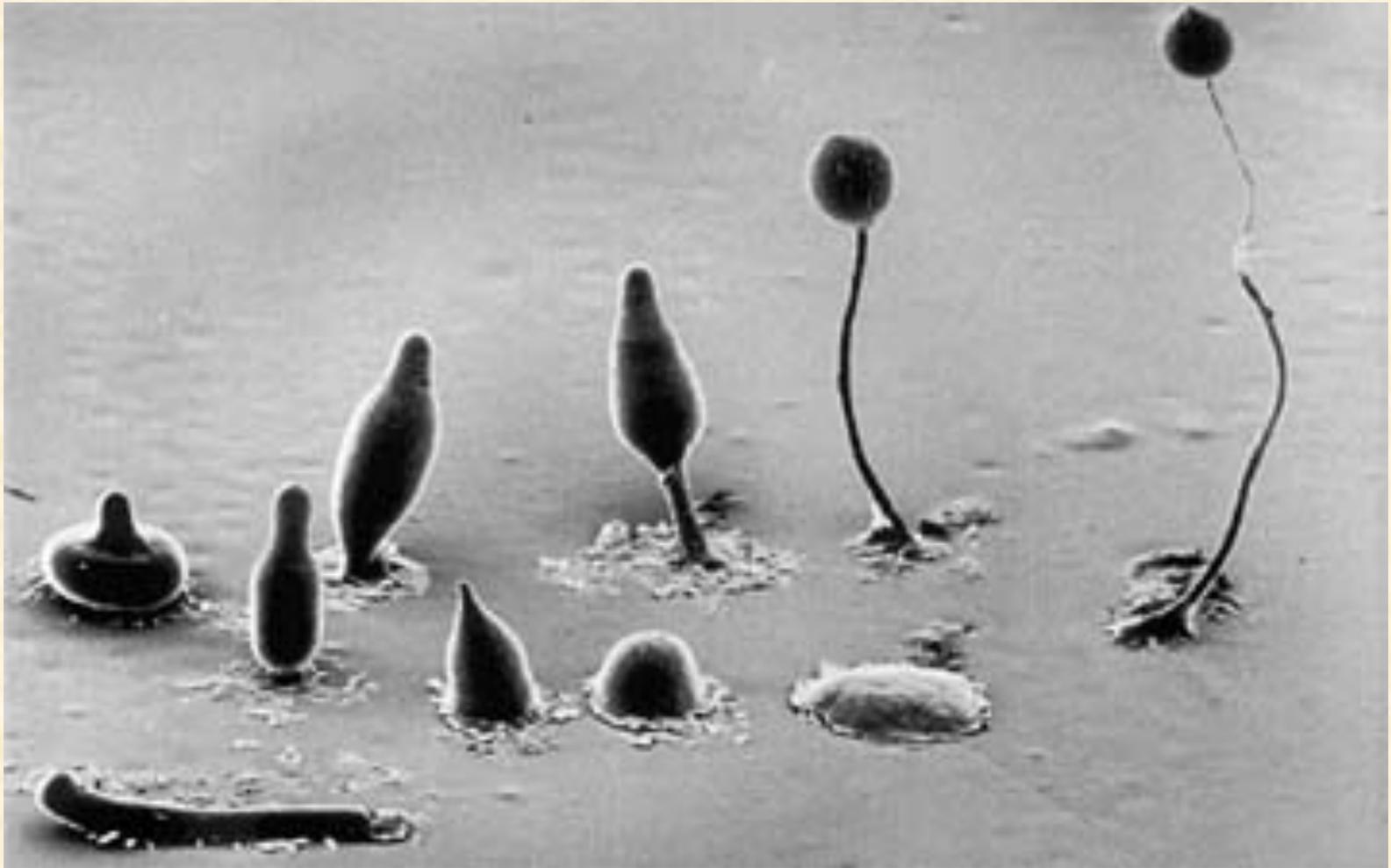


C.
Slime Mold

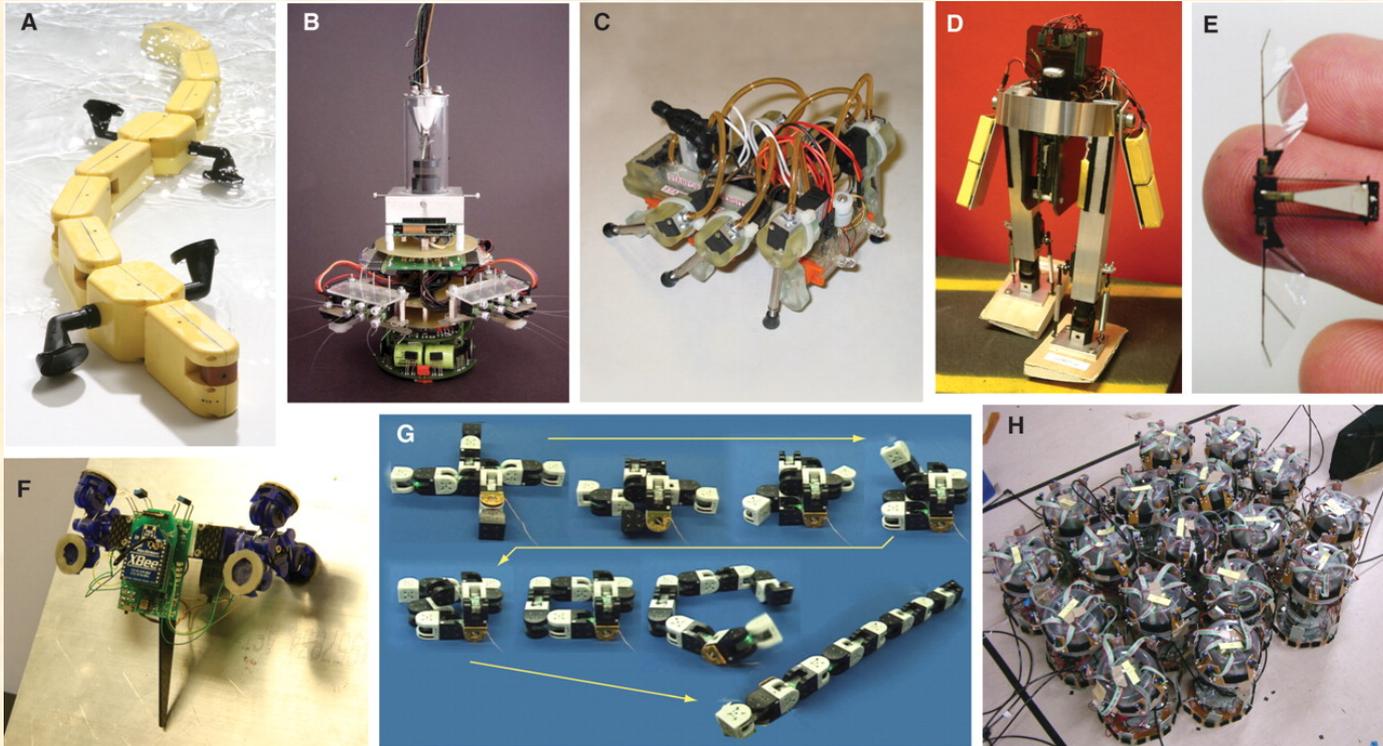
(Dictyostelium discoideum)

“Dicty”

Complete Life Cycle



Self-organization in Bio-inspired Robotics



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

Self-copying Robot (2005)

