Universitat
Pompeu Fabra
Barcelona

Self-organization of proliferating cellular aggregates

Jordi Garcia Ojalvo
Dynamical Systems Biology lab
Department of Experimental and Health Sciences
Universitat Pompeu Fabra

E-mail: jordi.g.ojalvo@upf.edu
Web: http://dsb.upf.edu
Twitter: @jgojalvo

Universitat Pompeu Fabra
Barcelona

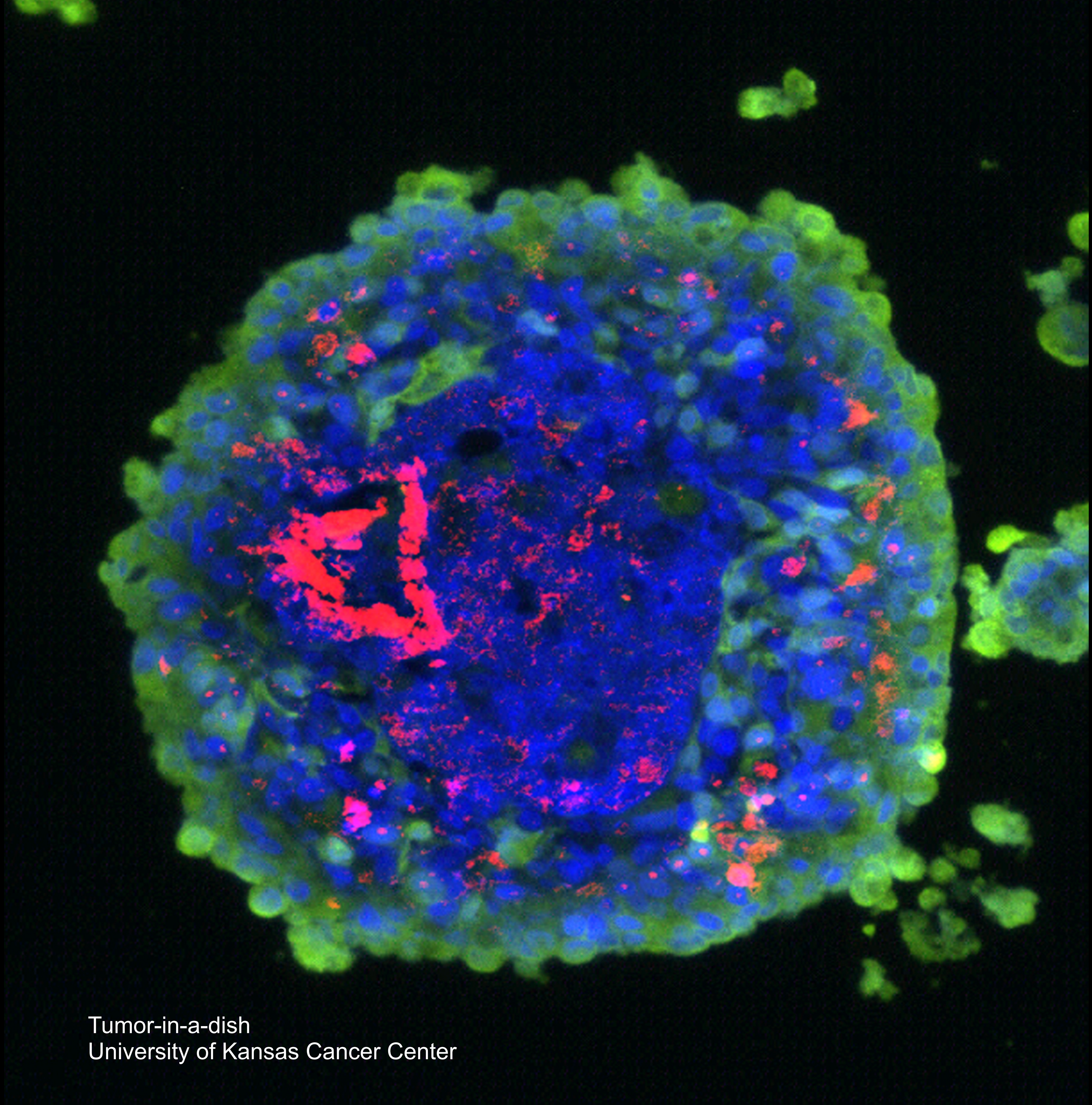
Self-organization of proliferating cellular aggregates

Marçal Gabaldà, Rosa Martínez-Corral (UPF)

Jintao Liu, Arthur Prindle, Jacy Humphries, Gürol Süel (UCSD)

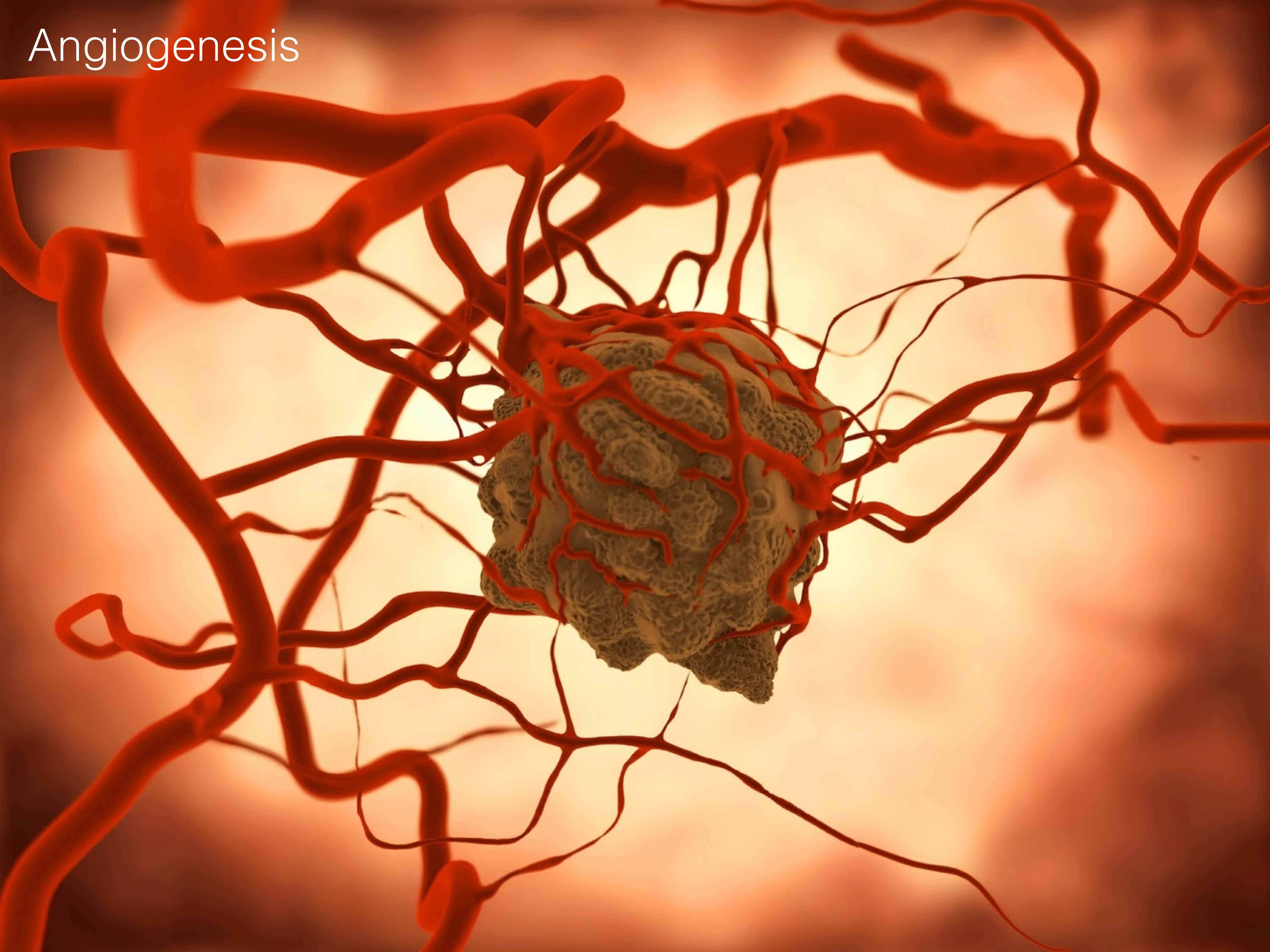
Munehiro Asally (Warwick)

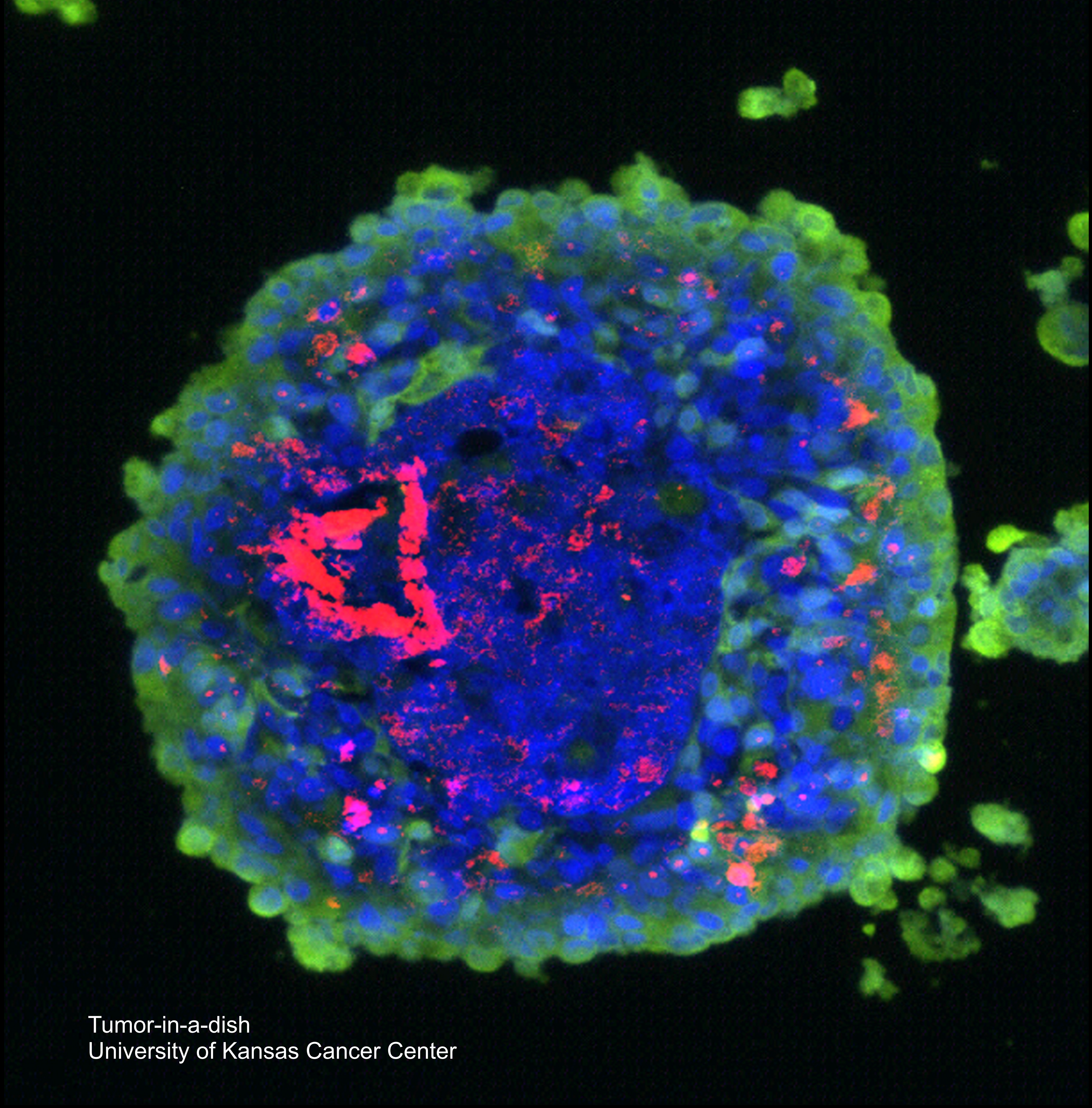
What makes populations of growing cells viable?



