Structure of the actin Cortical Layer and dynamics of Cytokinesis

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Outline

1. Cortical actin
   - Acto-Myosin Cortex
   - Thickness and density of the cortical layer

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   - Thickness and density of the cortical layer
2. Dynamics of cytokinesis
   - Cytokinesis
   - Contractile ring closure
   - Contractile ring formation

Outline

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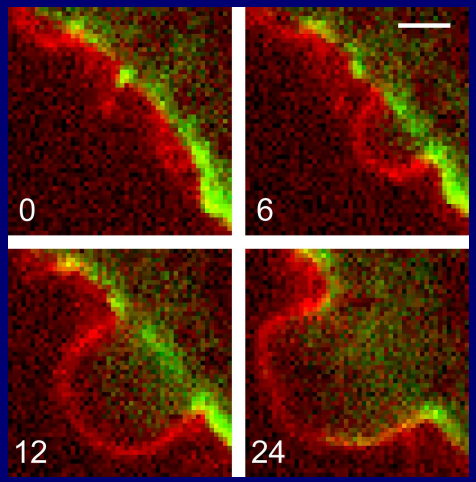
Cell Cortex

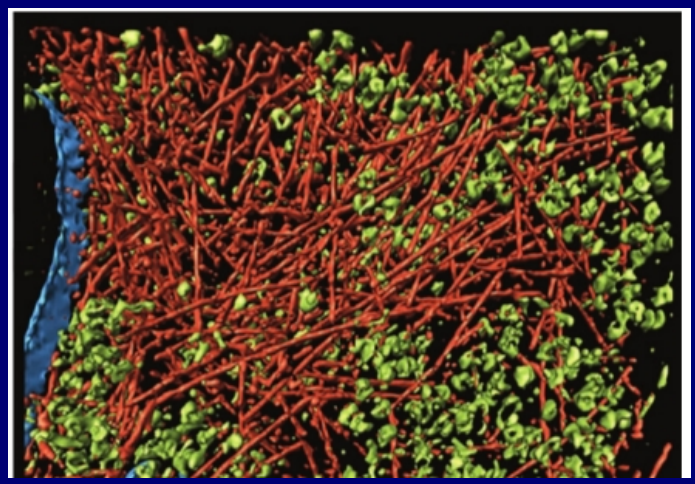
Optical Imaging



Charras

- Actomyosin layer
- Polymerization from the surface (formins)
- Treadmilling time $\sim$ 30s

Electron microscopy

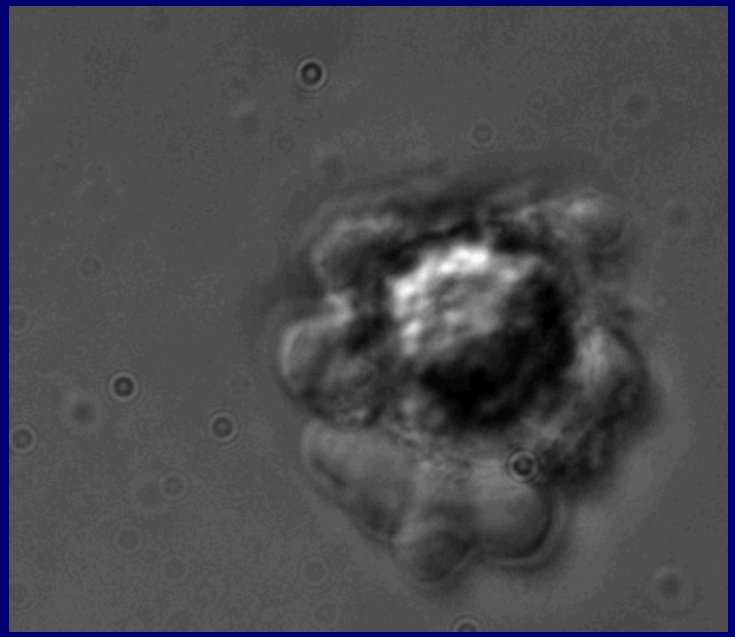


Medalia

- Dense actin layer
- Thickness $\sim 1\mu$m
- Filaments parallel to the cell surface