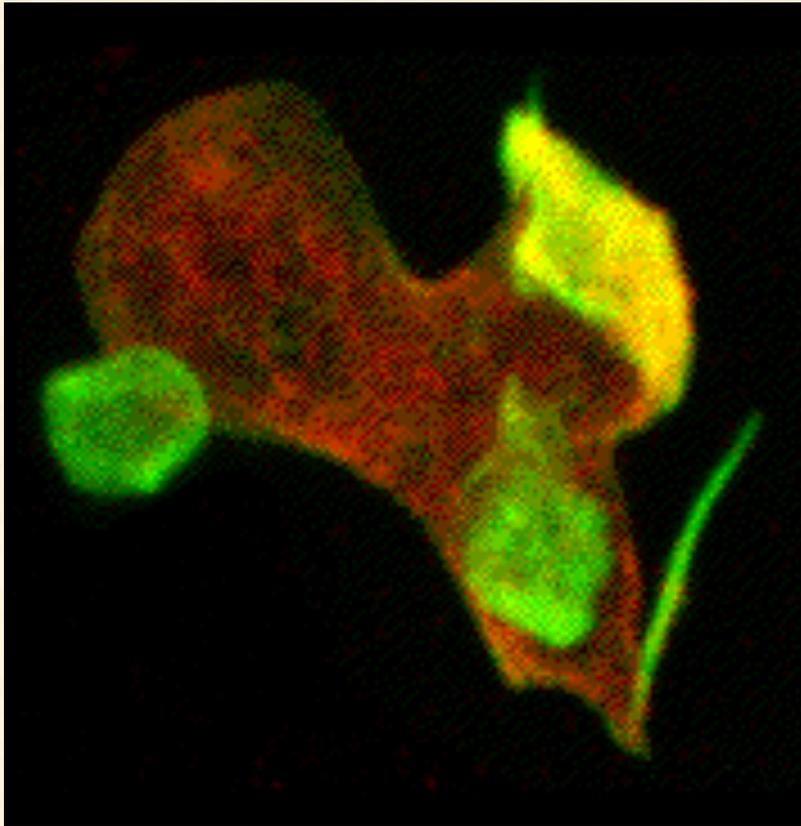


- Hod Lipson, Cornell
- Programmable blocks
- 2 swiveling pyramidal halves
- Magnetic connections
- 10 cm across
- One stack can assemble another

Dicty Videos

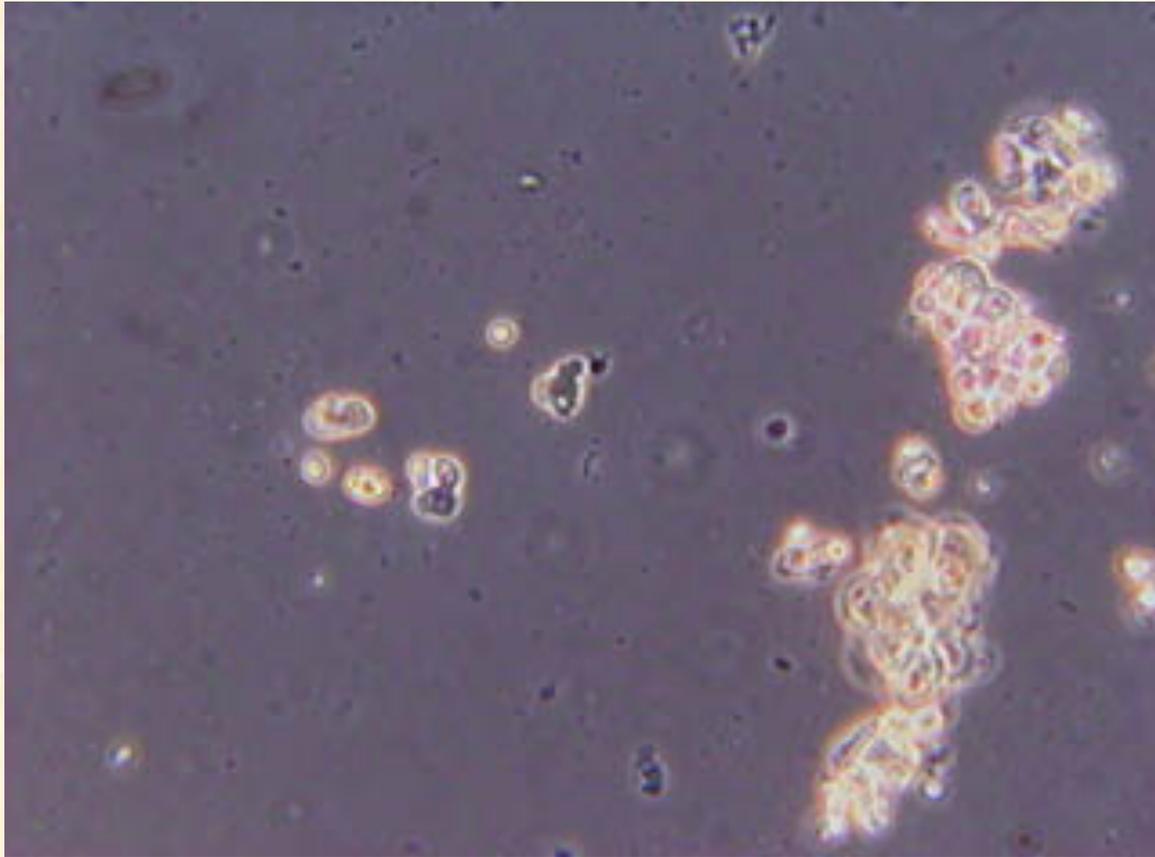
- Bonner's videos
- Aggregation
- Life cycle