Tumor-in-a-dish
University of Kansas Cancer Center

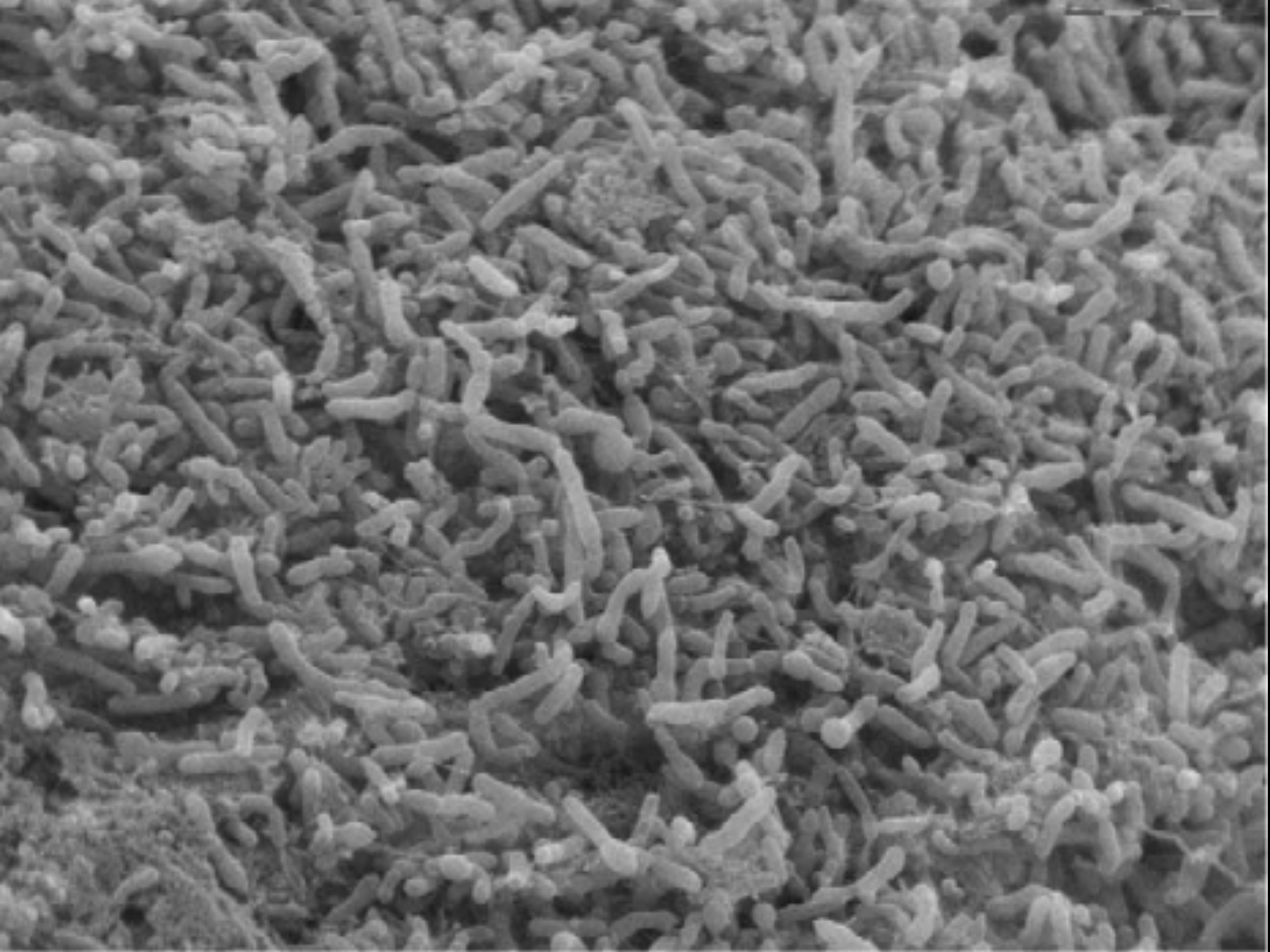
Angiogenesis



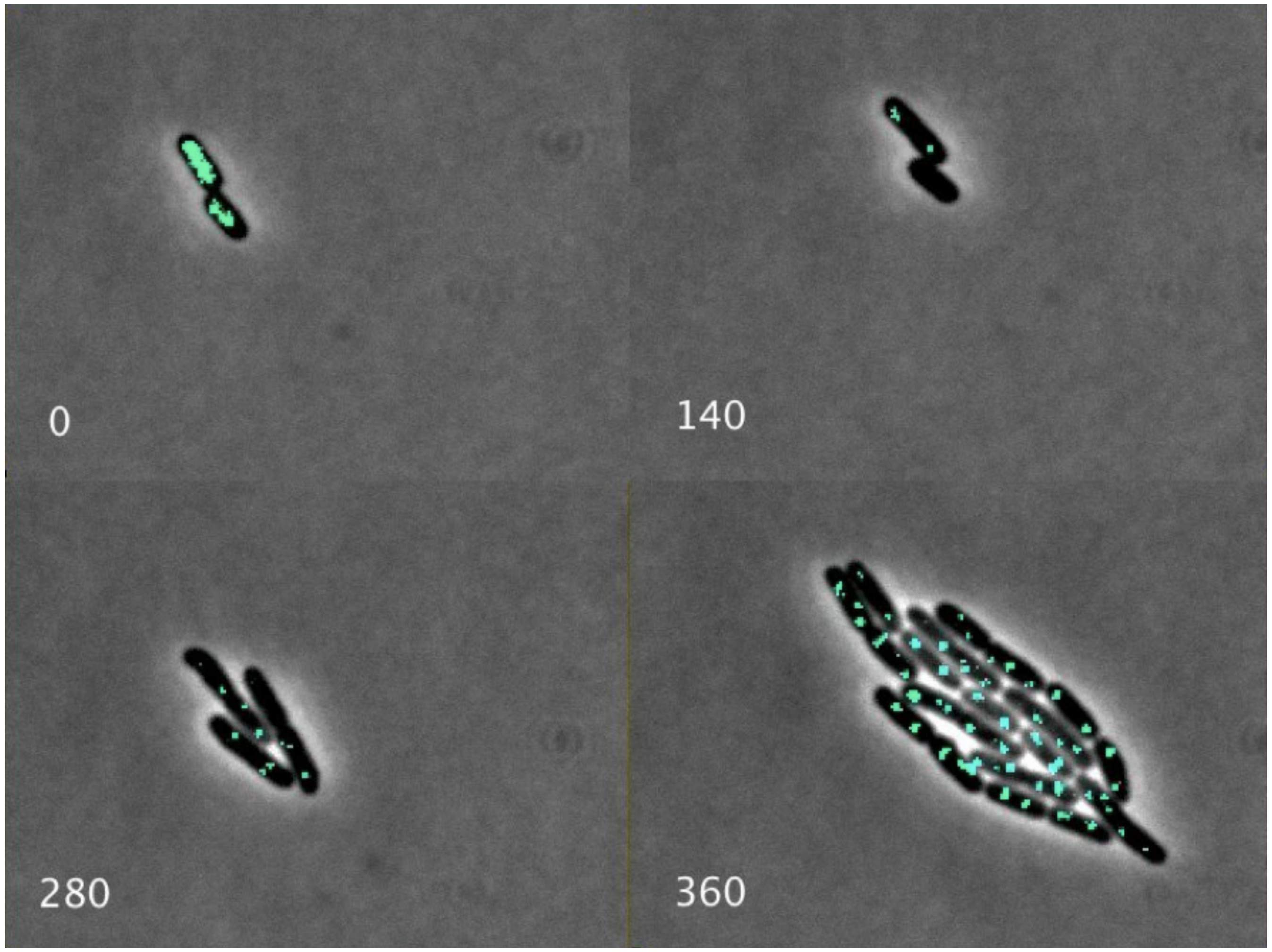

Tumor-in-a-dish
University of Kansas Cancer Center

Bacterial biofilm (*Bacillus subtilis*)


