse: about 14 hours
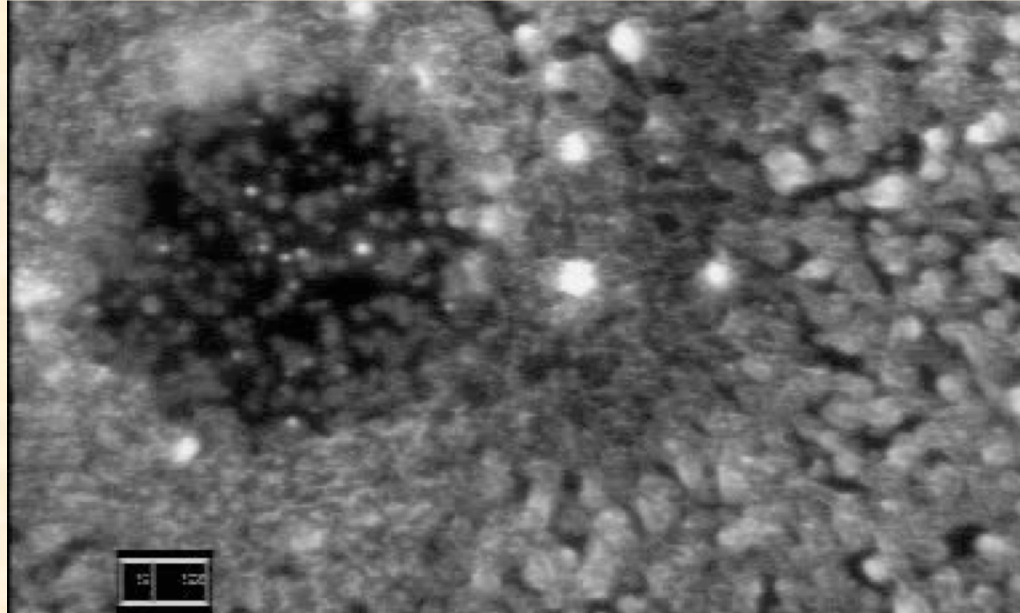
Aggregation Stage

- Triggered by exhaustion of food
- Aggregate by *chemotaxis*
- Form expanding concentric rings and spirals
- Up to 125 000 individuals

Spiral Waves

- Spiral accelerate cell aggregation (18 vs. 3 µm/min.)
- Waves propagate 120 – 60 µm/min.
- 1 frame = 36 sec.

(video < Zool. Inst., Univ. München)

Center of Spiral

- Mechanisms of spiral formation are still unclear
- Involves symmetry breaking
- 1 frame = 10 sec.

(video < Zool. Inst., Univ. München)

Stream Formation Stage
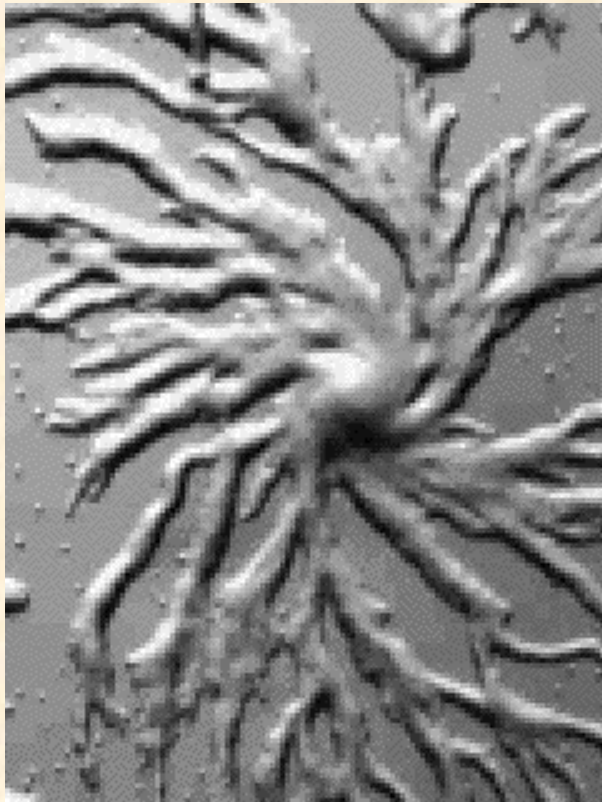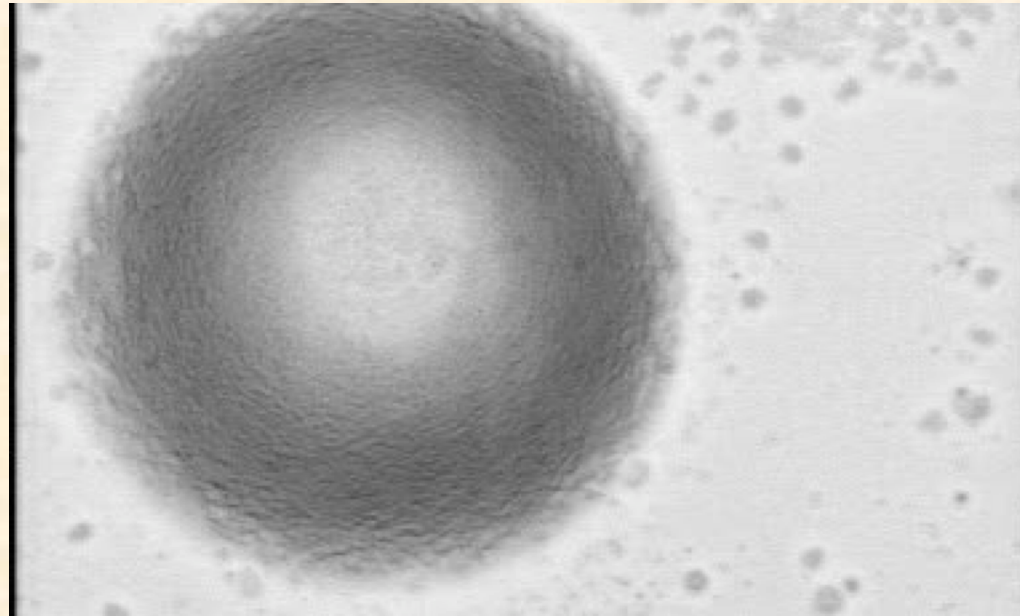