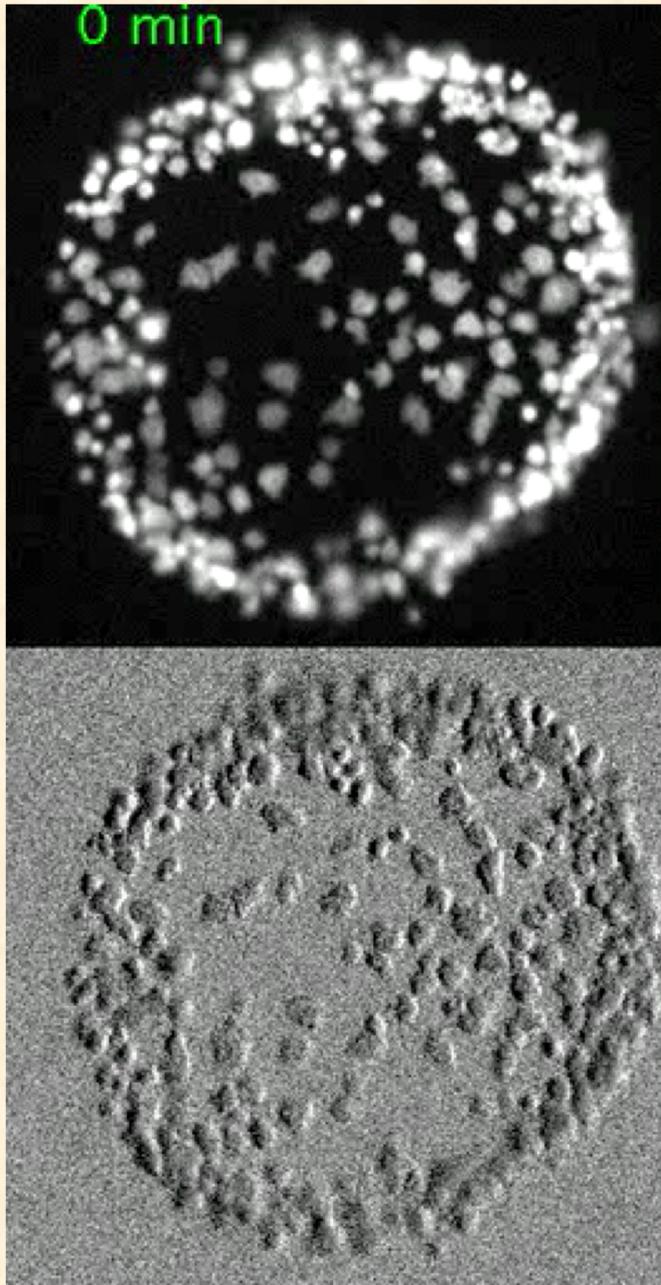
Amoeba Stage



- 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

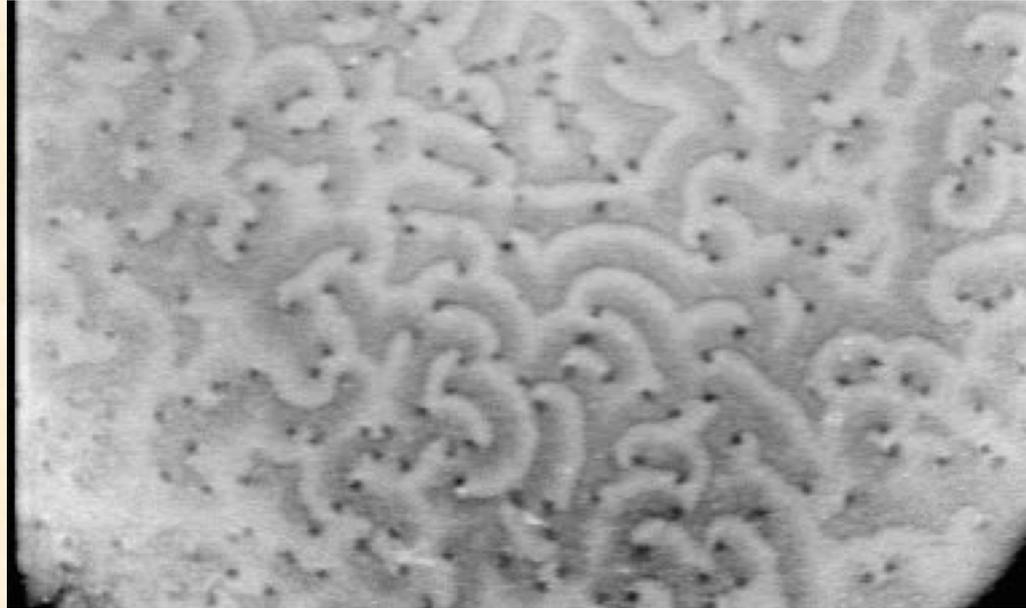
Science 21 May 2010: Vol. 328, 1021–1025

Aggregation Stage



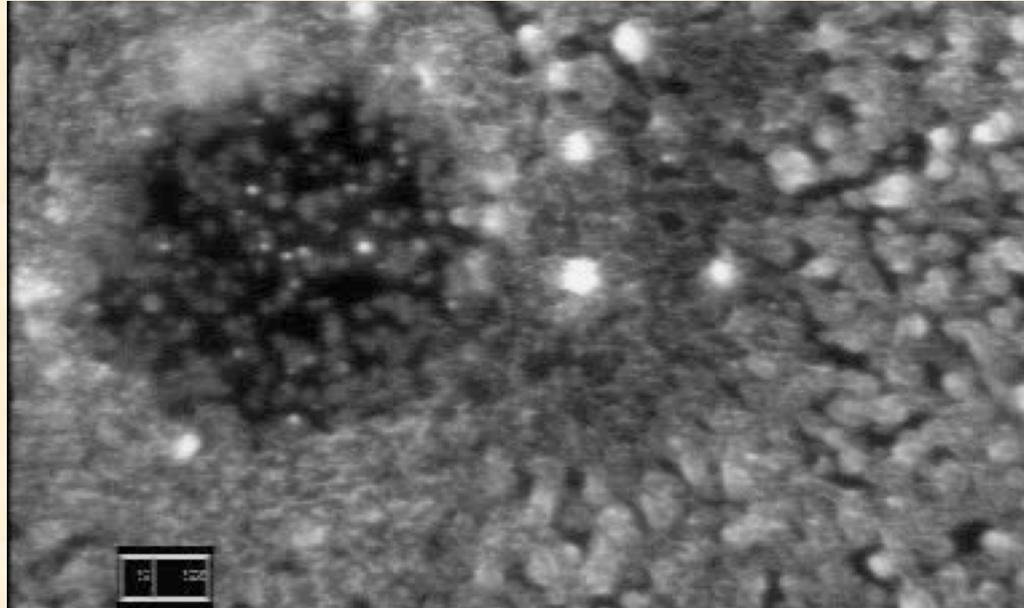
- Triggered by exhaustion of food
- Aggregate by *chemotaxis*
- Form expanding concentric rings and spirals
- Up to 125 000 individuals

Spiral Waves



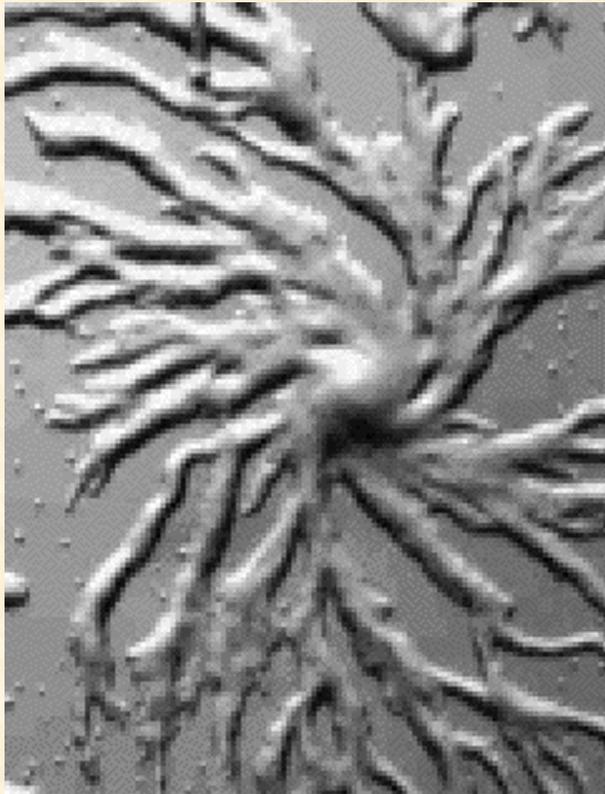
- Spiral accelerate cell aggregation (18 vs. 3 $\mu\text{m}/\text{min}.$)
- Waves propagate 120 – 60 $\mu\text{m}/\text{min}.$
- 1 frame = 36 sec.

Center of Spiral



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

Stream Formation Stage



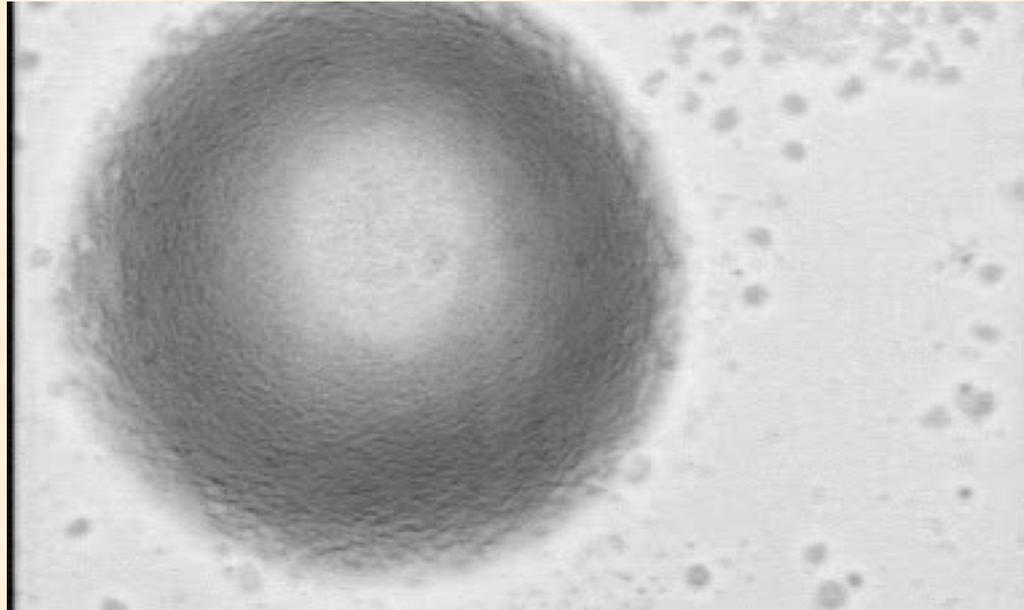
- Streams result from dependence of wave propagation velocity on cell density
- Breaks symmetry
- As density increases, begin to adhere
- Begin to form *mound*