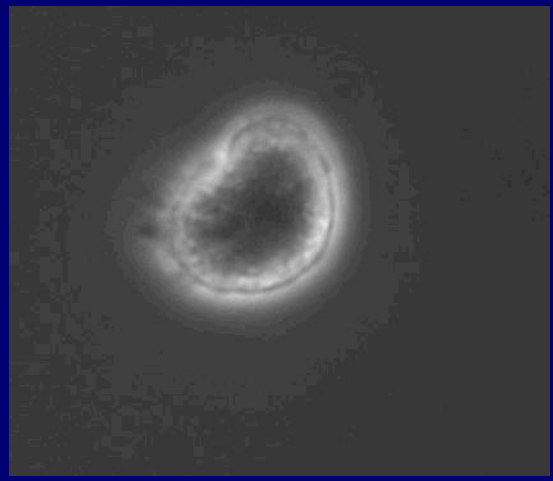
Cell instabilities associated to cortical layer

Blebs Paluch



- Detachments of the membrane form the cortical layer
- Bleb lifetime 30s

Cell oscillations Pullarkat



- Oscillations depend on actin contractility
- Oscillations depend on calcium (threshold density)

Outline

Hydrodynamic Theory of Active Gels

- Macroscopic description

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- Description based only on symmetries
  - Polar symmetry: vector **p**, tensor $q_{\alpha\beta} = p_\alpha p_\beta - \frac{1}{3} p^2 \delta_{\alpha\beta}$
  - Time reversal symmetry
    reactive and dissipative components
  - Active effects (motors) described in terms of ATP consumption $\Delta\mu = \mu_{ATP} - \mu_{ADP} - \mu_P$

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- Linear relations between fluxes and forces
- Myosin motors create a contractile stress in the actin gel

Multicomponent active gels Callan-Jones and Julicher

- Random polarization parallel to the membrane
- Two component system: actin and cytoplasm
- Actin conservation law

$$\partial_t \rho_g + \partial_\alpha \rho_g v_{g,\alpha} = -k_d \rho_g$$

- Boundary condition $\rho_g v_{g,z}\big|_{z=0} = v_p \rho_0$
- Constitutive equation, relative flux

$$\begin{aligned} \rho_g \left(v_\alpha - v_{g,\alpha} \right) = & \quad \chi \left(\partial_\beta \sigma^g_{\alpha\beta} - \partial_\alpha \Pi \right) \\ 0 = & \quad 2\eta \partial_\beta v_{g,\alpha\beta} - \partial_\alpha \Pi \quad . \end{aligned}$$

- Effective pressure includes contractile stress of molecular motors $\Pi(\rho) = P(\rho) - \zeta \Delta\mu$
- Neglect permeation