- Streams result from dependence of wave propagation velocity on cell density

- Breaks symmetry

- As density increases, begin to adhere

- Begin to form *mound*

Mound Stage
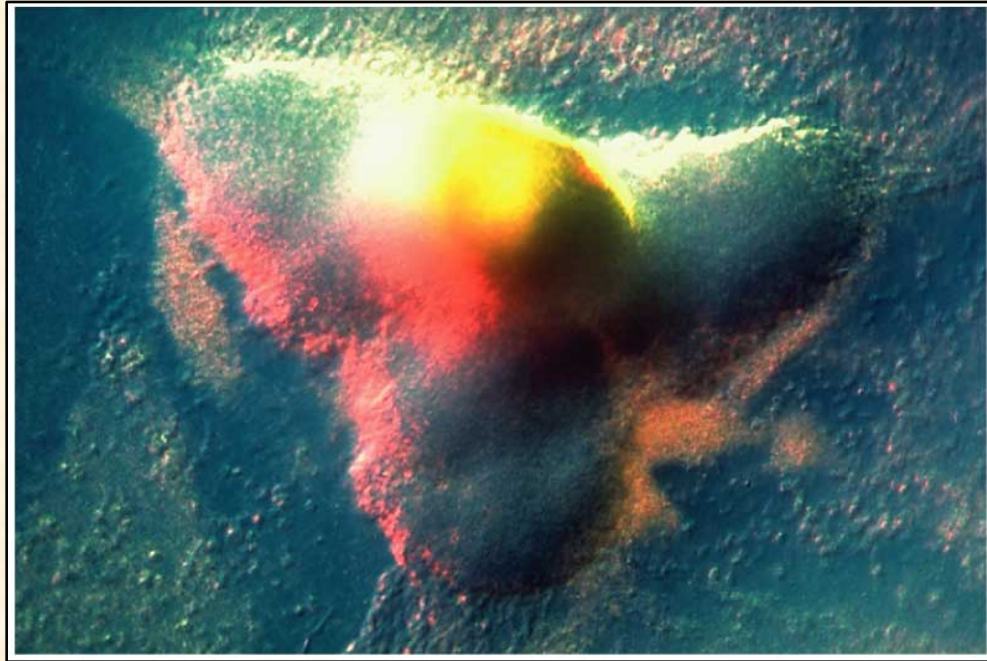
- Cells differentiate
- Some form an elongated finger
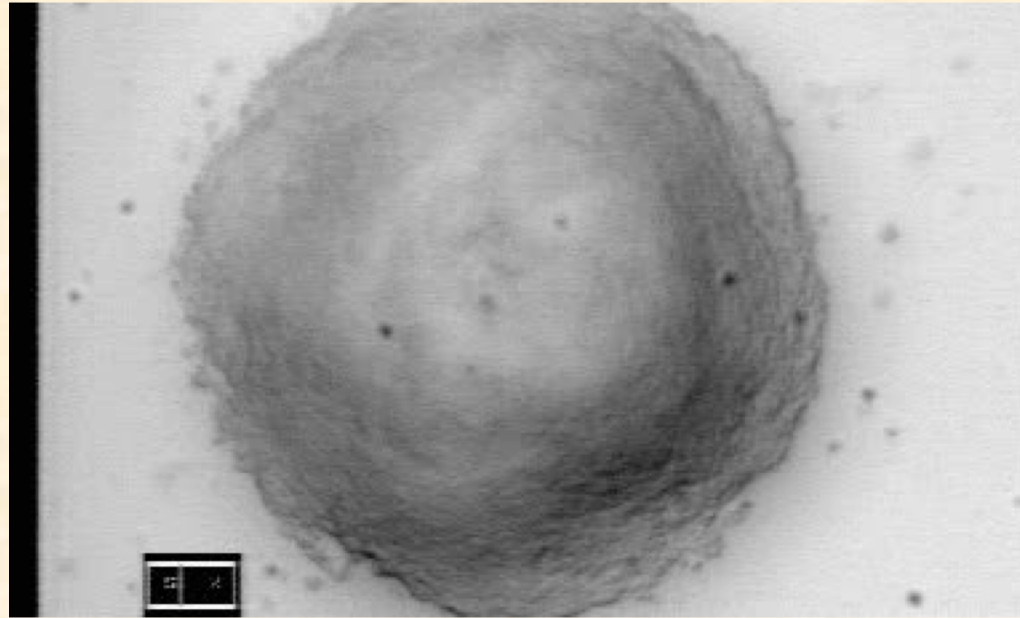
Concentric Waves in Mounds

- Concentric or spiral waves
- Mound comprises 10^3 to 10^5 cells
- Cells begin to differentiate
- 1 frame = 20 sec.

Multiple Centers
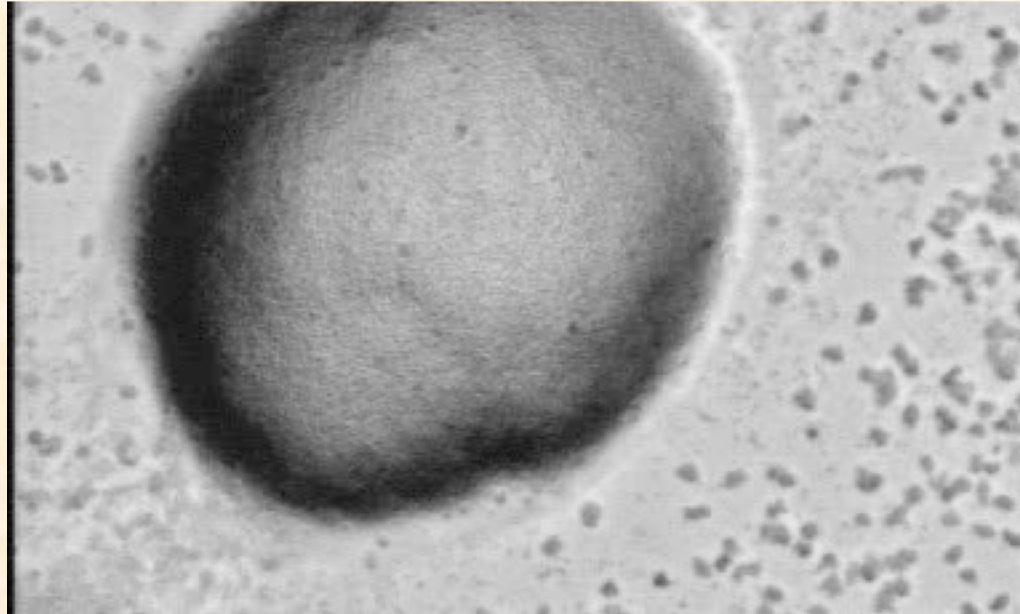
- Multiple pacemakers
- Wave fronts mutually extinguish (typical of excitable media)
- One center eventually dominates