Mound Stage



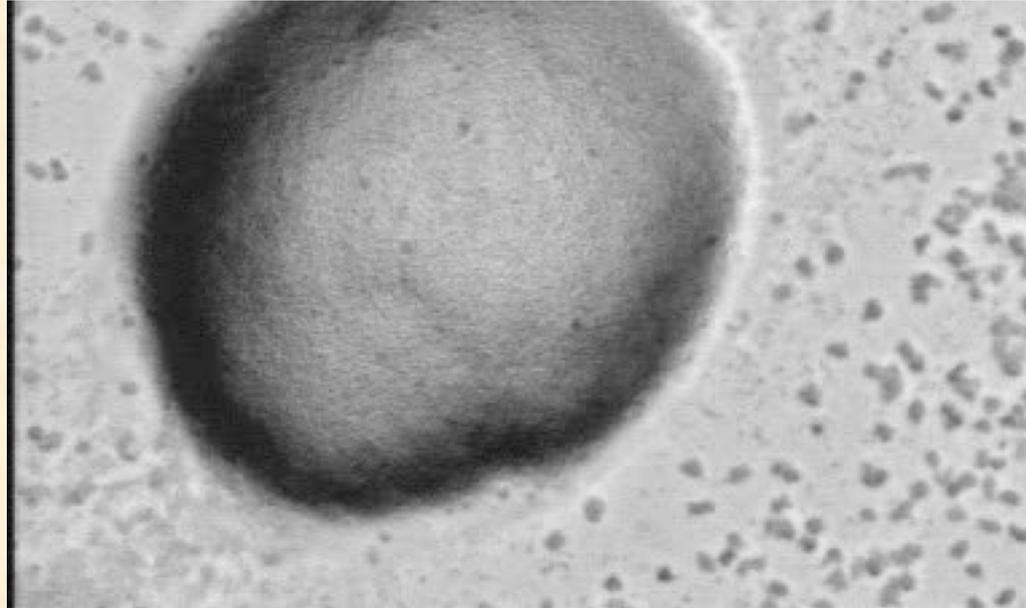
- Cells differentiate
- Some form an elongated finger

Concentric Waves in Mounds



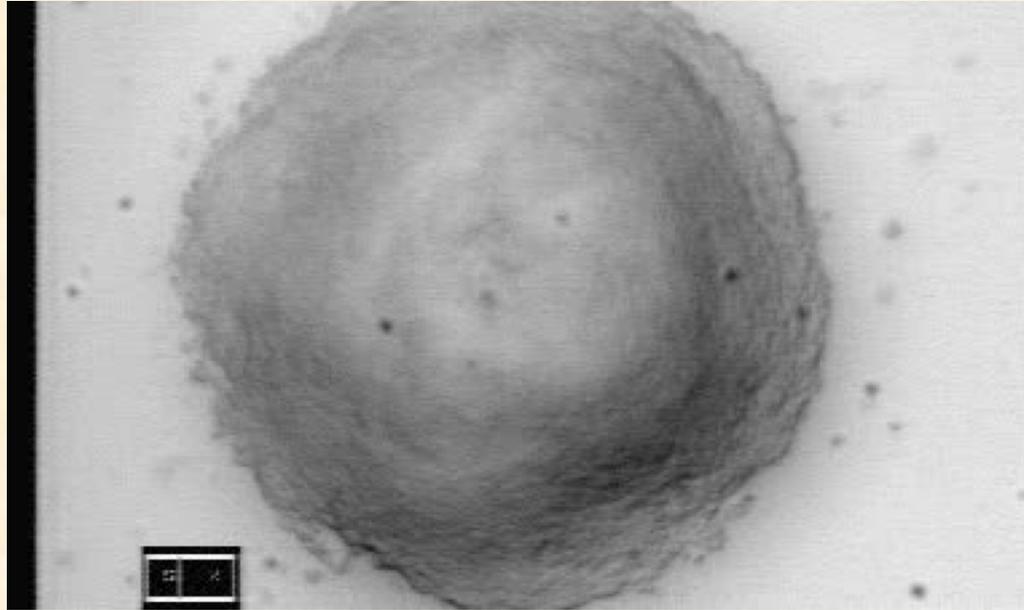
- Concentric or spiral waves
- Mound comprises 10^3 to 10^5 cells
- Cells begin to differentiate
- 1 frame = 20 sec.

Multiple Centers



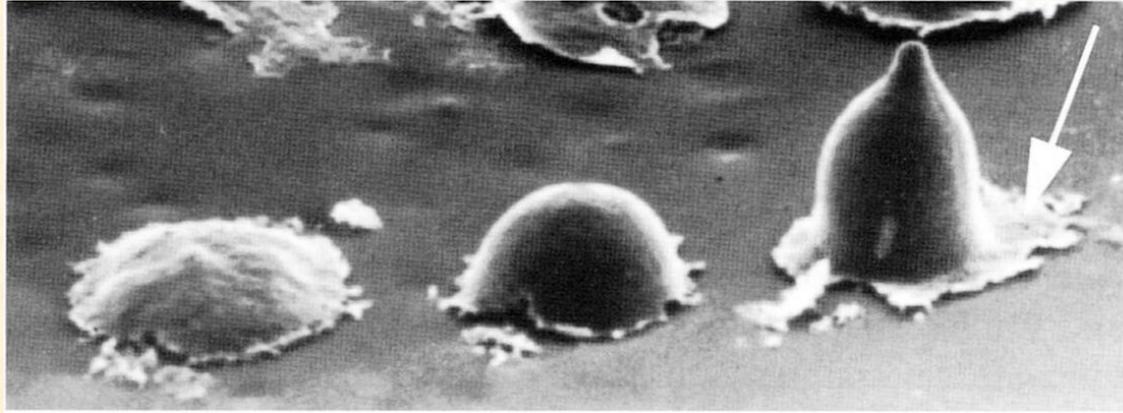
- Multiple pacemakers
- Wave fronts mutually extinguish (typical of excitable media)
- One center eventually dominates