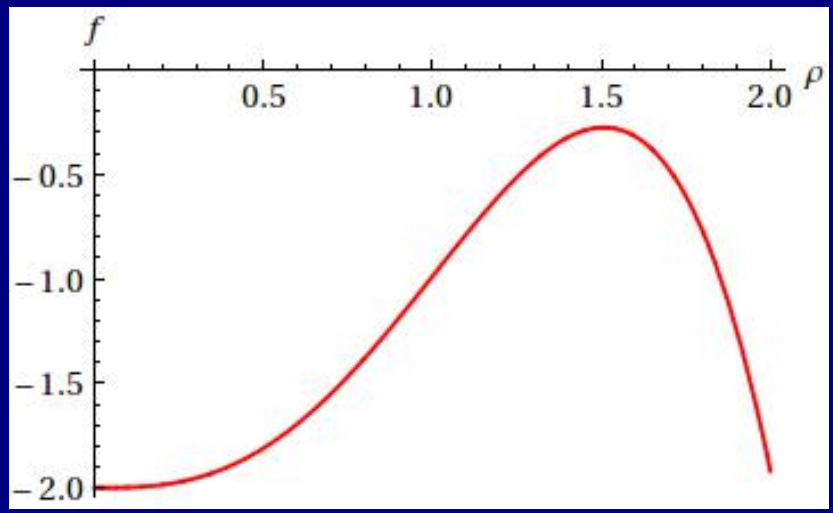
Active prewetting

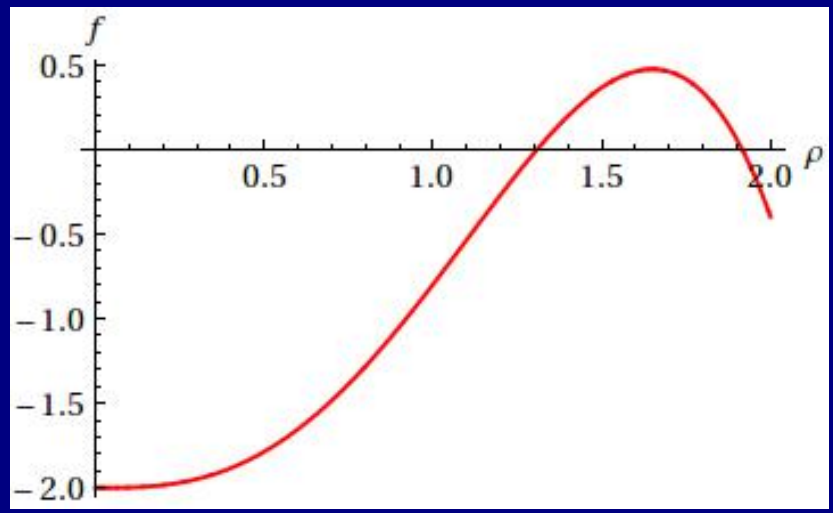
- One-dimensional geometry

Dynamic equations

$$\partial_t \rho + \partial_z \rho v = -k_d \rho$$
$$\eta \partial_z v - \Pi(\rho) = 0$$

- Actin velocity $\eta v = \left(\frac{\partial \rho}{\partial z}\right)^{-1} \rho f(\rho) \quad f(\rho) = -k_d \eta - \Pi(\rho)$

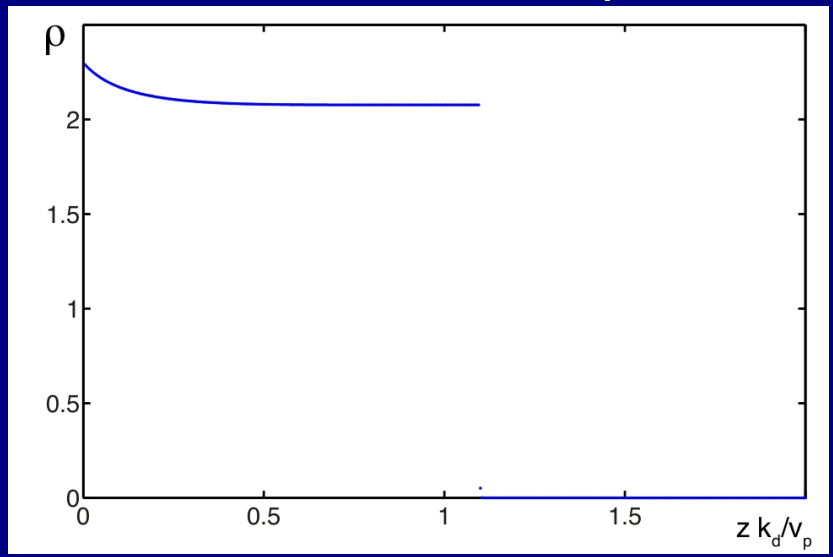




- No Flux at infinity
- 3 possible fixed points

Concentration profile in actin layer

- Small activity (Myosin concentration): exponential decay of cencentration
- Large activity: formation of an active prewetting layer



- Actin cortical layer viewed as a wetting layer
- Almost constant concentration
- Thickness $e \sim v_p/k_d$