Multi-armed Spirals

- This mound has 5 spiral arms
- Up to 10 have been observed

Formation of Acellular Sheath
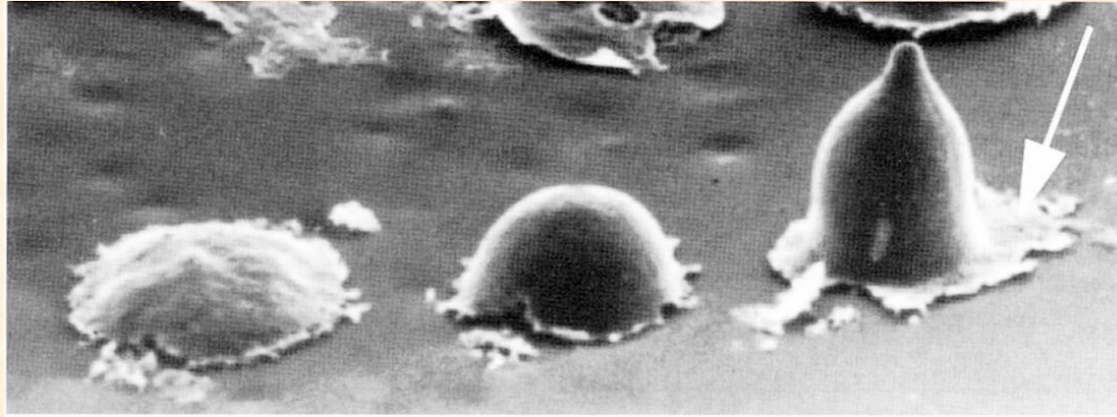
- Composed of cellulose & a large glycoprotein
- Covers mound and is left behind slug as trail
- Function not entirely understood:
  - protection from nematodes (worms)
  - control of diffusion of signaling molecules

Slug Stage

- Prestalk elongates, topples, to form slug
- Behaves as single organism with 10^5 cells
- Migrates; seeks light; seeks or avoids heat
- No brain or nervous system

Movement of Young Slug
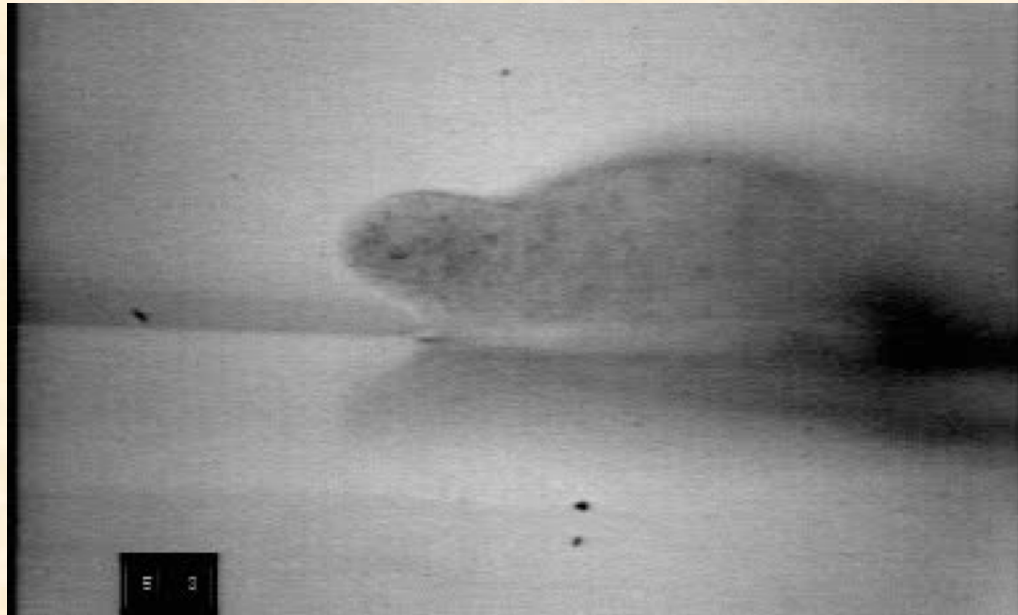
- Time-lapse (1 frame = 10 sec.)
- Note periodic up-and-down movement of tip

Movement of Older Slug
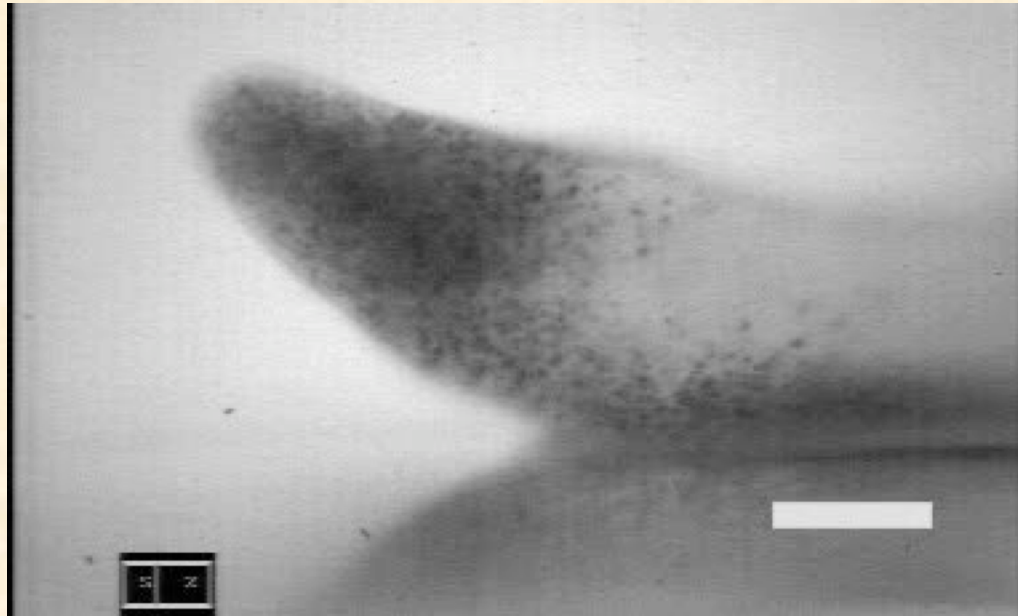
- Note rotating prestalk cells in tip
- Pile of anterior-like cells on prestalk/prespore boundary
- Scale bar = 50 μm, 1 frame = 5 sec.