Multi-armed Spirals



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

Formation of Acellular Sheath



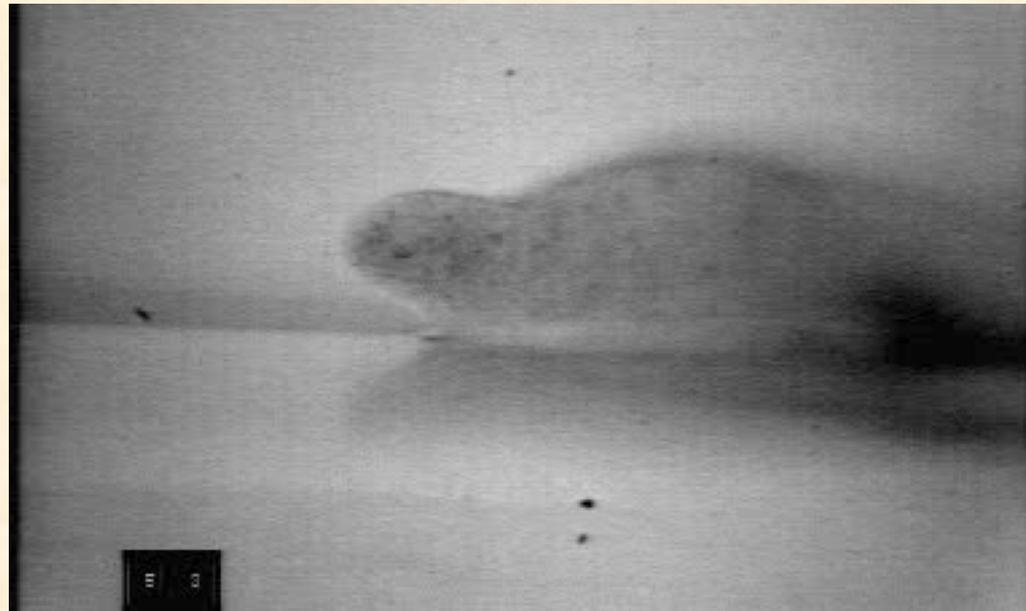
- Composed of cellulose & a large glycoprotein
- Covers mound and is left behind slug as trail
- Function not entirely understood:
 - protection from nematodes (worms)
 - control of diffusion of signaling molecules

Slug Stage



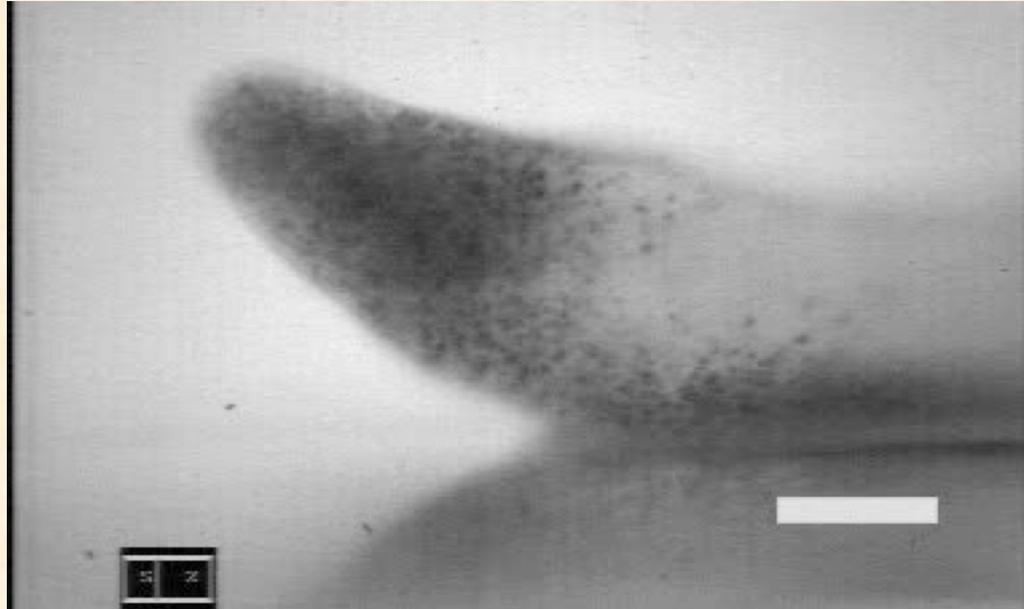
- Prestalk elongates, topples, to form slug
- Behaves as single organism with 10^5 cells
- Migrates; seeks light; seeks or avoids heat
- No brain or nervous system

Movement of Young Slug



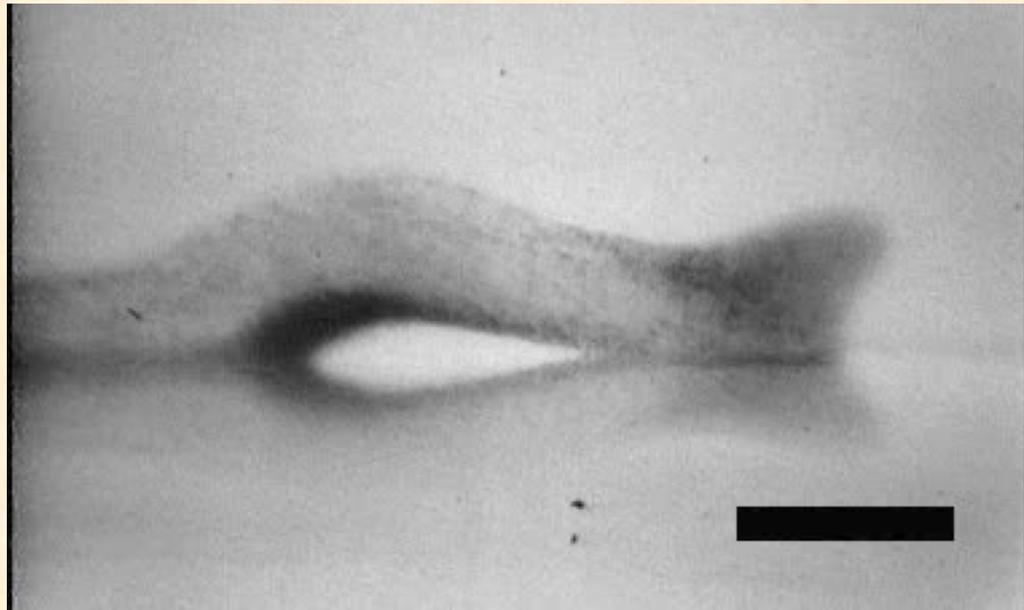
- Time-lapse (1 frame = 10 sec.)
- Note periodic up-and-down movement of tip

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.

Migration of Older Slug



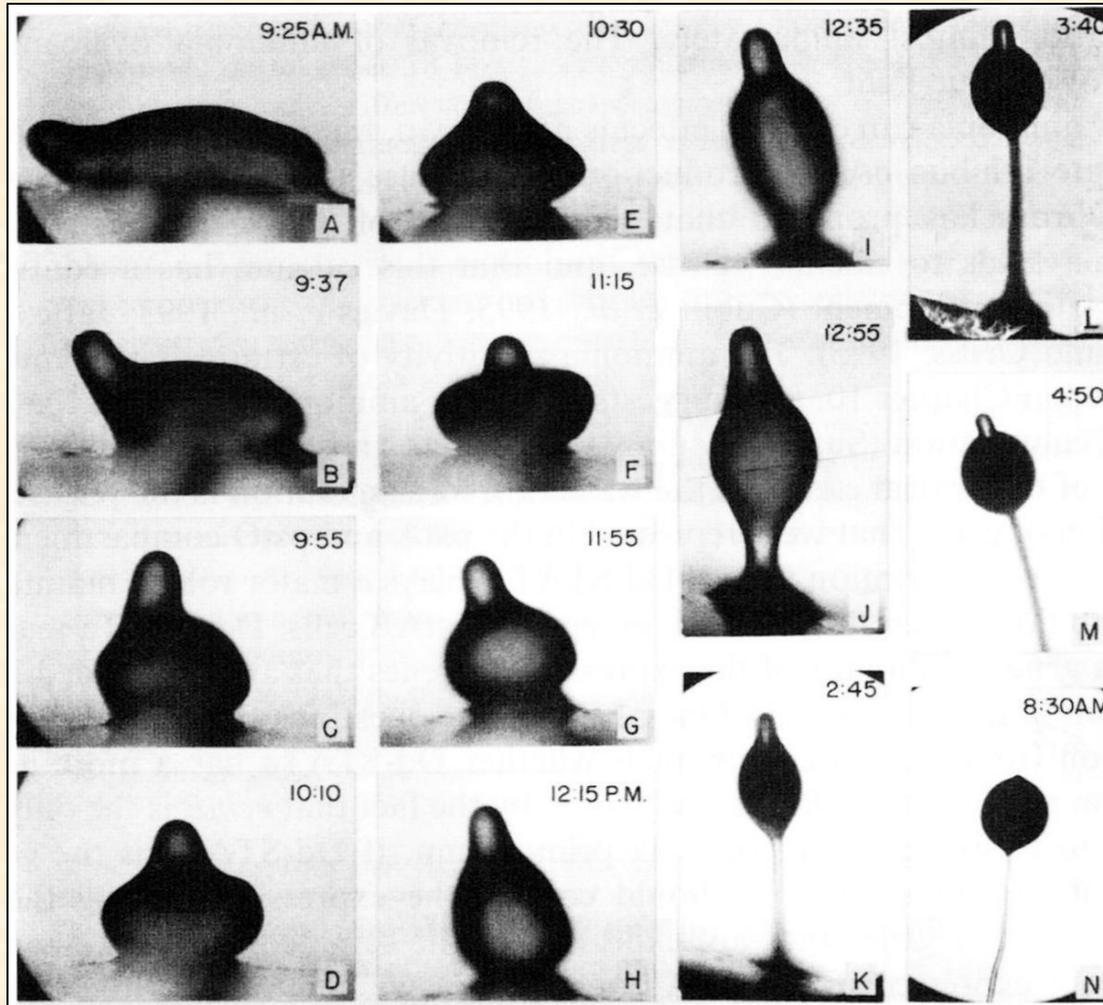
- Scale bar = 100 μm , 1 frame = 20 sec.