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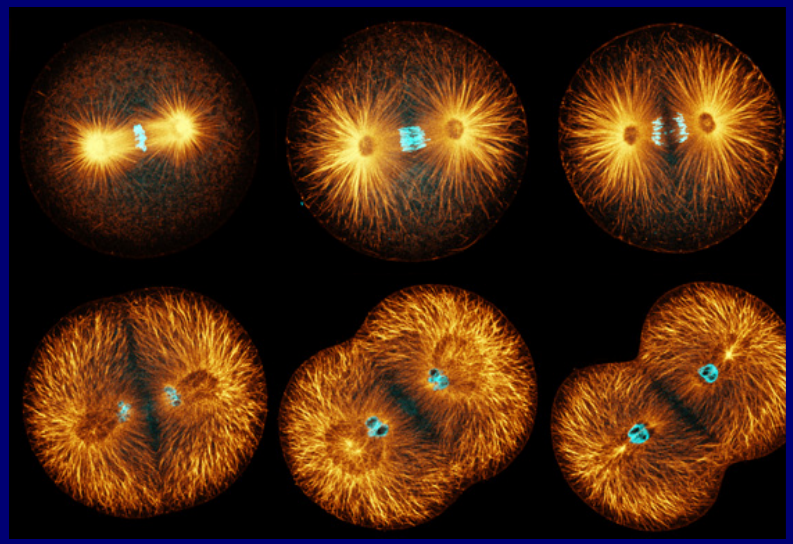
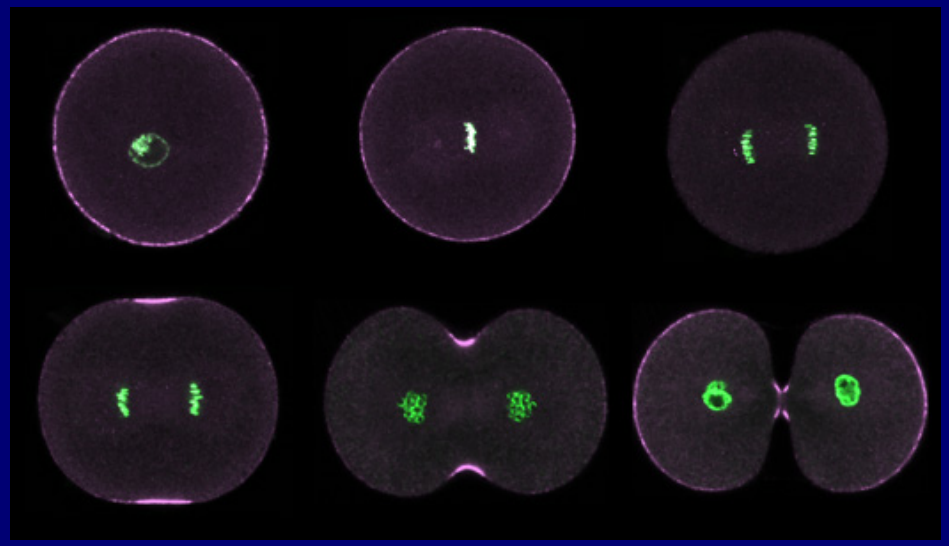
Final stages of cell division von Dassow

Final stage of cell division



- Separation between daughter cells
- See urchin

Myosin contractility



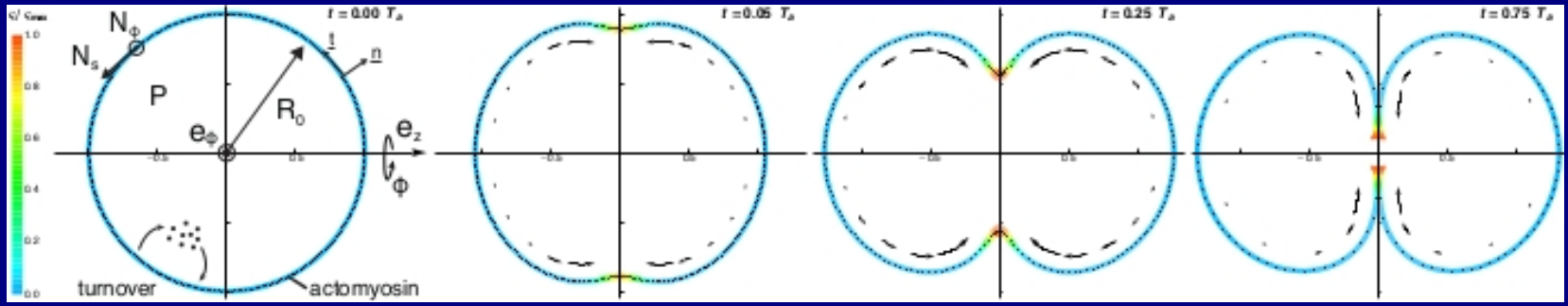
- Ring closure due to actin contractility
- Local enhancement of myosin activity due to astral microtubules