(video < Zool. Inst., Univ. München)

Migration of Older Slug
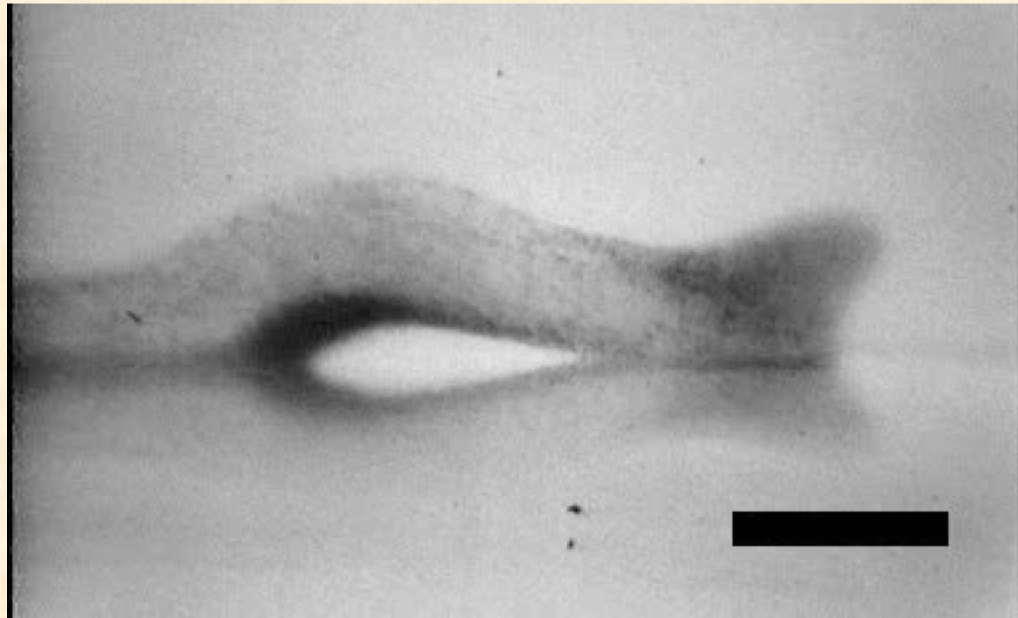
- Scale bar = 100 μm, 1 frame = 20 sec.

Culmination Stage

- Cells differentiate into base, stalk, and spores
- Prestalk cells form rigid bundles of cellulose & die
- Prespore cells (at end) cover selves with cellulose & become dormant