Culmination Stage

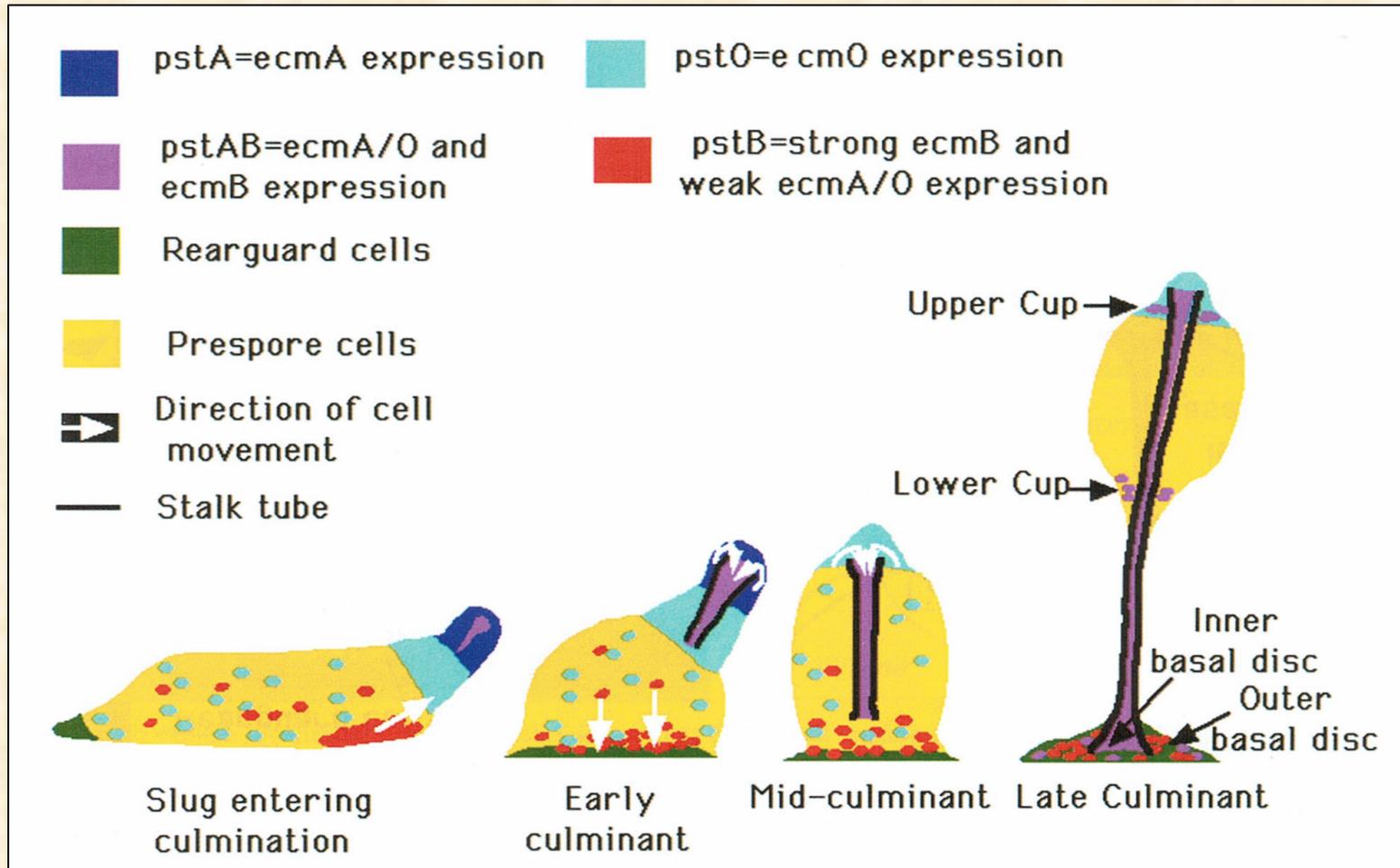


- Cells differentiate into base, stalk, and spores
- Prestalk cells form rigid bundles of cellulose & die
- Prespore cells (at end) cover selves with cellulose & become dormant