Outline

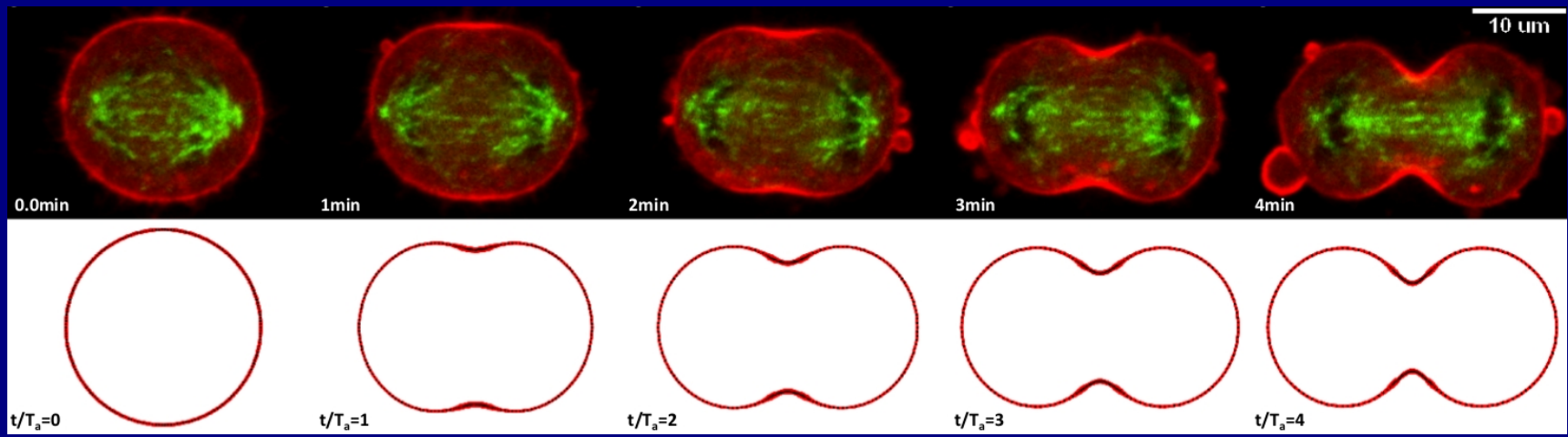
Active gel theory of Cytokinesis

- Cytokinesis driven by myosin contractility in the actin cortical layer: cortical flow
- Excess of contractility at the equator of the cell.
- Actin cortical layer described by active gel theory
  - Constant density in cortical layer
  - Ignore polarization effects
  - Viscoelastic actin layer
  - Active stress $\zeta \Delta\mu$ non homogeneous, increases at the equator
- Numerical solution of active gel equations, using Lagrangian coordinates
- Impose cylindrical symmetry of the cell