Stages of Culmination

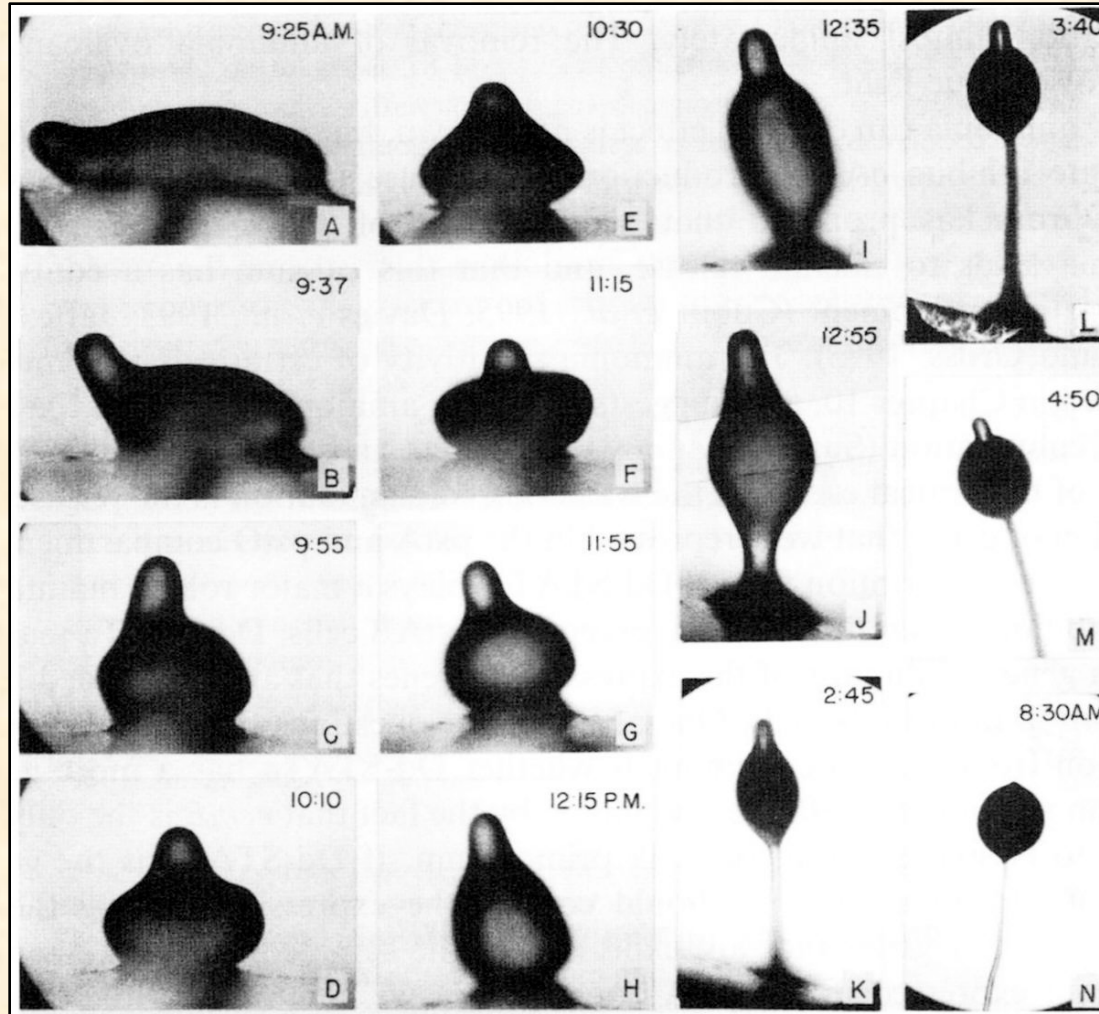# Cell Differentiation at Culmination

pstA=ecmA expression

pstO=e cmO expression

pstAB=ecmA/O and ecmB expression

pstB=strong ecmB and weak ecmA/O expression

Rearguard cells

Prespore cells

Direction of cell movement

Stalk tube

Upper Cup

Lower Cup

Inner basal disc

Outer basal disc

Slug entering culmination

Early culminant

Mid-culminant

Late Culminant

(figure from Kessin, *Dictyostelium*)
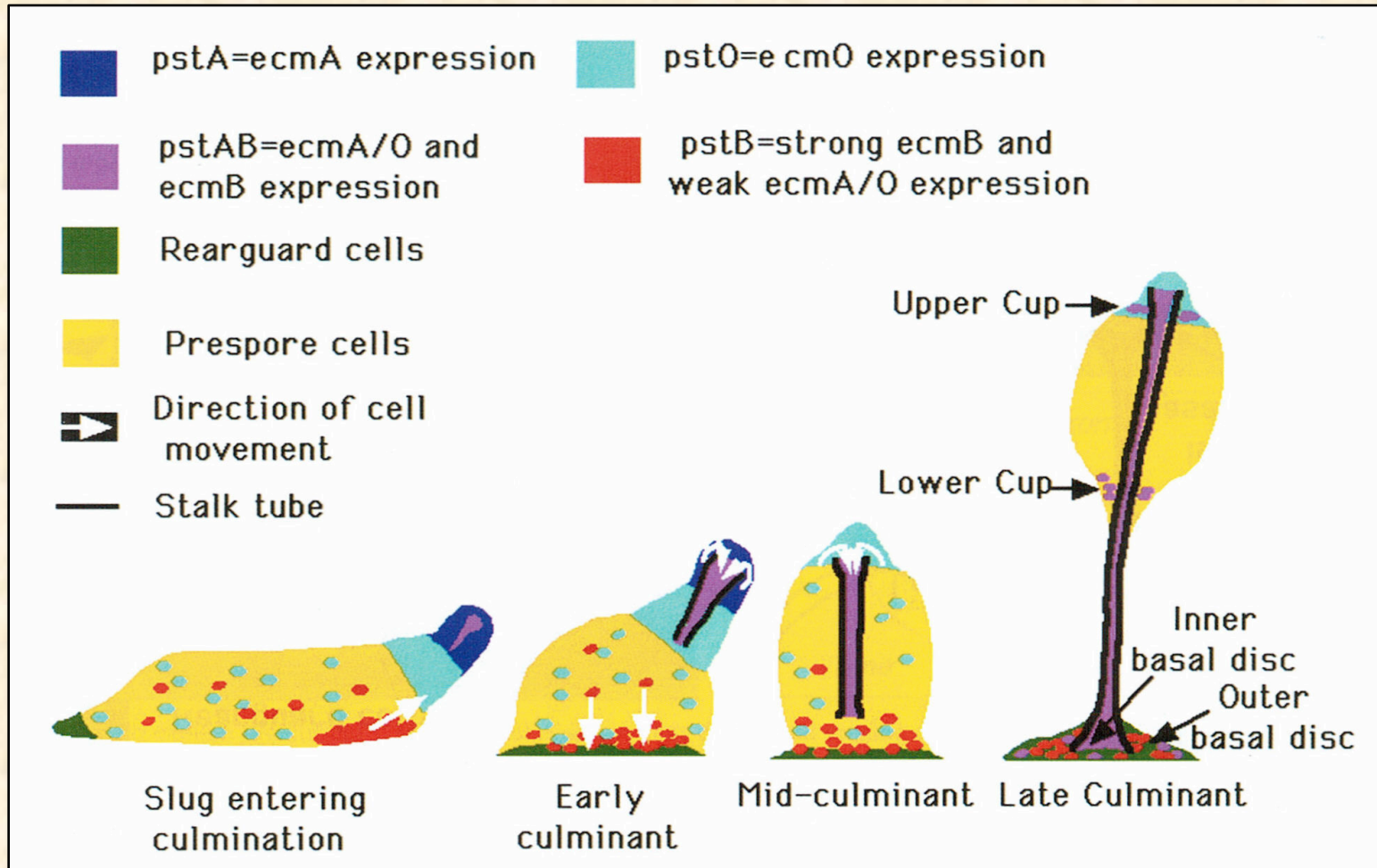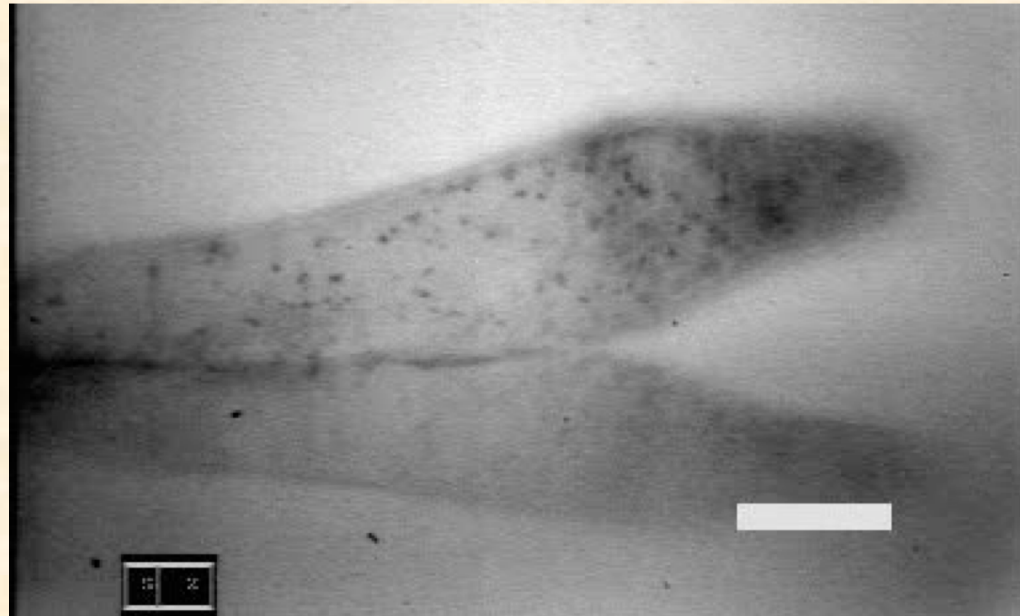
Early Culmination