Jan Egil Kirkebø



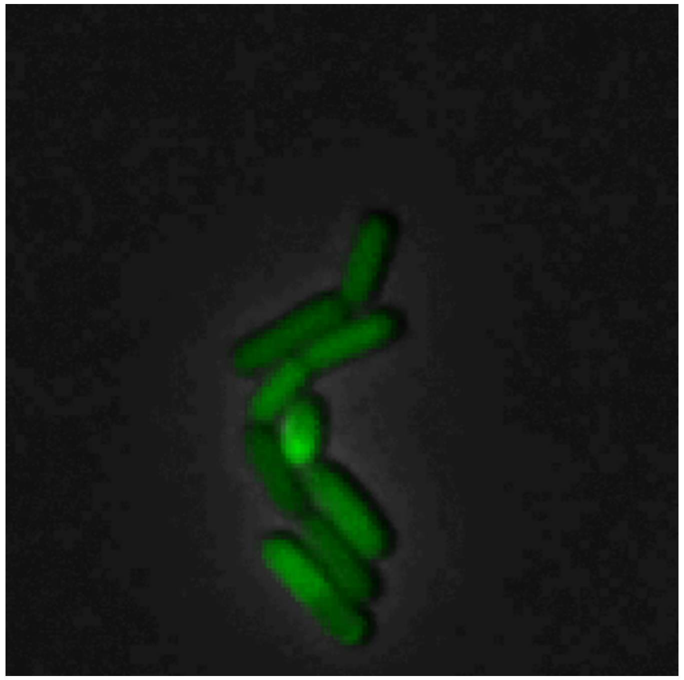
Studying bacteria in isolation



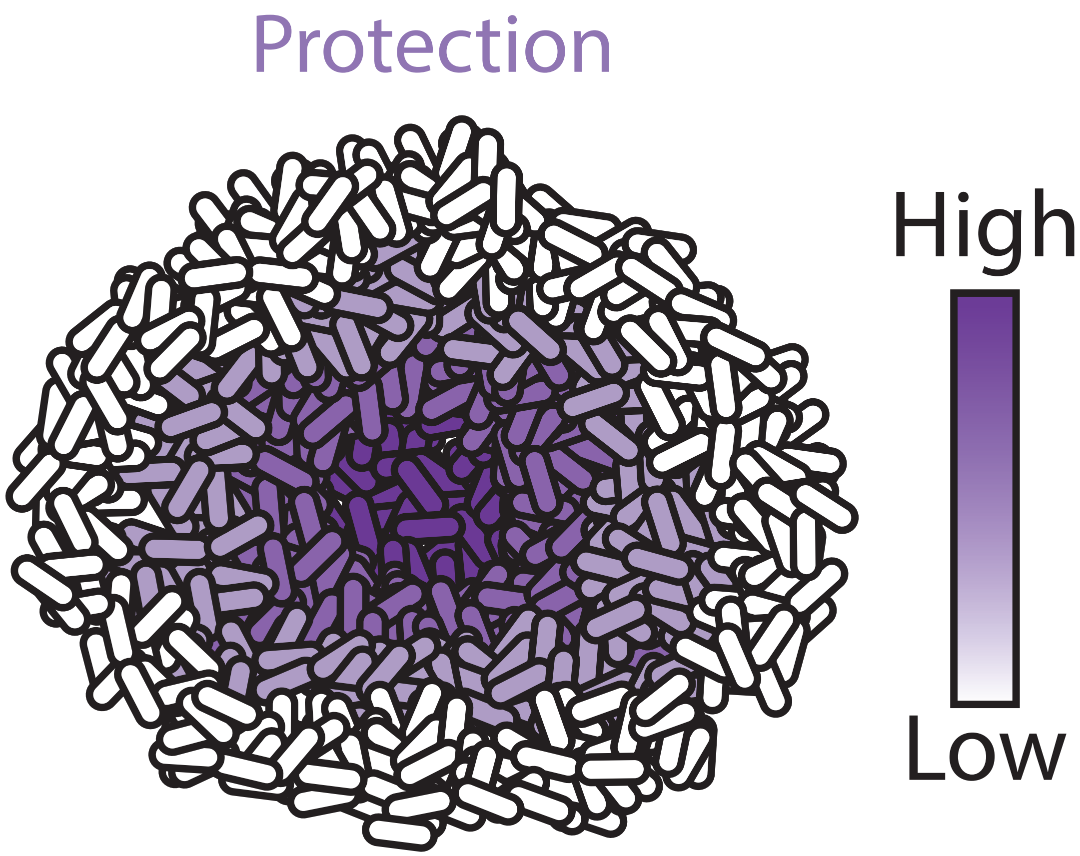
Leticia Galera

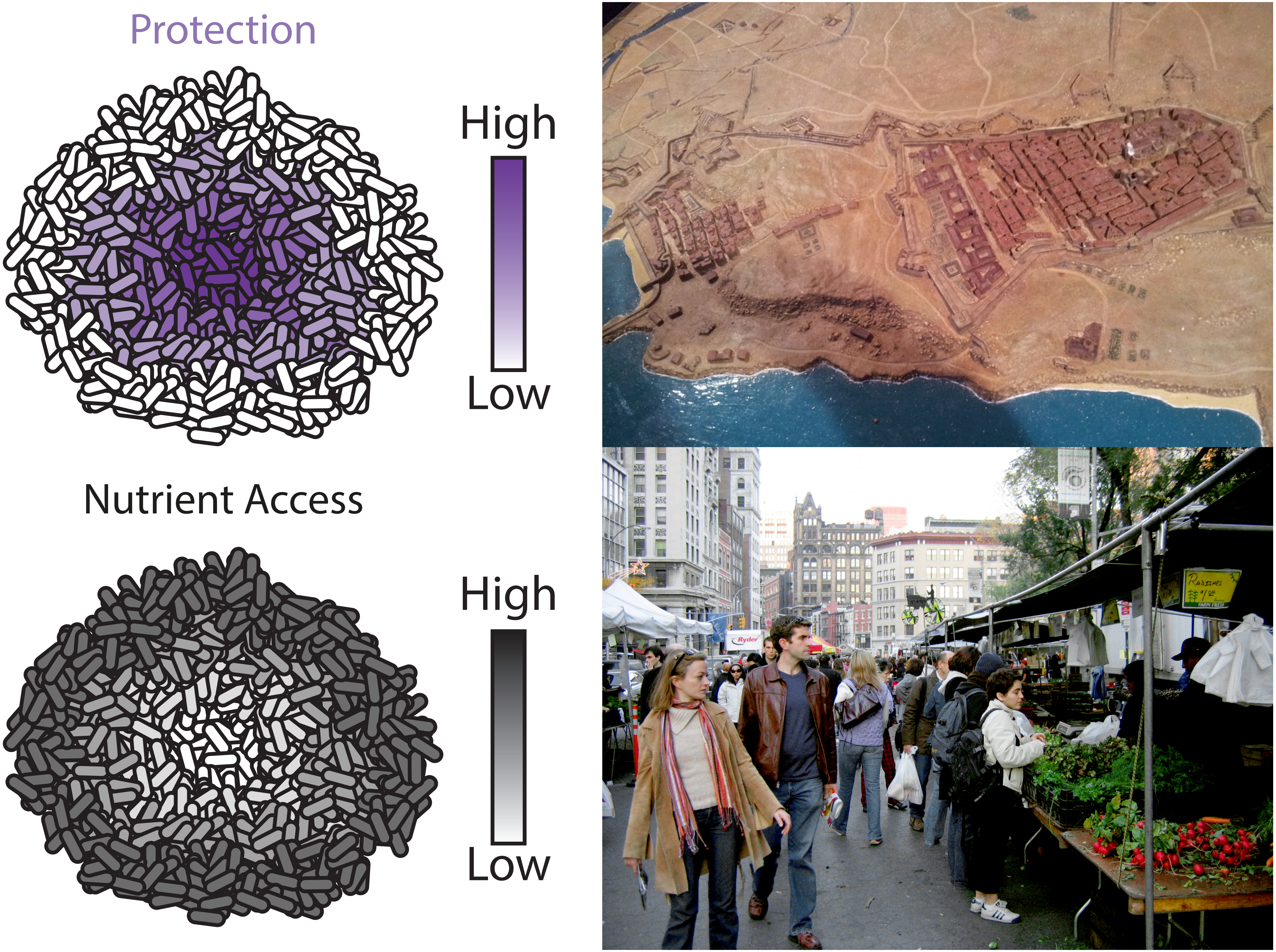
Dynamics of single bacteria under stress

sigB activity pulses
[Locke et al, Science, 2011]

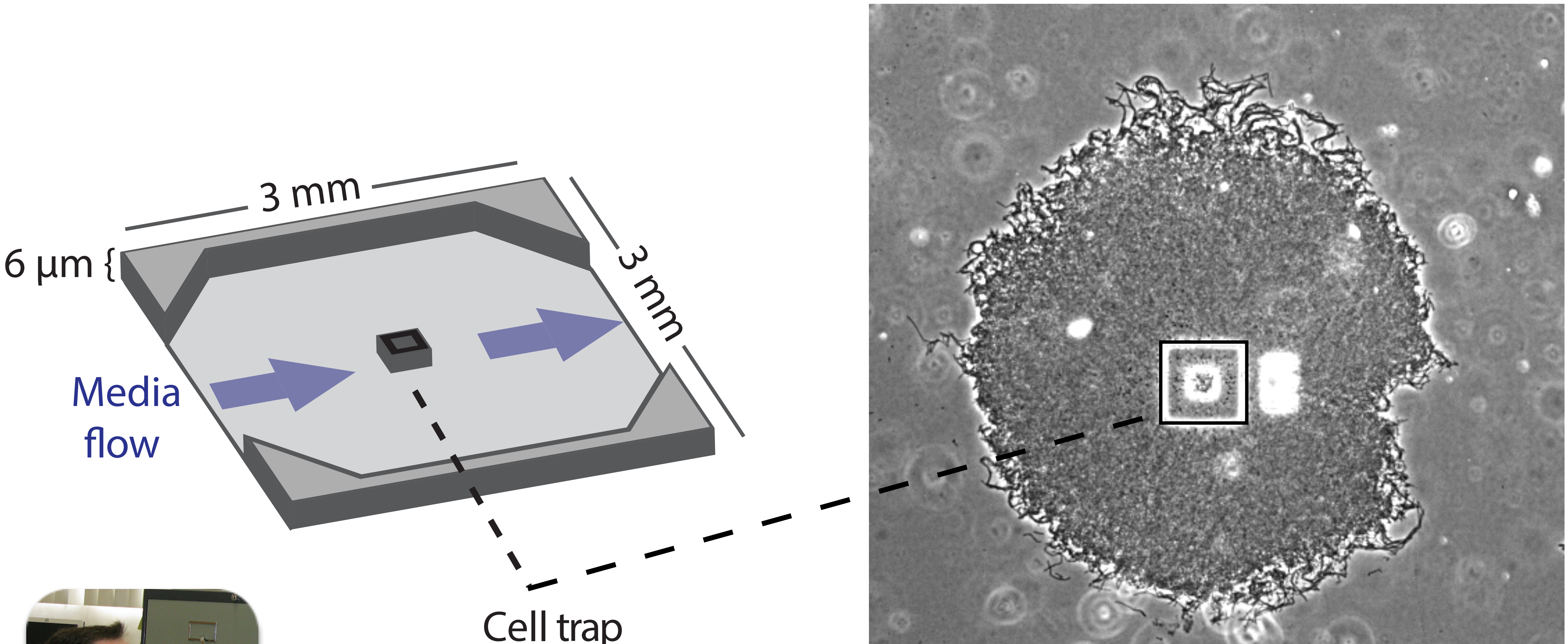


genetic competence
[Suel et al, Nature, 2006]

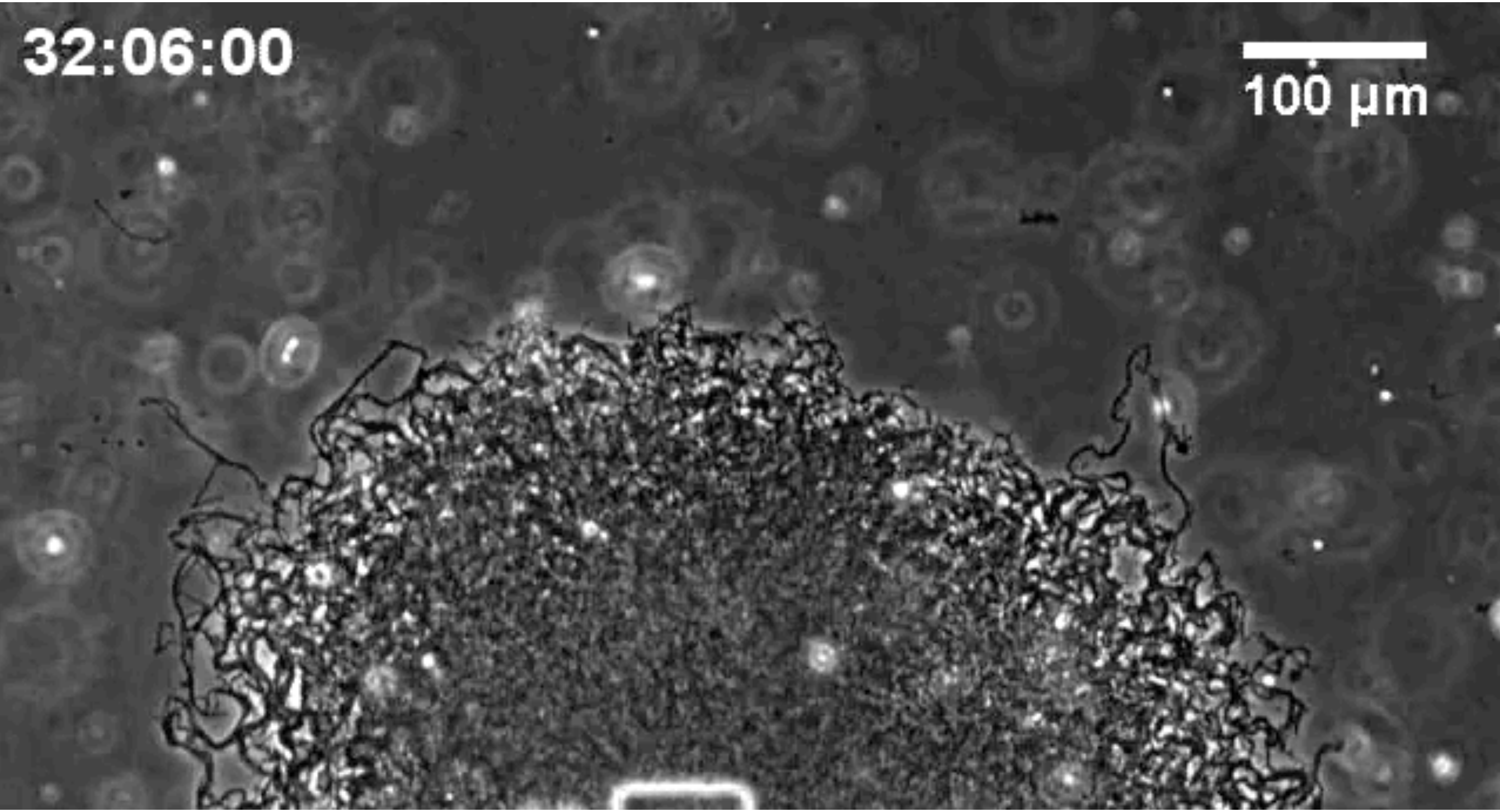

Protection
High
Low


Protection
High
Low
Nutrient Access
High
Low
Ryder

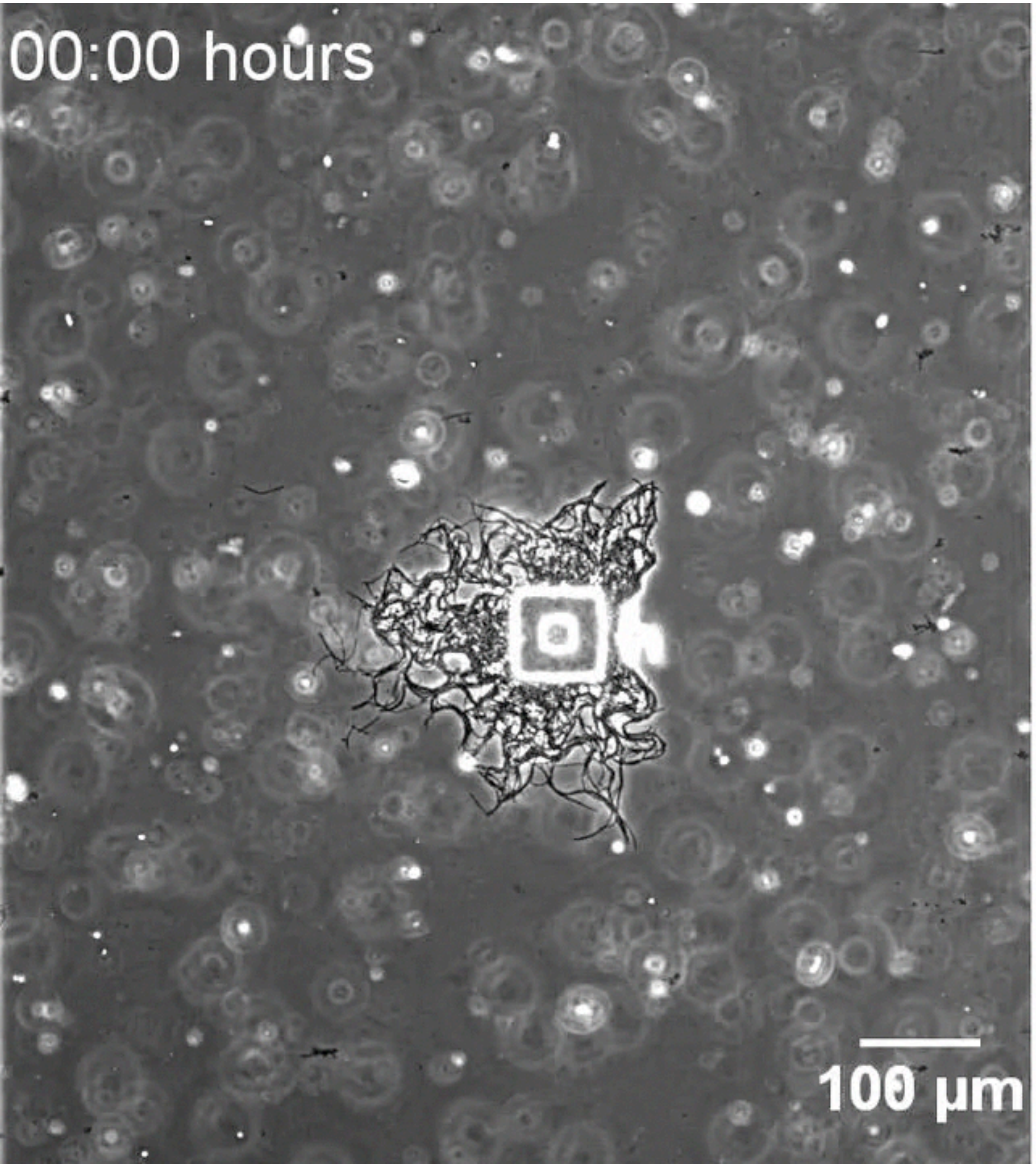
A microfluidics chip for 2D biofilm monitoring