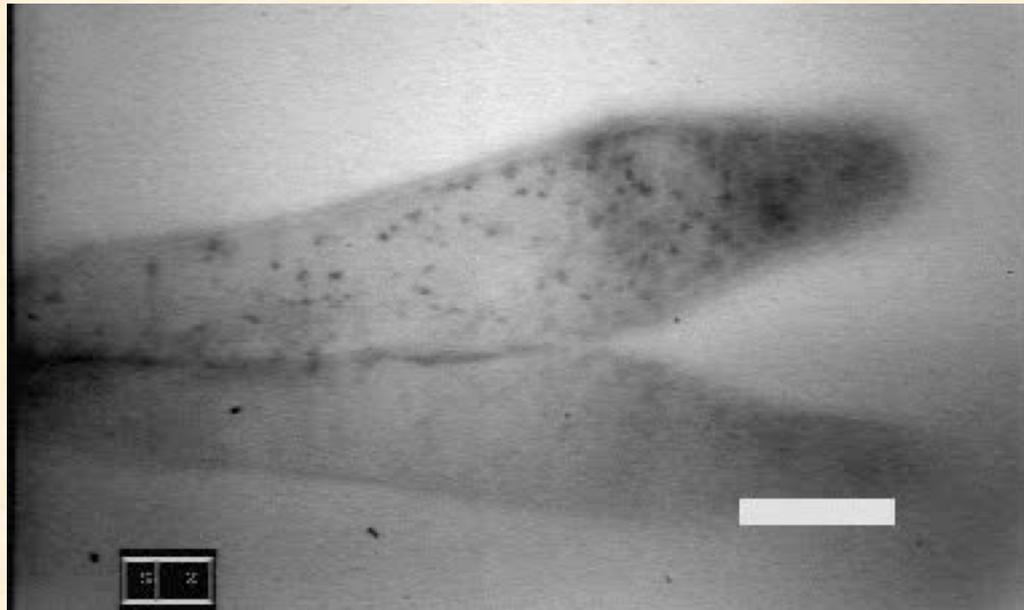
Stages of Culmination



Cell Differentiation at Culmination

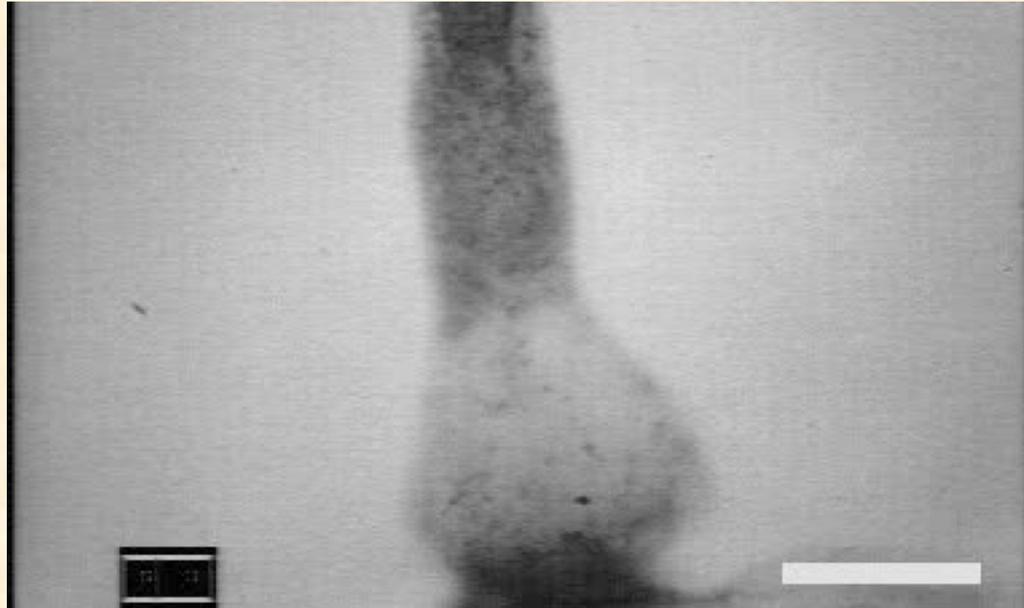


Early Culmination



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

Late Culmination



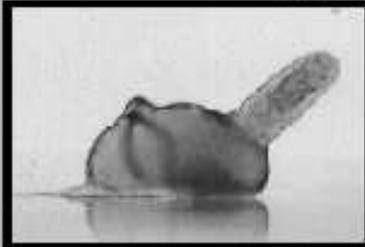
- Vigorous rotation at prestalk/prespore boundary
- Scale bar = 100 μm , 1 frame = 10 sec.