- During early culmination all cells in prestalk rotate
- Scale bar = 50 µm, 1 frame = 25 sec.

(video < Zool. Inst., Univ. München)

Late Culmination

- Vigorous rotation at prestalk/prespore boundary
- Scale bar = 100 µm, 1 frame = 10 sec.

Fruiting Body Stage
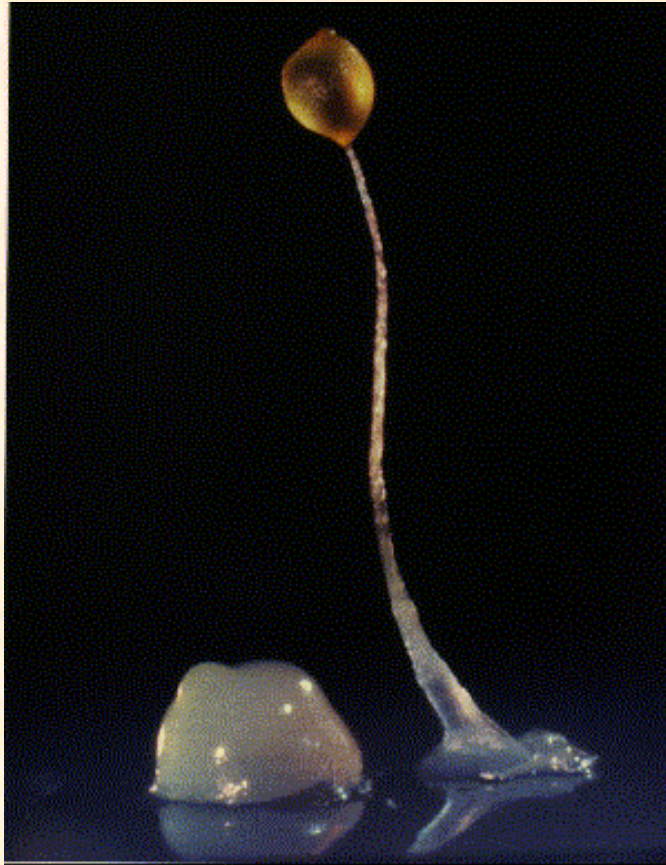
- Spores are dispersed
- Wind or animals carry spores to new territory
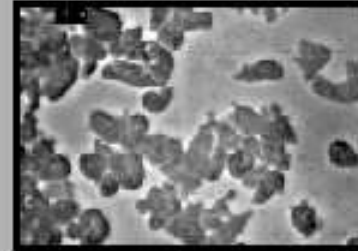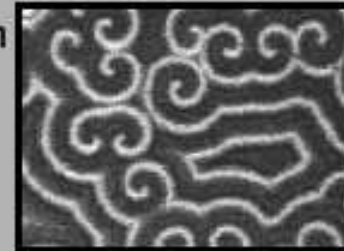- If sufficient moisture, spores germinate, release amoebas
- Cycle begins again

Life Cycle of *Dictyostelium discoideum*

Culmination 22h

Fruiting Body 24h

Vegetative Amoebae

Aggregation 4h

18h

Slug Stage

6h
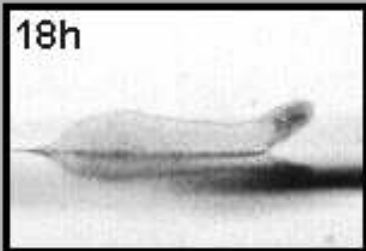
Mound 12h
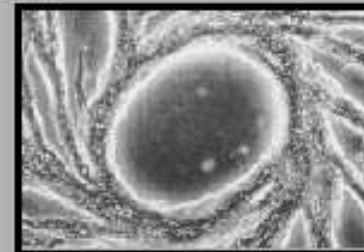
Stream Formation

Cooperation and Altruism in Dicty

- Cooperation is essential to Dicty signaling and aggregation
- "Altruism" is essential in stalk formation
- How is cooperation encouraged and cheating discouraged?
- In one case the same gene prevents cheating and allows cohesion
- Green-beard genes? Requires:
  - perceptible trait (e.g., green beard)
  - recognition of trait by others
  - preferential treatment of individuals with trait