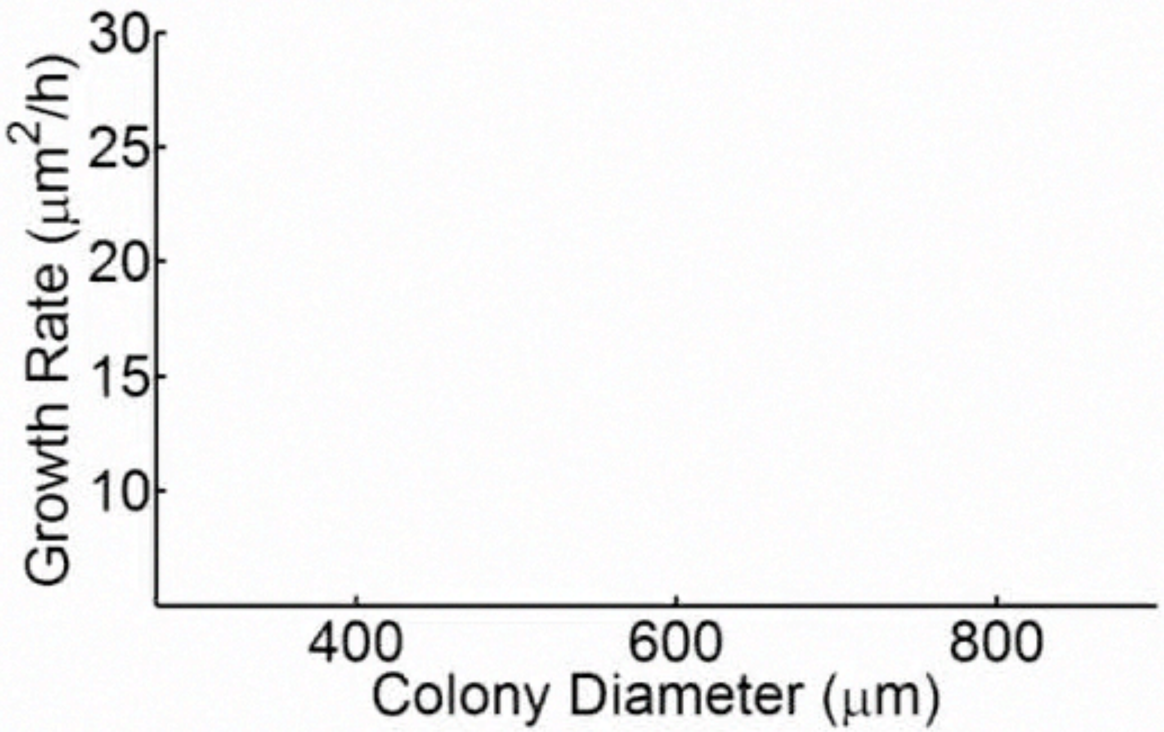


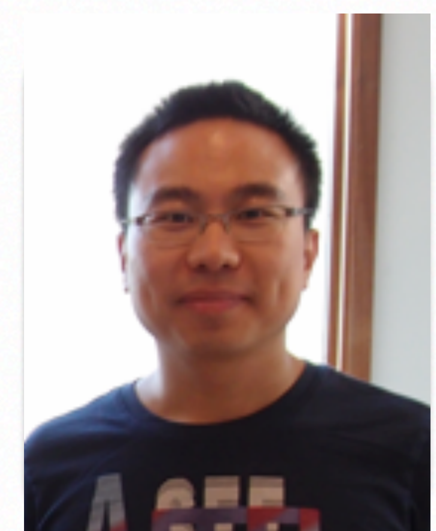
Gürol Süel



Liu et al, Nature **523**, 550-554 (2015)



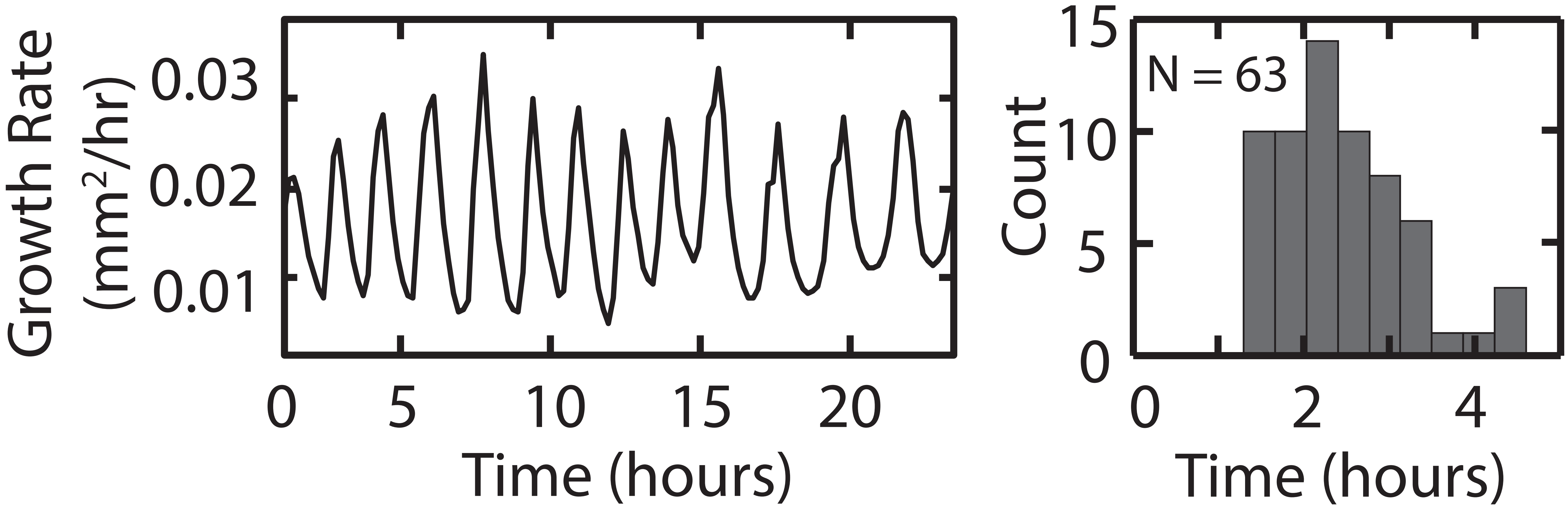




Jintao Liu

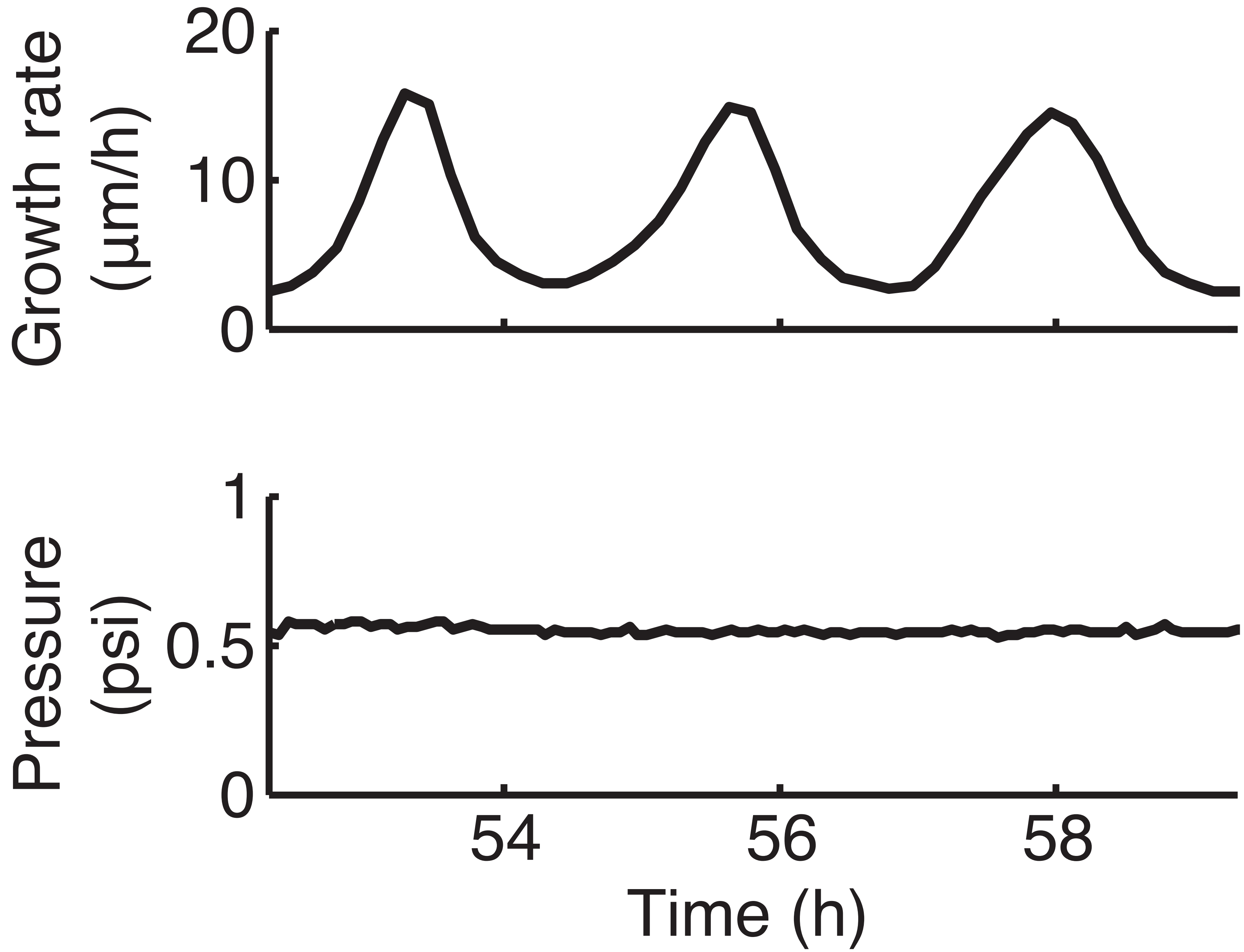
Liu et al, Nature **523**, 550-554 (2015)

The oscillations persist for very long time

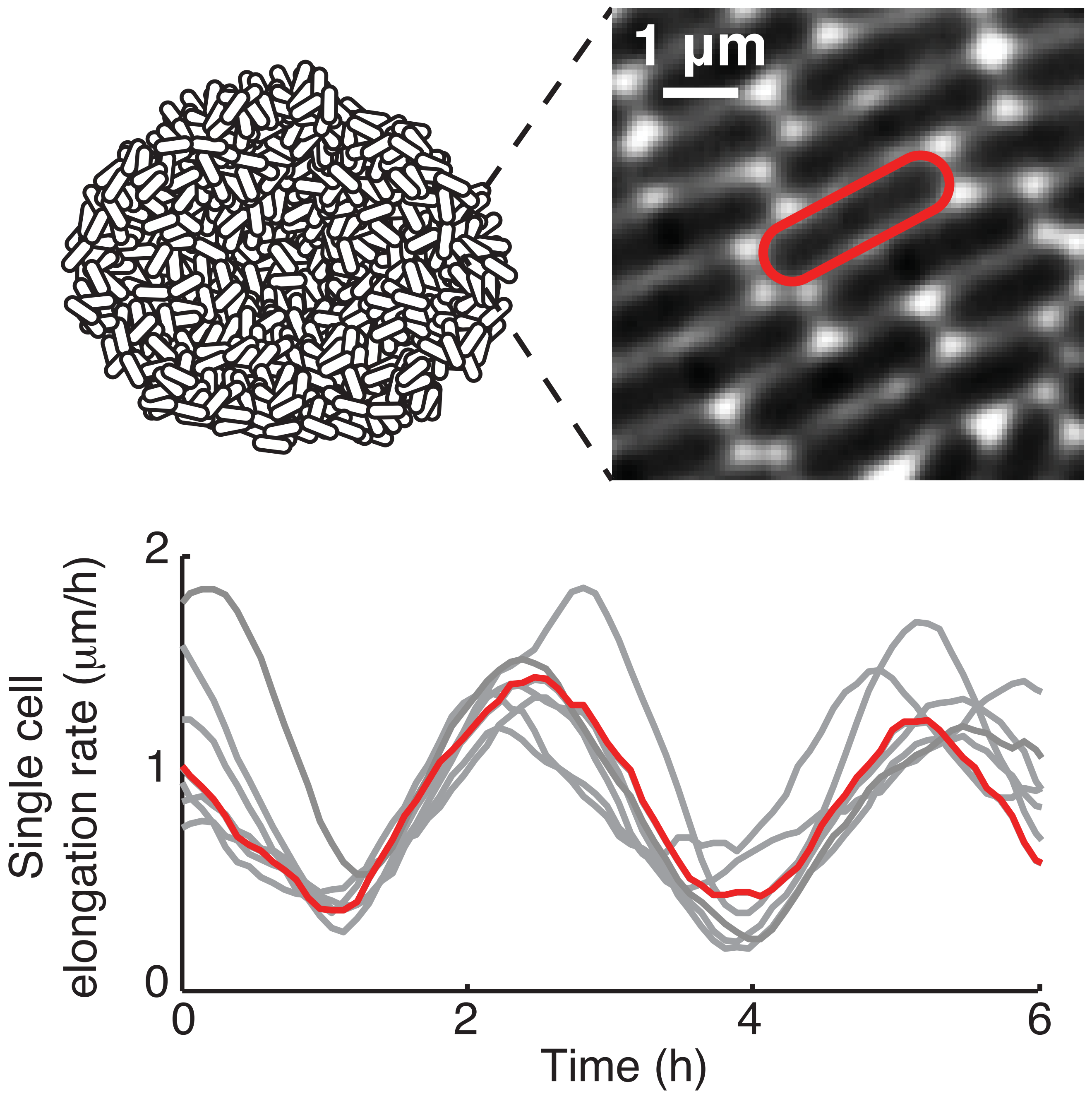


Liu et al, Nature **523**, 550-554 (2015)