Dynamics of Cytokinesis

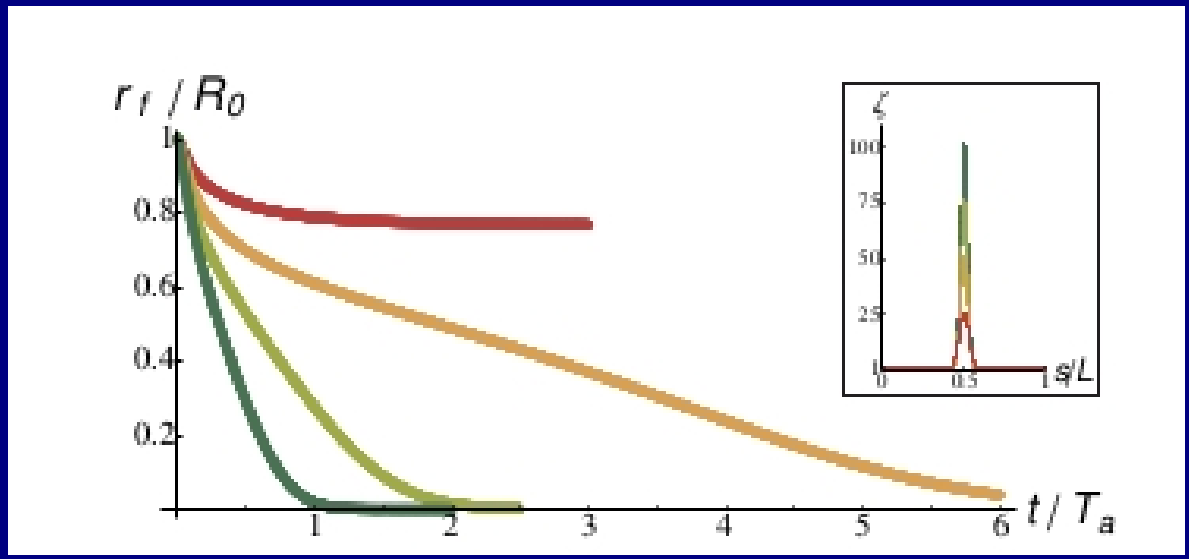


- Critical value of activity for cytokinesis completion
- Low activity of the ring: cytokinesis failure
- Large activity of the ring: cytokinesis success

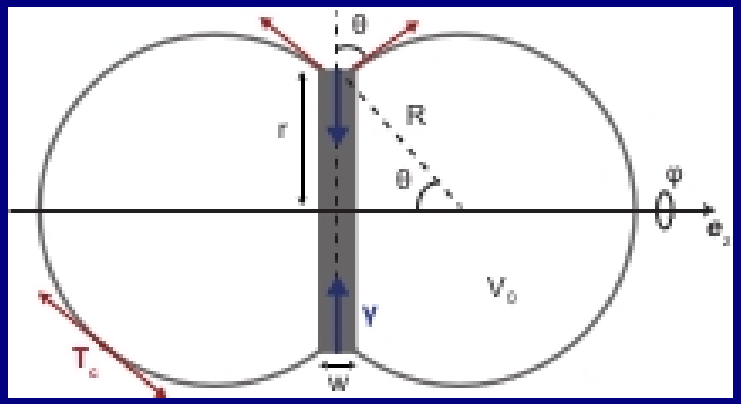


Kinetics of ring closure

- Quasi-linear furrow constriction
- Rate of constriction increases with amplitude and width of input signal
- If $w \sim R_0 \frac{dR}{dt} \sim R_0$, Closure time independent of R_0
- Good agreement with experiments