Microbial Cooperation and Altruism

30
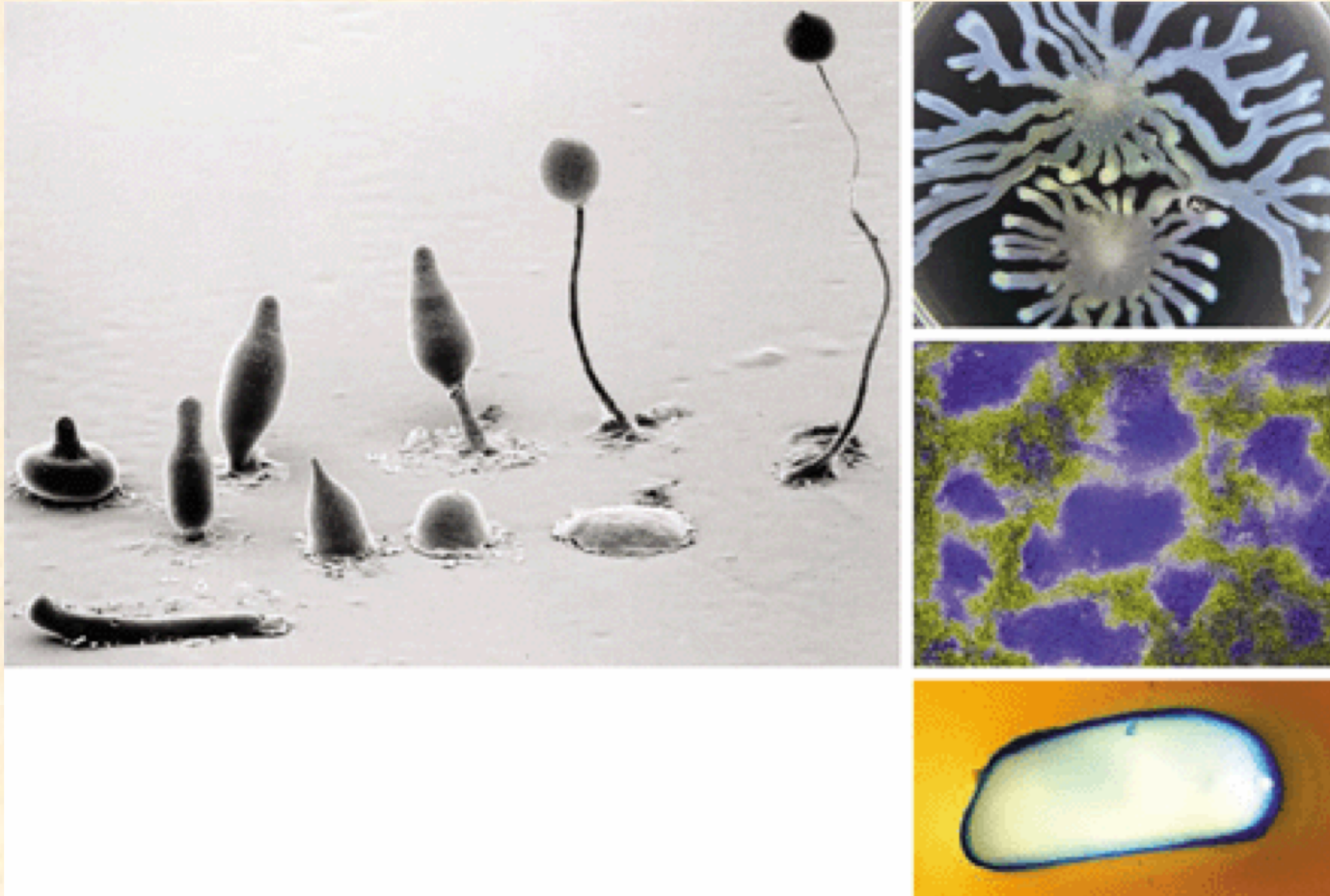
Siphonophore

Emergent Patterns During Aggregation

- a-c. As aggregate, wave lengths shorten

- d. Population divides into disjoint domains
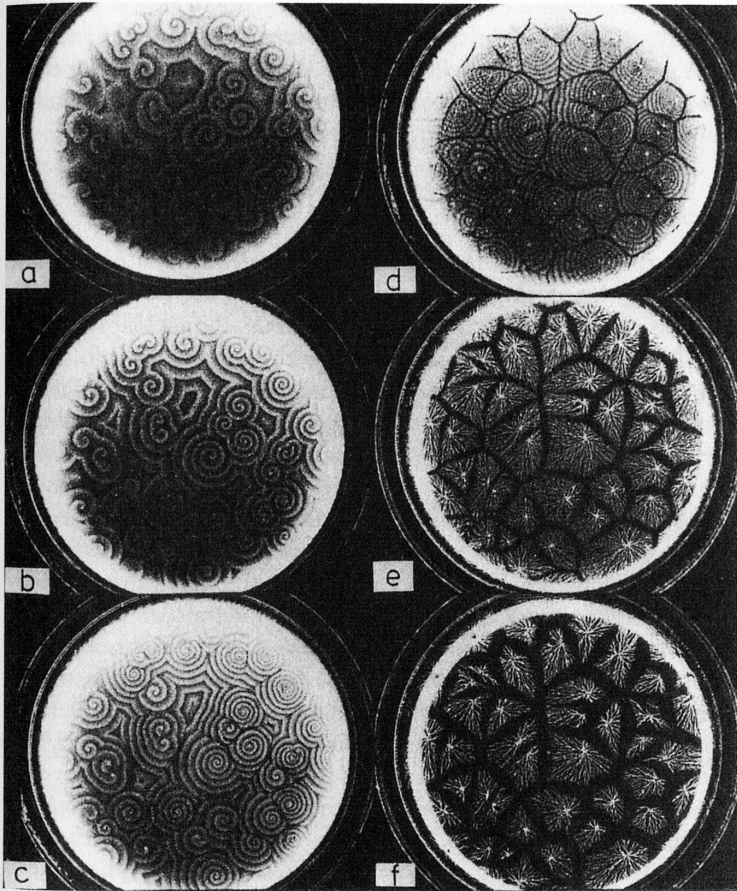
- e-f. Domains contract into "fingers" (streaming stage)
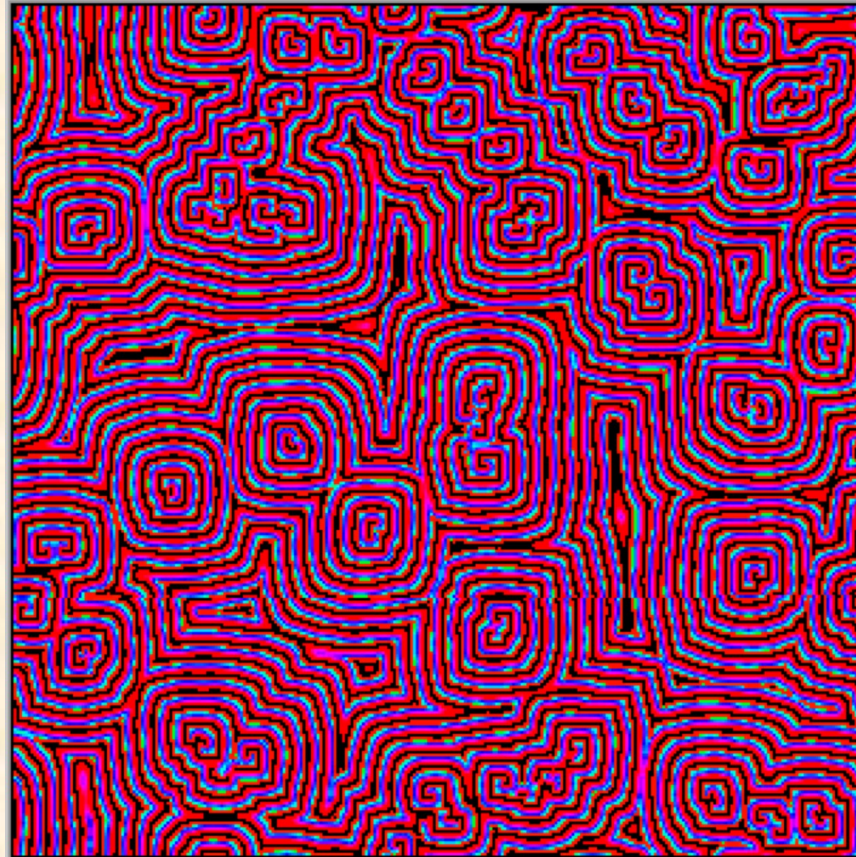
fig. from Solé & Goodwin