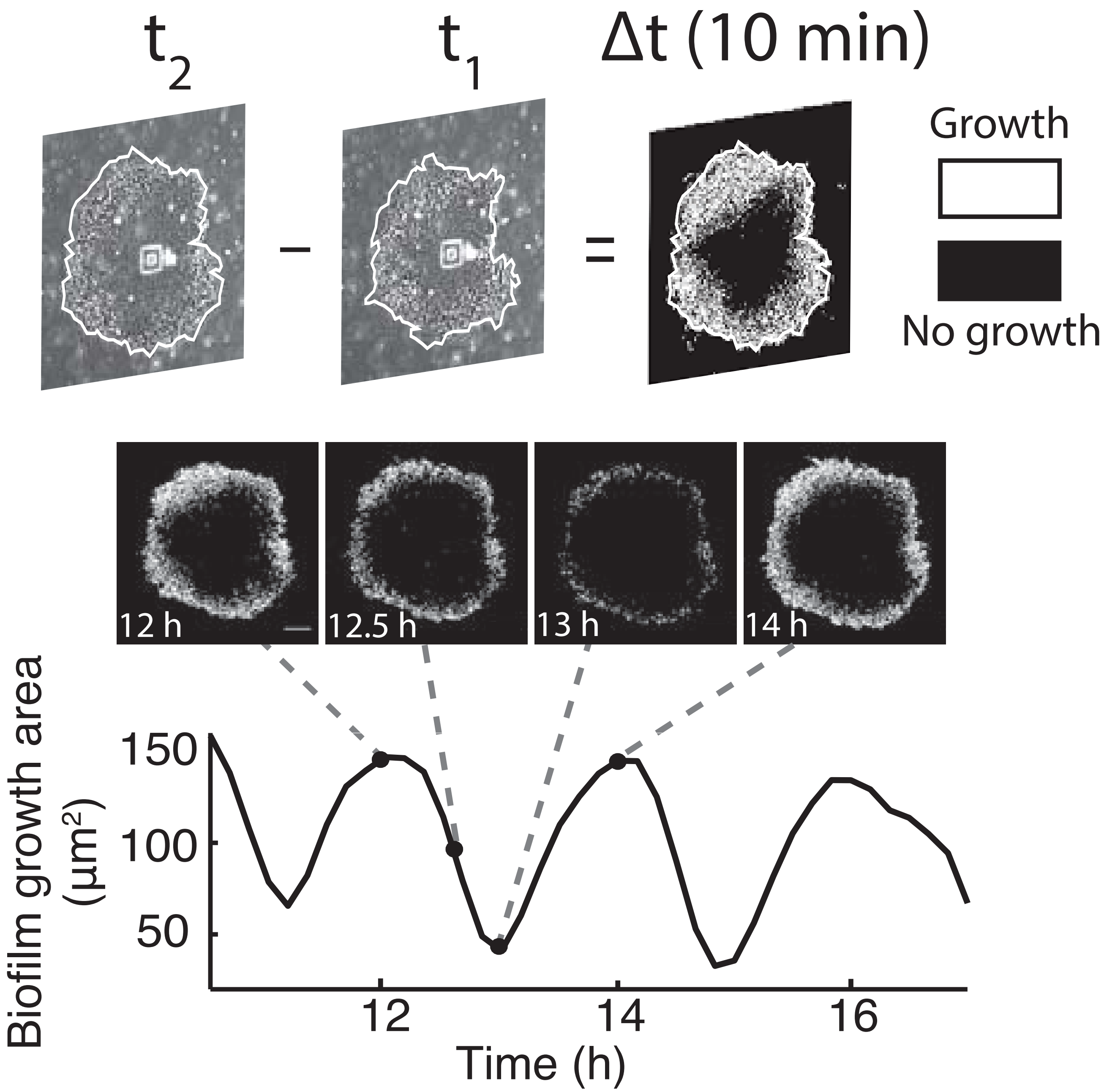
The oscillations are not due to the flow



The elongation rate of peripheral cells oscillates



Where does growth stop within the biofilm?



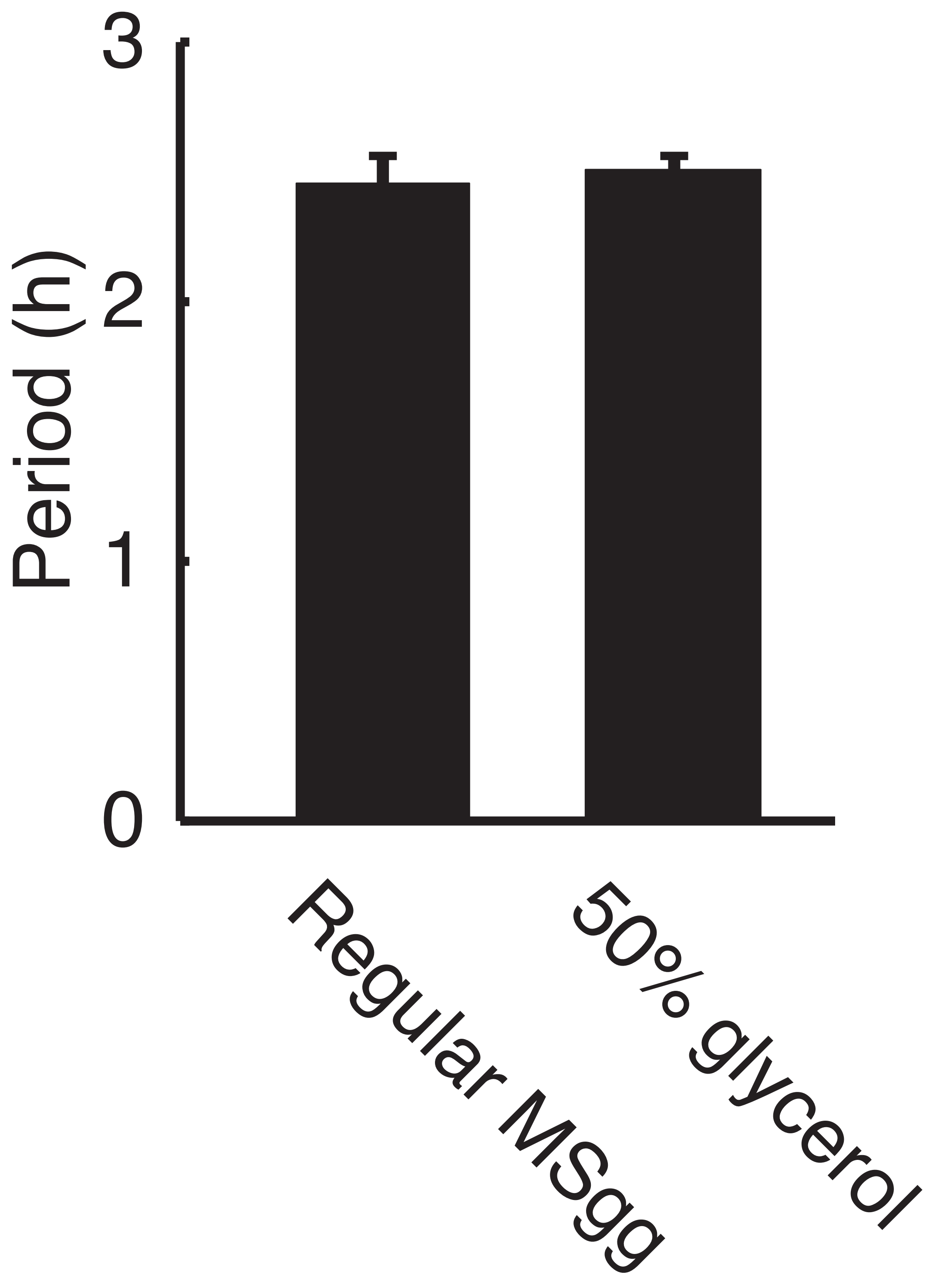
What causes peripheral cells to stop growing?

- Growth medium: MSgg (minimal salts glycerol glutamate)
  - **pH buffers**: potassium phosphate, MOPS
  - **Salts**: magnesium chloride, calcium chloride, manganese chloride, iron chloride, zinc chloride, thiamine hydrochloride
  - **Glycerol**
  - **Glutamate**

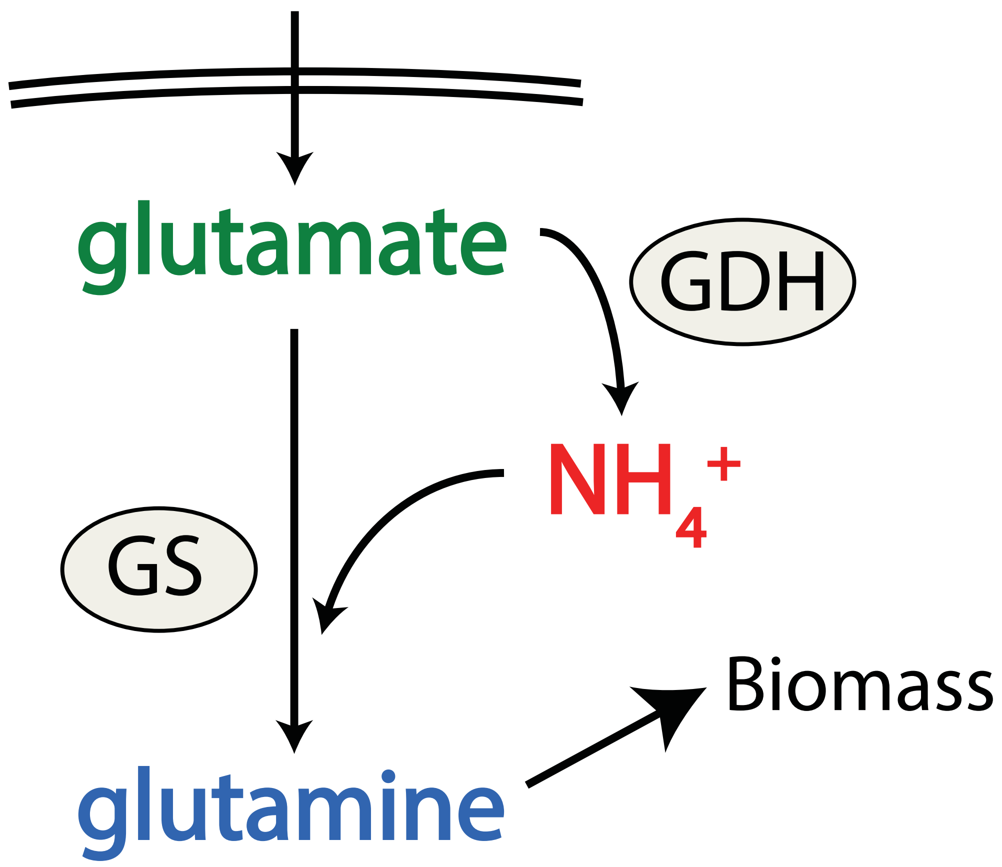
What causes peripheral cells to stop growing?