Fruiting Body Stage



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

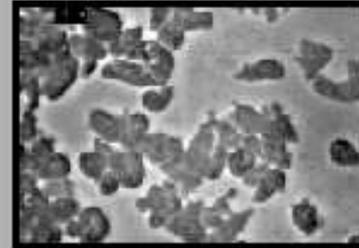
Culmination 22h



Fruiting Body

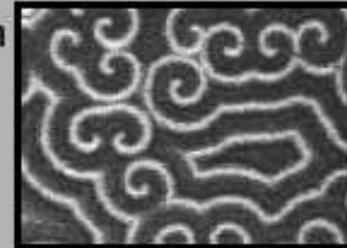
24h

Vegetative Amoebae



Aggregation

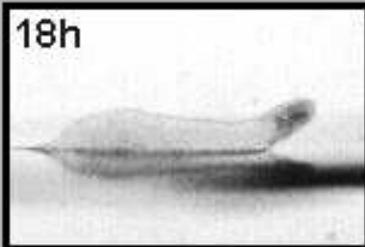
4h



Life Cycle
of

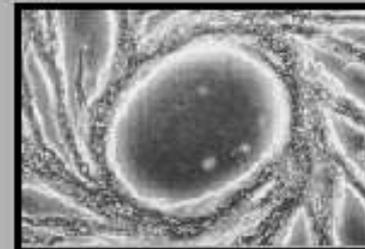
Dictyostelium discoideum

18h



Slug Stage

6h



Stream Formation

12h

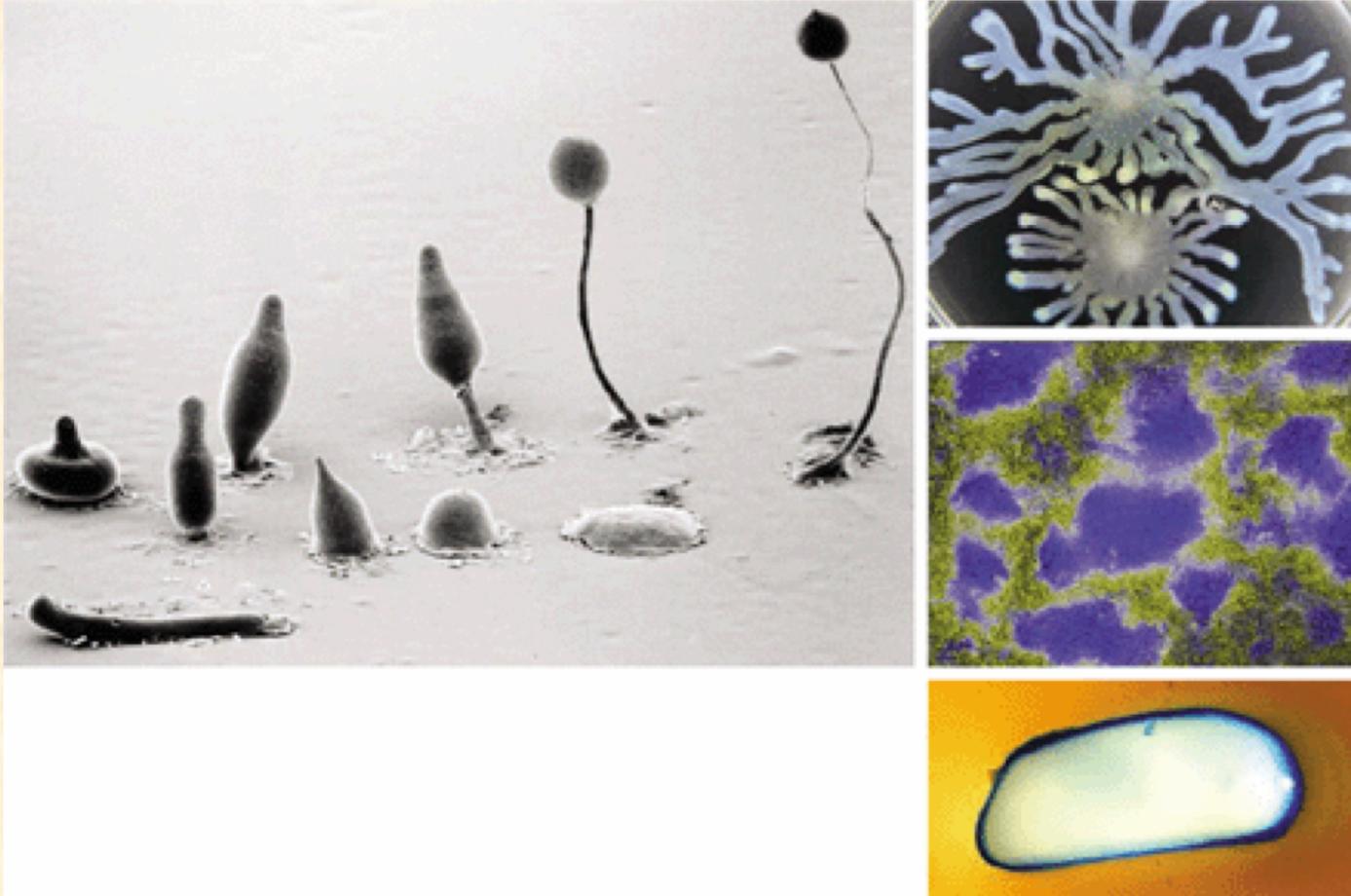


Mound

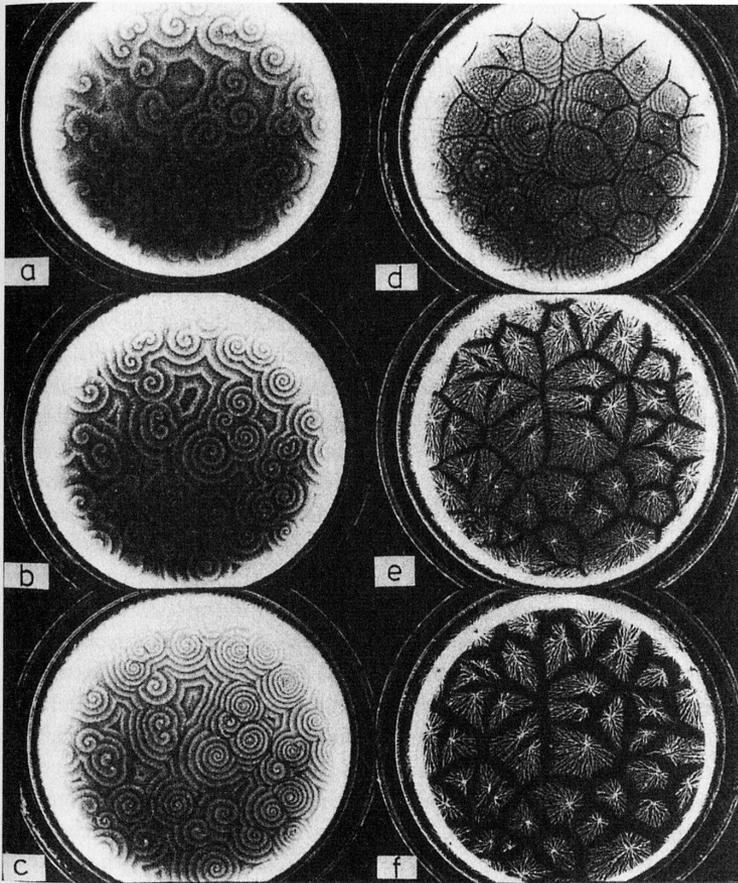
Cooperation and Altruism in Dicty

- 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?

Microbial Cooperation and Altruism



Emergent Patterns During Aggregation

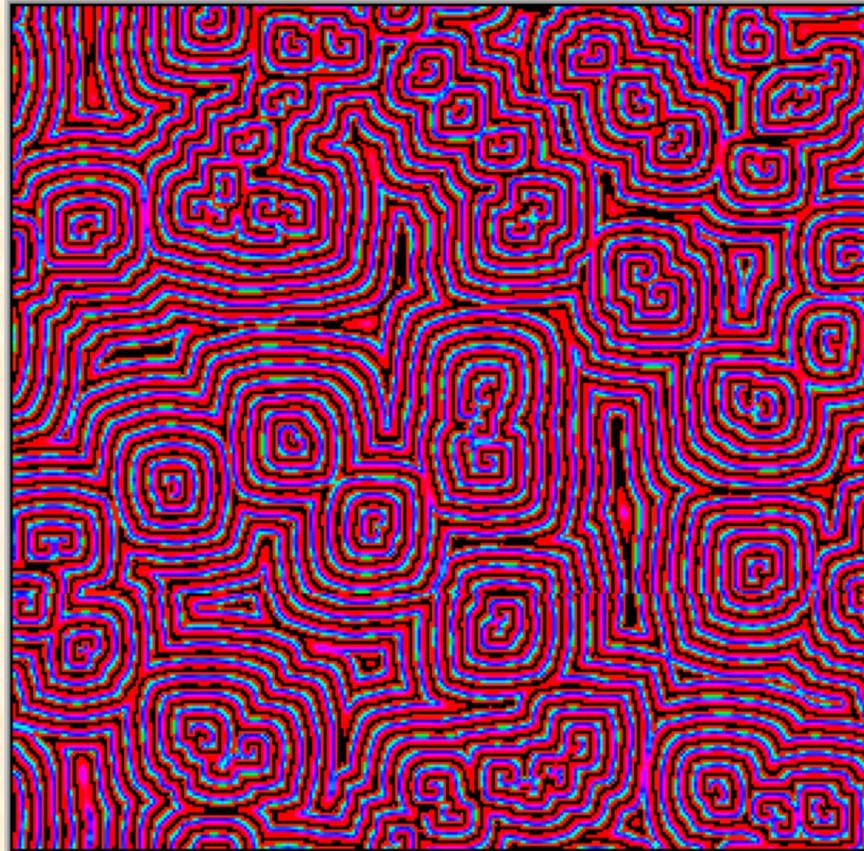


- a-c. As aggregate, wave lengths shorten
- d. Population divides into disjoint domains
- e-f. Domains contract into “fingers” (streaming stage)

Belousov-Zhabotinski Reaction



Hodgepodge Machine



Demonstration of Hodgepodge Machine

[Run NetLogo B-Z Reaction Simulator](#)

or

[Run Hodgepodge simulator at CBN
Online Experimentation Center](#)

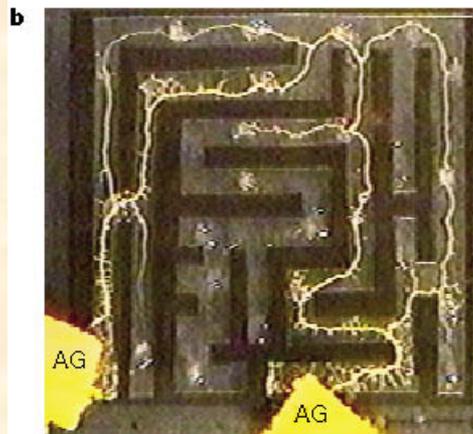
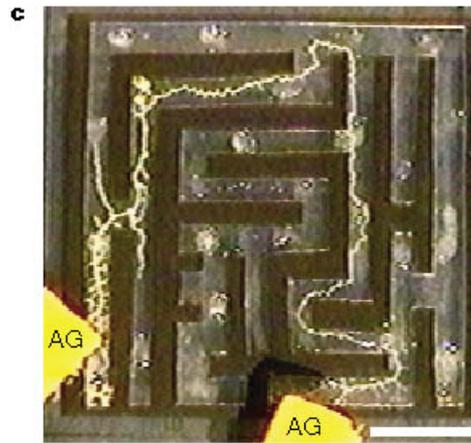
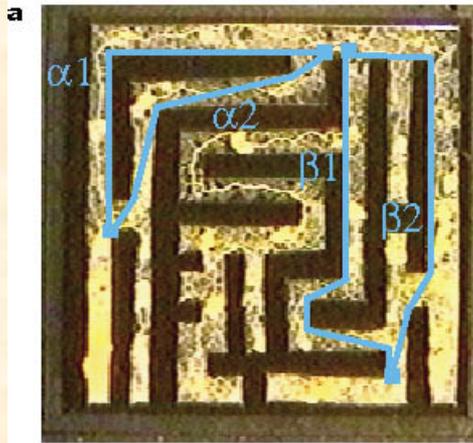
mitpress.mit.edu/books/FLAOH/cbnhtml/java.html

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



d

	None	$\beta 1$	$\beta 2$	$\beta 1, \beta 2$
None	2	0	0	0
$\alpha 1$	0	0	0	0
$\alpha 2$	0	5	6	3
$\alpha 1, \alpha 2$	0	0	0	3

- Different slime mold: *Physarum polycephalum*
- Lengths: $\alpha 1$ (41mm), $\alpha 2$ (33), $\beta 1$ (44), $\beta 2$ (45)
- AG = food sources
- (a) initial, (b) exploring possible connections (4 hrs), (c) shortest (4 more)

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*



Slime Mold Computation of Roman Road Network