Belousov-Zhabotinski Reaction

Belousov-Zhabotinski Reaction

Hodgepodge Machine

Demonstration of Hodgepodge Machine

Run NetLogo B-Z Reaction Simulator

or

Run Hodgepodge simulator at CBN Online Experimentation Center
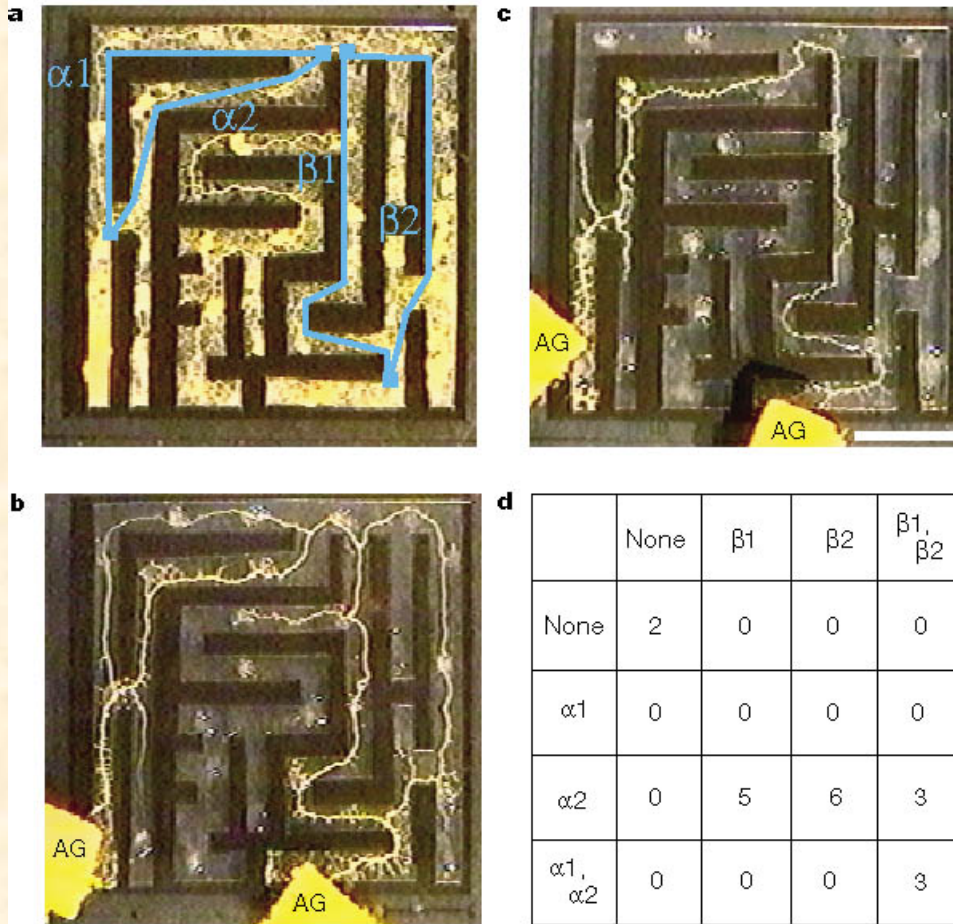
`<mitpress.mit.edu/books/FLAOH/cbnhtml/java.html>`

Universal Properties

- What leads to these expanding rings and spirals in very different systems?
- Under what conditions do these structures form?
- What causes the rotation?
- These are all examples of *excitable media*

Slime Mold Solving Maze

- Different slime mold: *Physarum polycephalum*

- Lengths: α1 (41mm), α2 (33), β1 (44), β2 (45)

- AG = food sources

- (a) initial, (b) exploring possible connections (4 hrs), (c) shortest (4 more)

	None	β1	β2	β1, β2
None	2	0	0	0
α1	0	0	0	0
α2	0	5	6	3
α1, α2	0	0	0	3

Slime Mold-Controlled Robot

- Robot sensors relayed to remote computer
- Light image shines on slime mold
- Slime mold retracts
- Motion tracked and used to control robot
- *Physarum polycephalum*

(Klaus-Peter Zauner, University of Southampton, UK, 2006)

Slime Mold Computation of Roman Road Network

2/12/20   Strano, Adamatzky & Jones, *Int. J. Nanotech. & Mol. Comp.*, in press