- Growth medium: MSgg (minimal salts glycerol glutamate)
  - **pH buffers**: potassium phosphate, MOPS
  - **Salts**: magnesium chloride, calcium chloride, manganese chloride, iron chloride, zinc chloride, thiamine hydrochloride
  - **Glycerol** → carbon source
  - **Glutamate** → nitrogen source

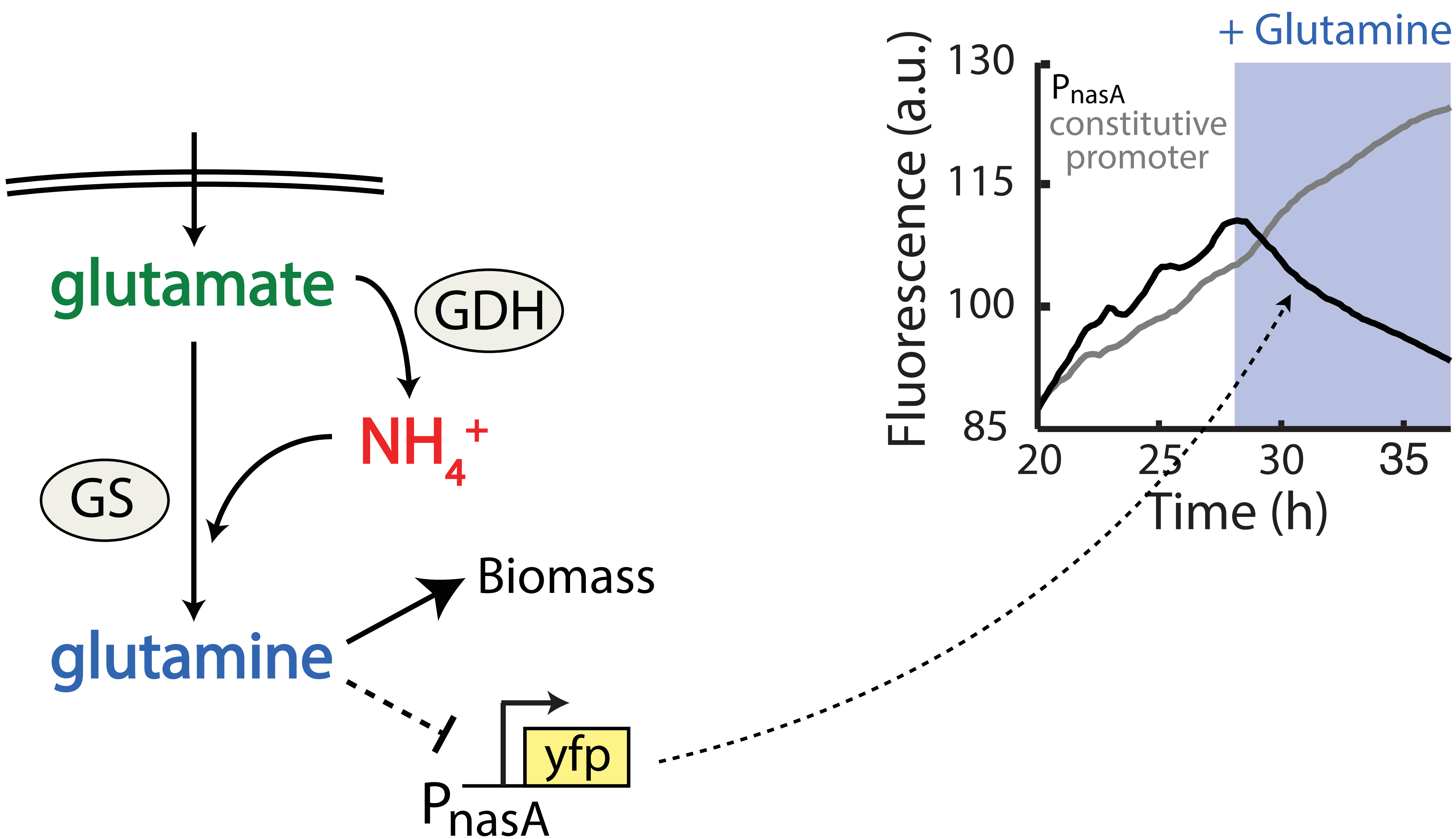
Carbon limitation does not affect oscillations