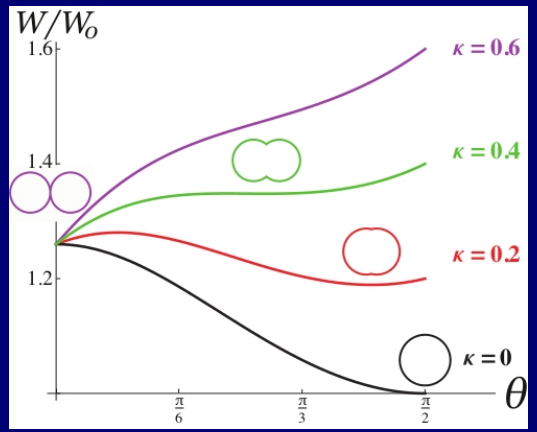


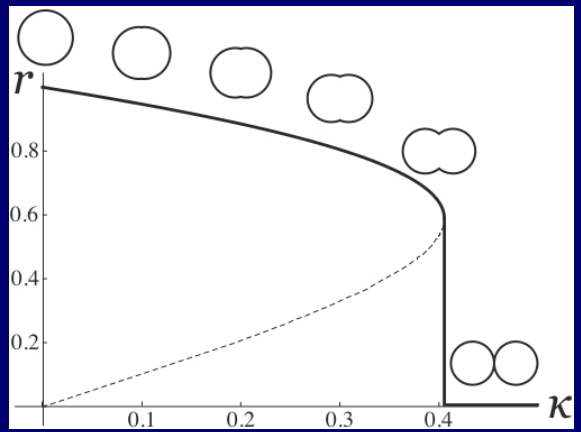
Qualitative interpretation



- Cell tension $T = \frac{e\zeta\Delta\mu}{2}$
- Line tension $\lambda = \int ds(T(s) - T_p) \sim w\delta T$
- Dimensionless number $\kappa \sim \lambda/(2T_pR_0)$

Discontinuous closure transition



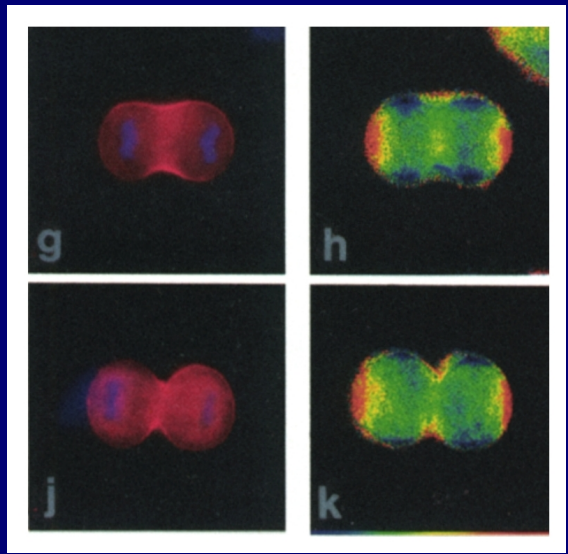


- Linear constriction if dissipation dominated by cortical flow

Outline

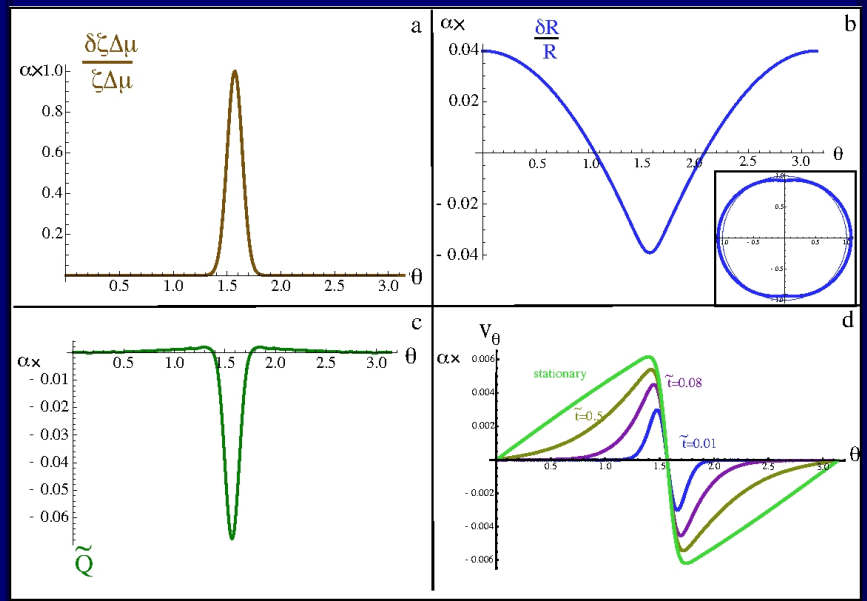
Furrow formation during cytokinesis G.Salbreux

Cleavage furrow Y. Wang et al.



- Enhanced myosin activity at the equator
- Actin flow
- Flow alignment coupling

Active gel theory



- C.Elegans embryos S.Grill

Summary

- Cortical Actin layer as an active prewetting transition
  - Actin polarization
  - Stability of the cortical layer
  - Dynamics of the cortical layer
- Cytokinesis
  - Actin polarization
  - Blebs
  - Cell oscillations
  - Asymmetric cell division