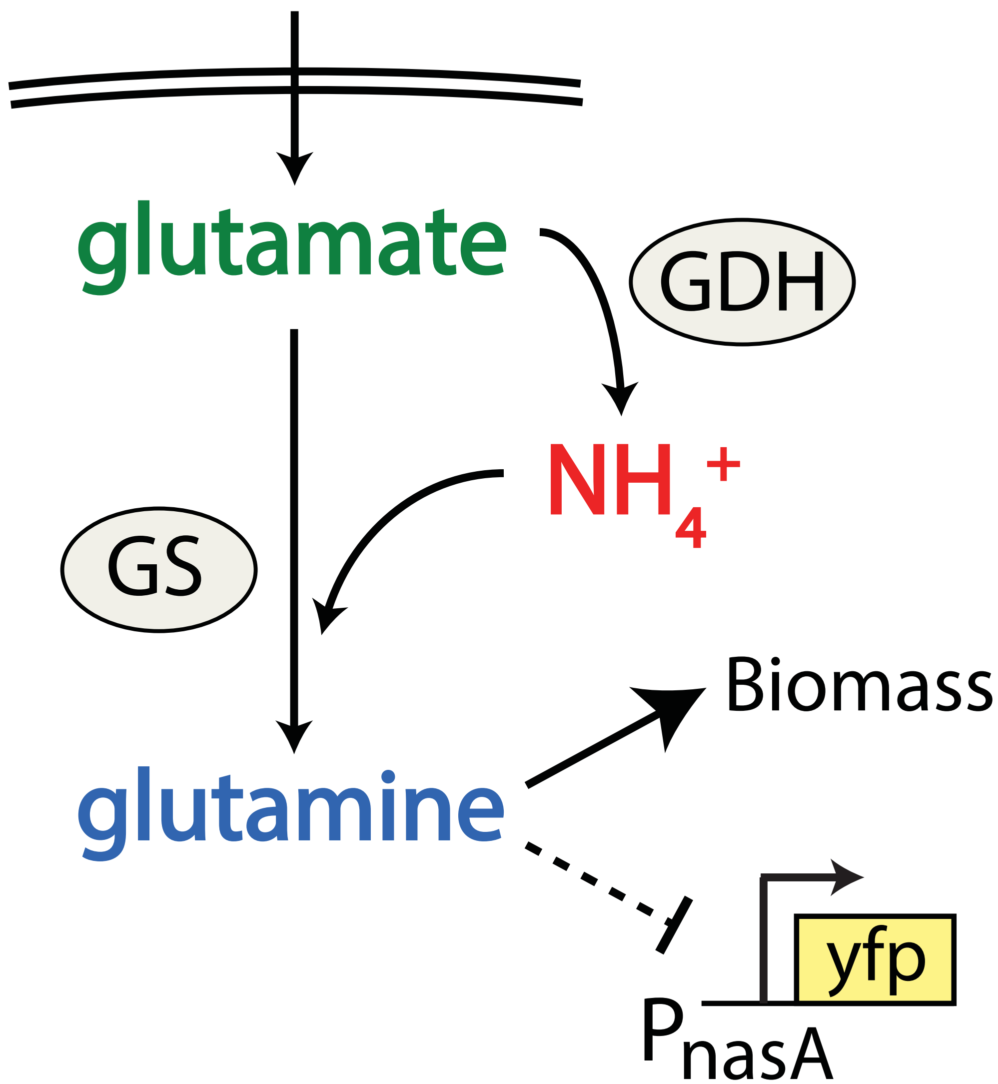
Nitrogen metabolism

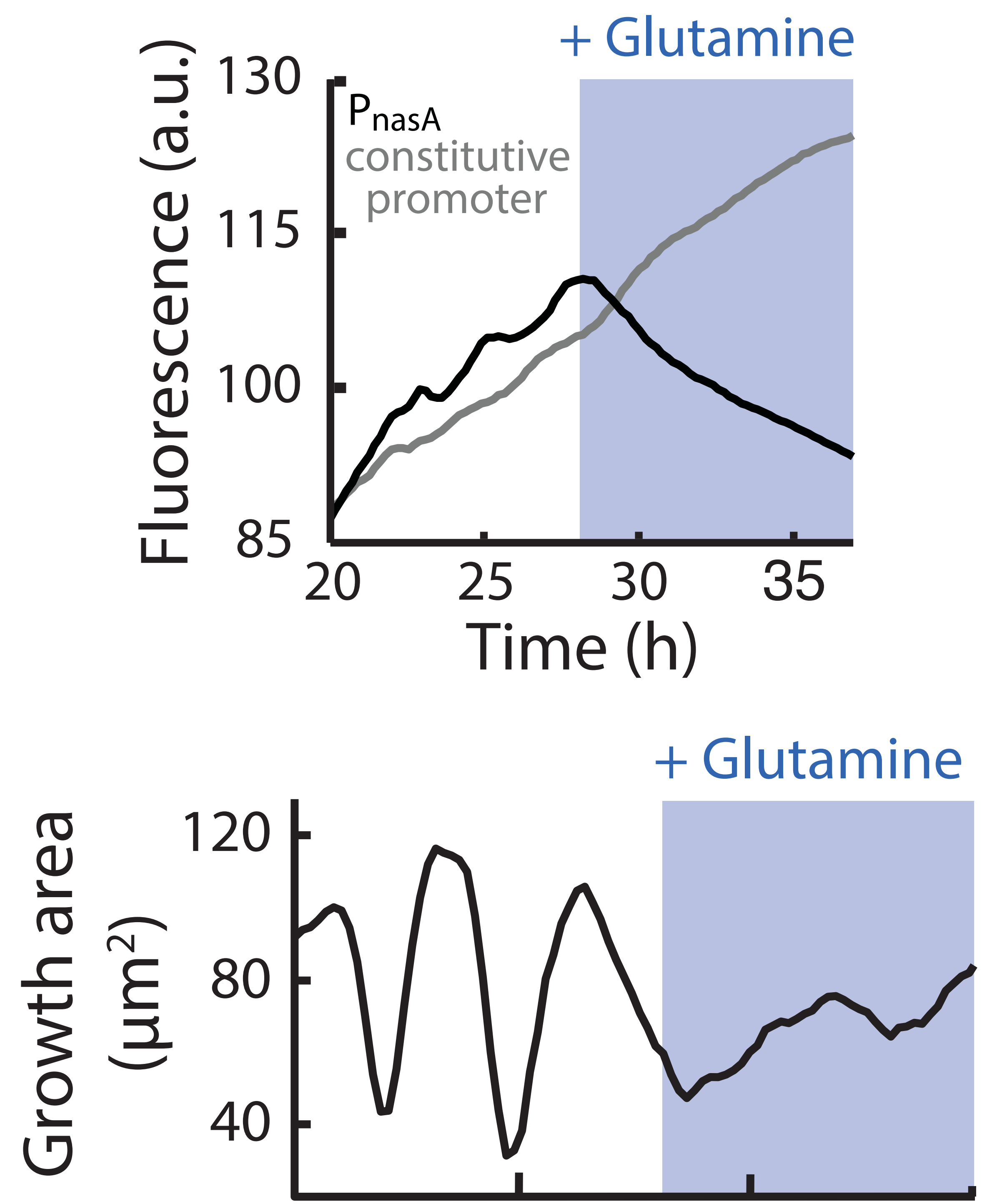


Biofilms experience glutamine limitation during growth

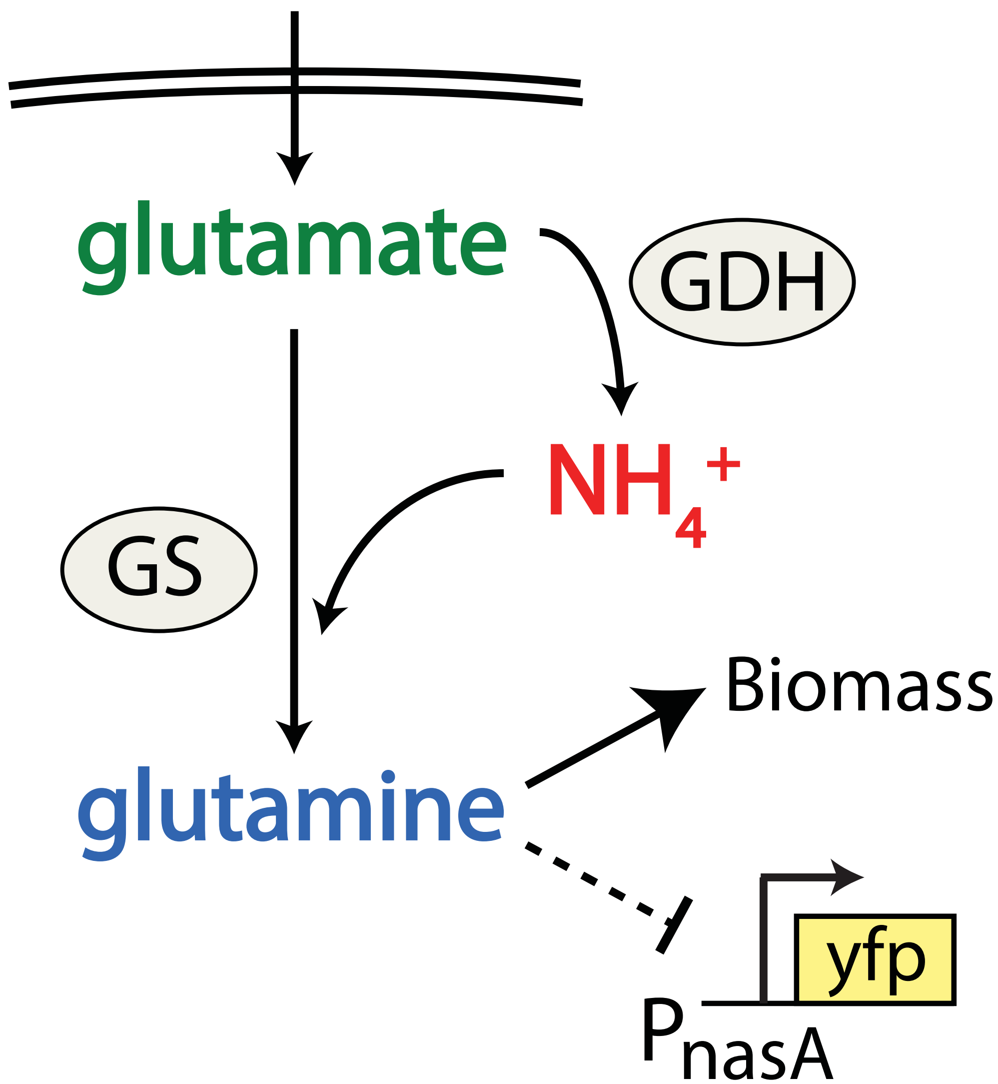


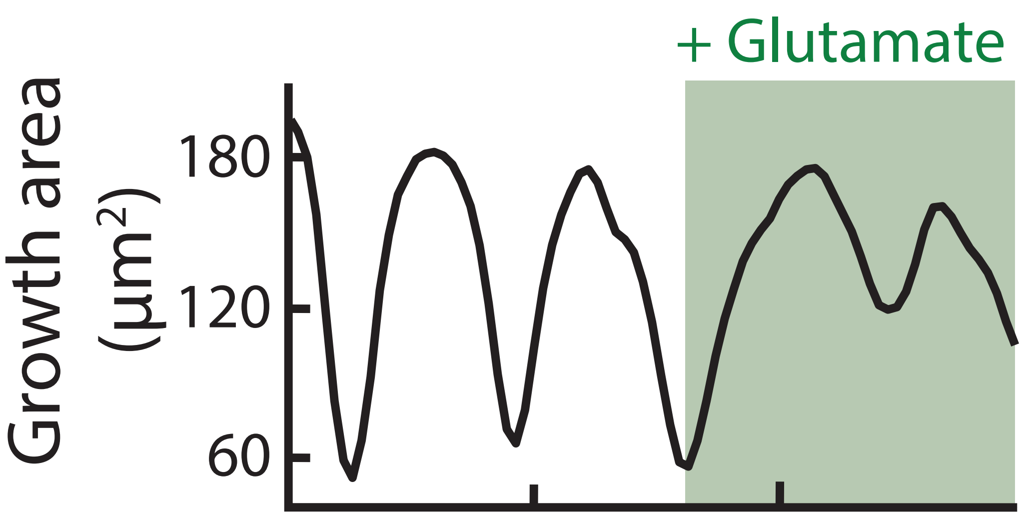
Addition of exogenous glutamine stops oscillations



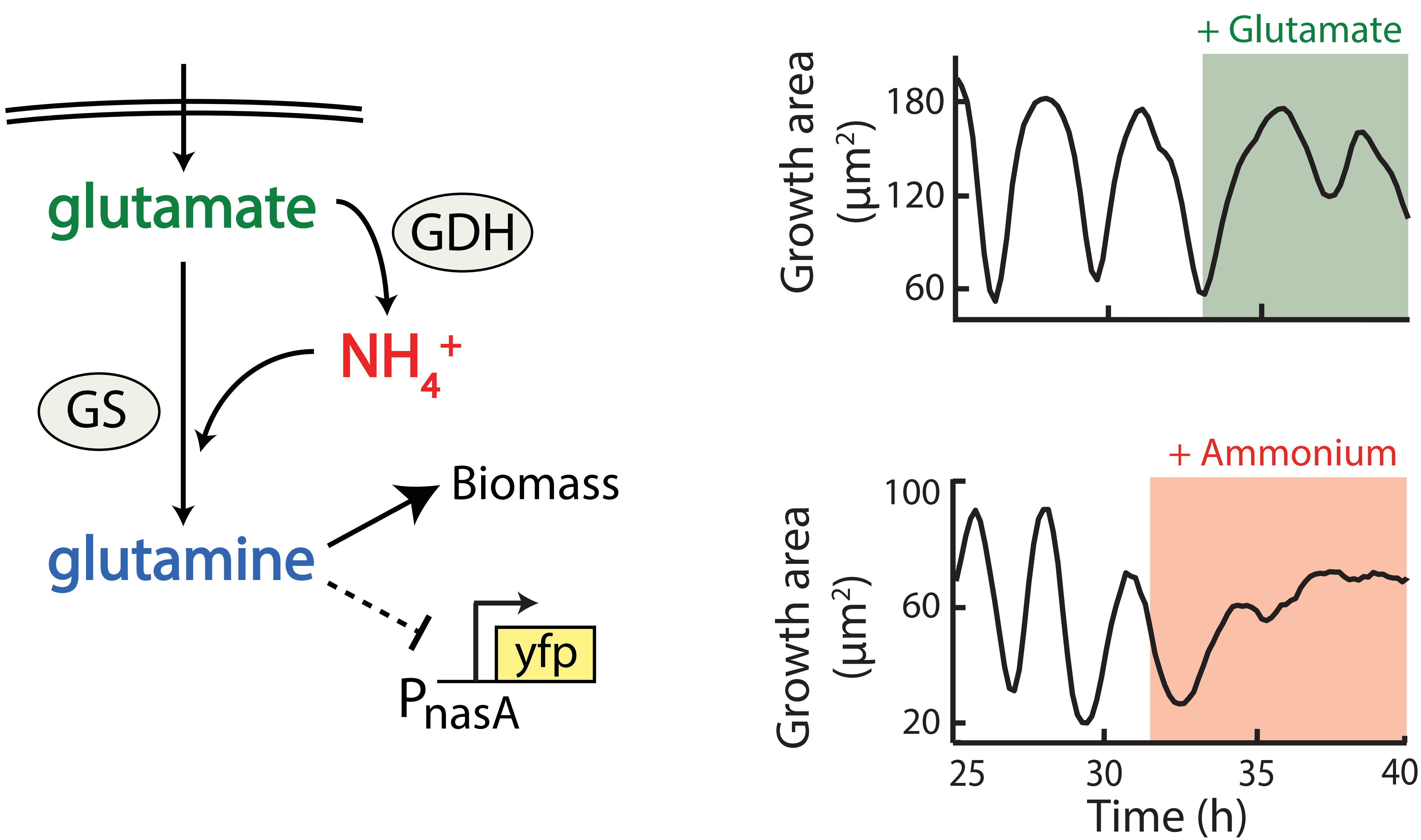


…but glutamate is not limiting





It’s ammonium that is limiting!

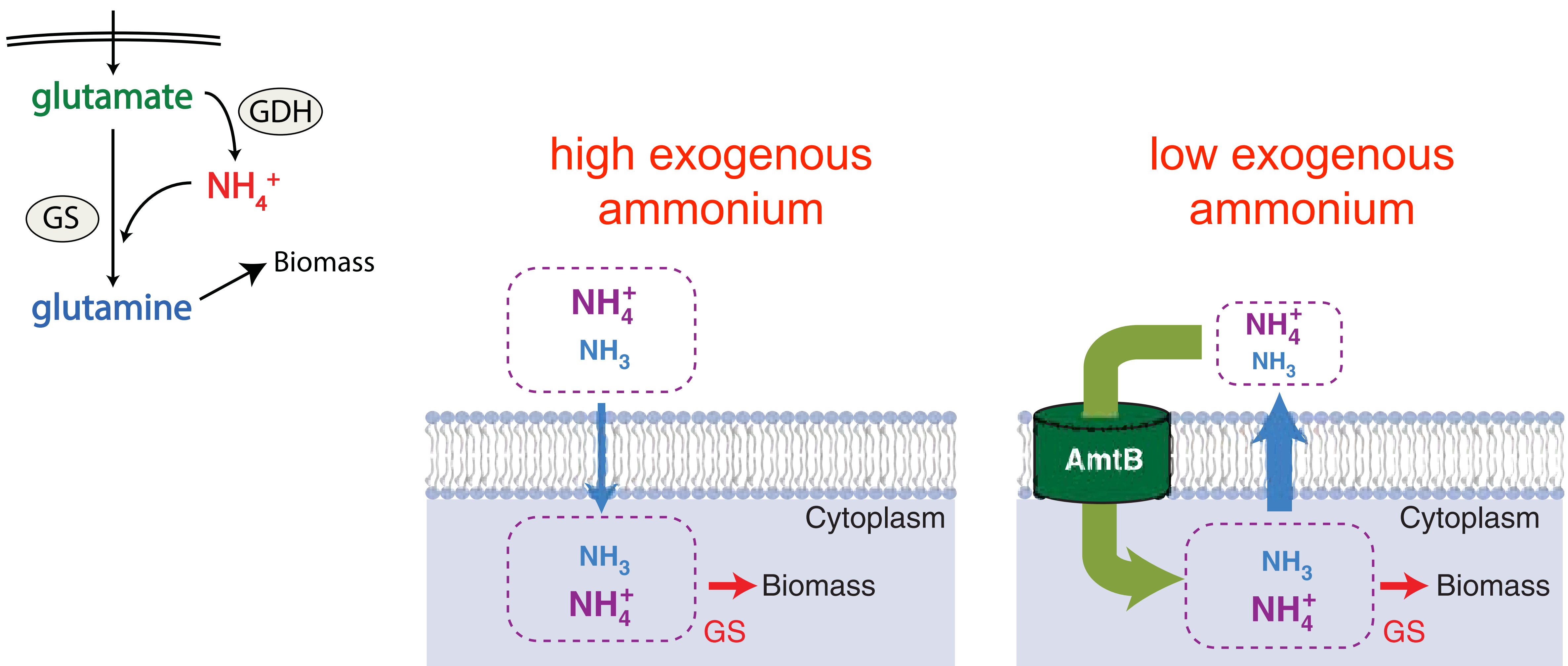


Molecular Systems Biology 8; Article number 616; doi:10.1038/msb.2012.46
Citation: *Molecular Systems Biology* 8:616

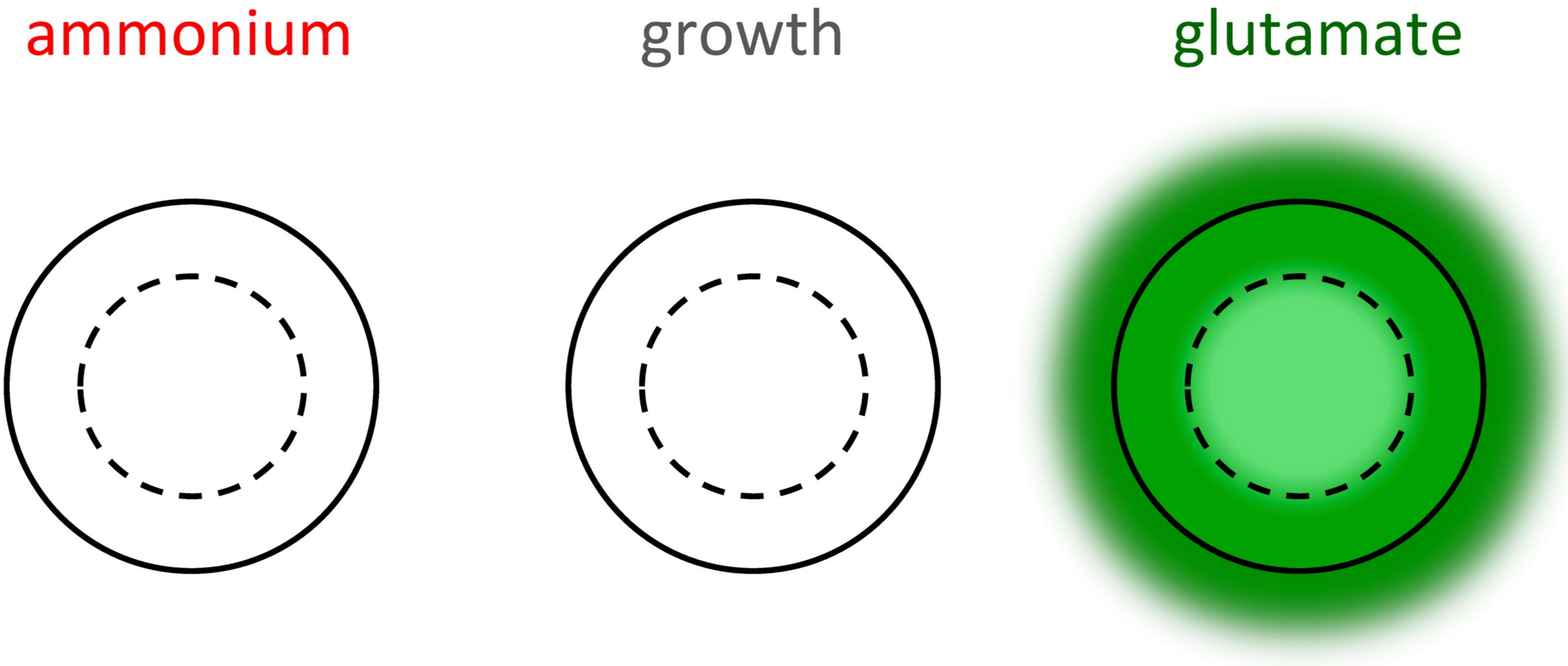
www.molecularsystemsbiology.com

Need-based activation of ammonium uptake in *Escherichia coli*

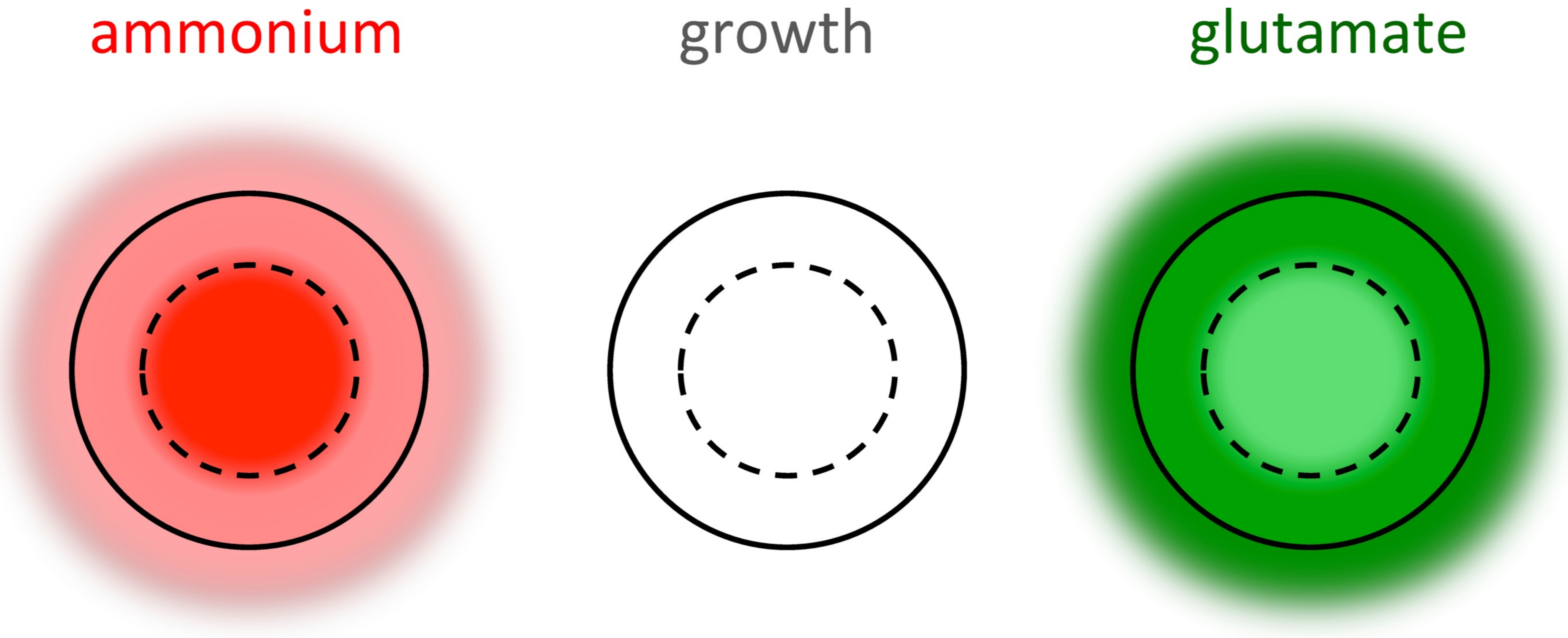
Minsu Kim[1], Zhongge Zhang[2], Hiroyuki Okano[1], Dalai Yan[3], Alexander Groisman[1,*] and Terence Hwa[1,2,4,*]



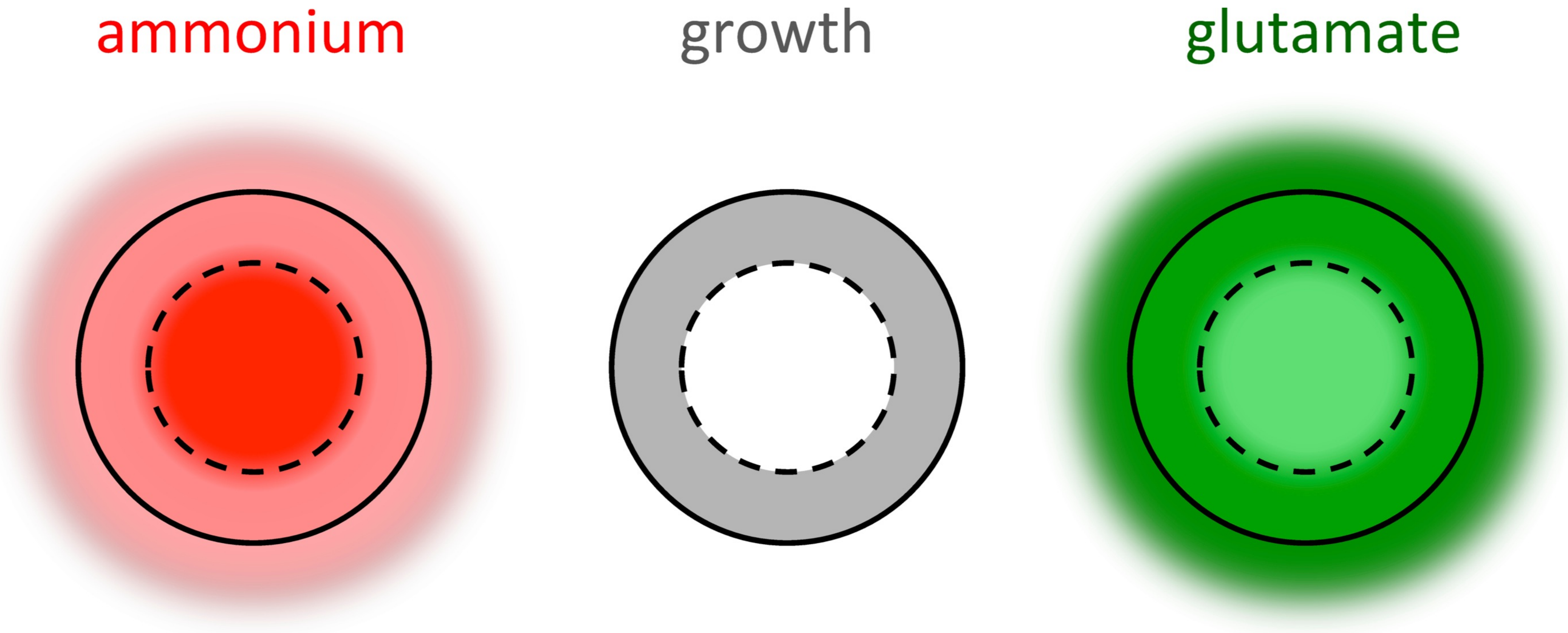
A metabolic tug-of-war between interior and periphery



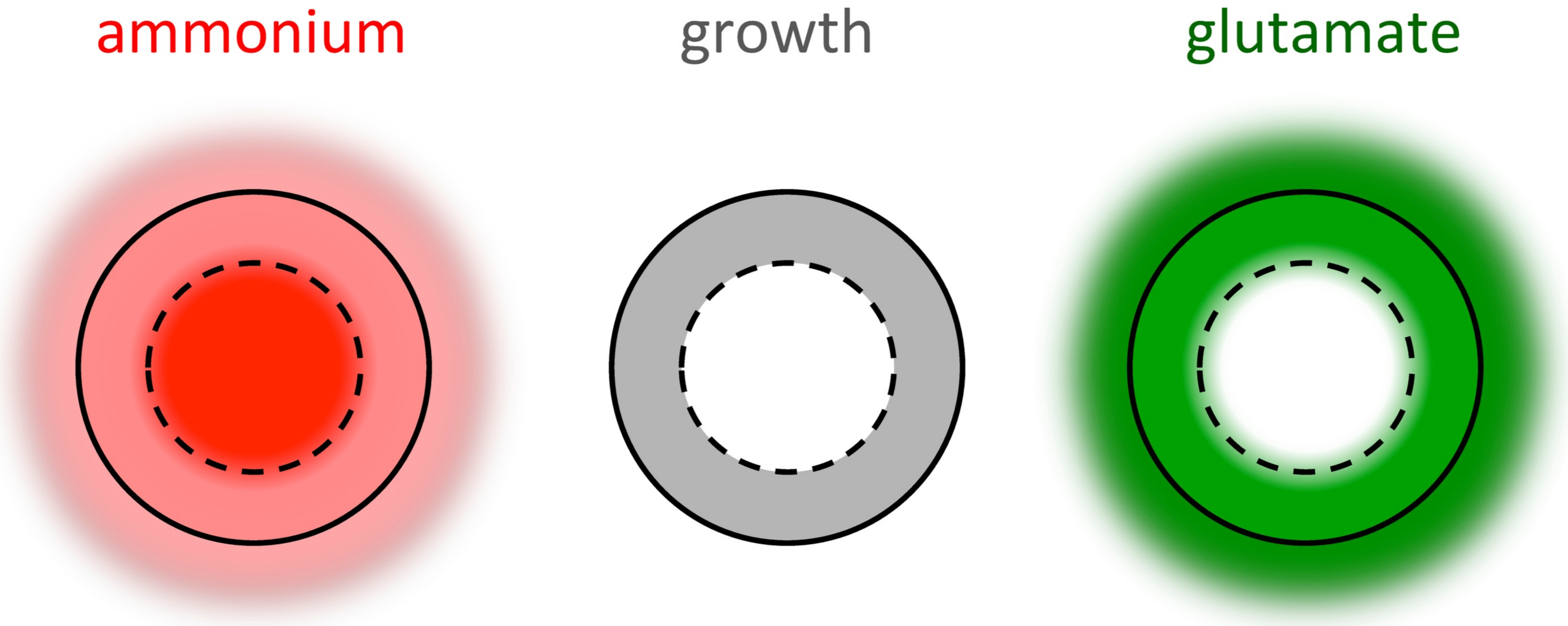
A metabolic tug-of-war between interior and periphery



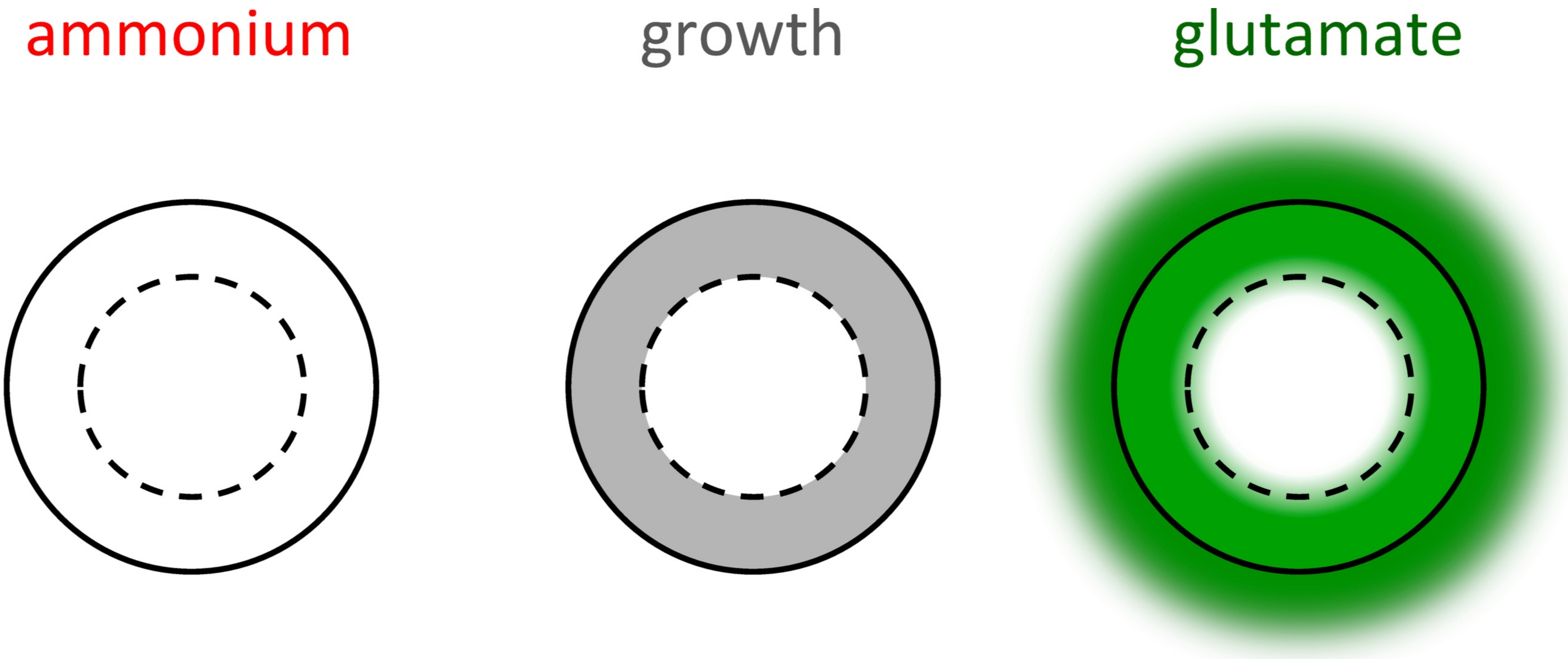
A metabolic tug-of-war between interior and periphery



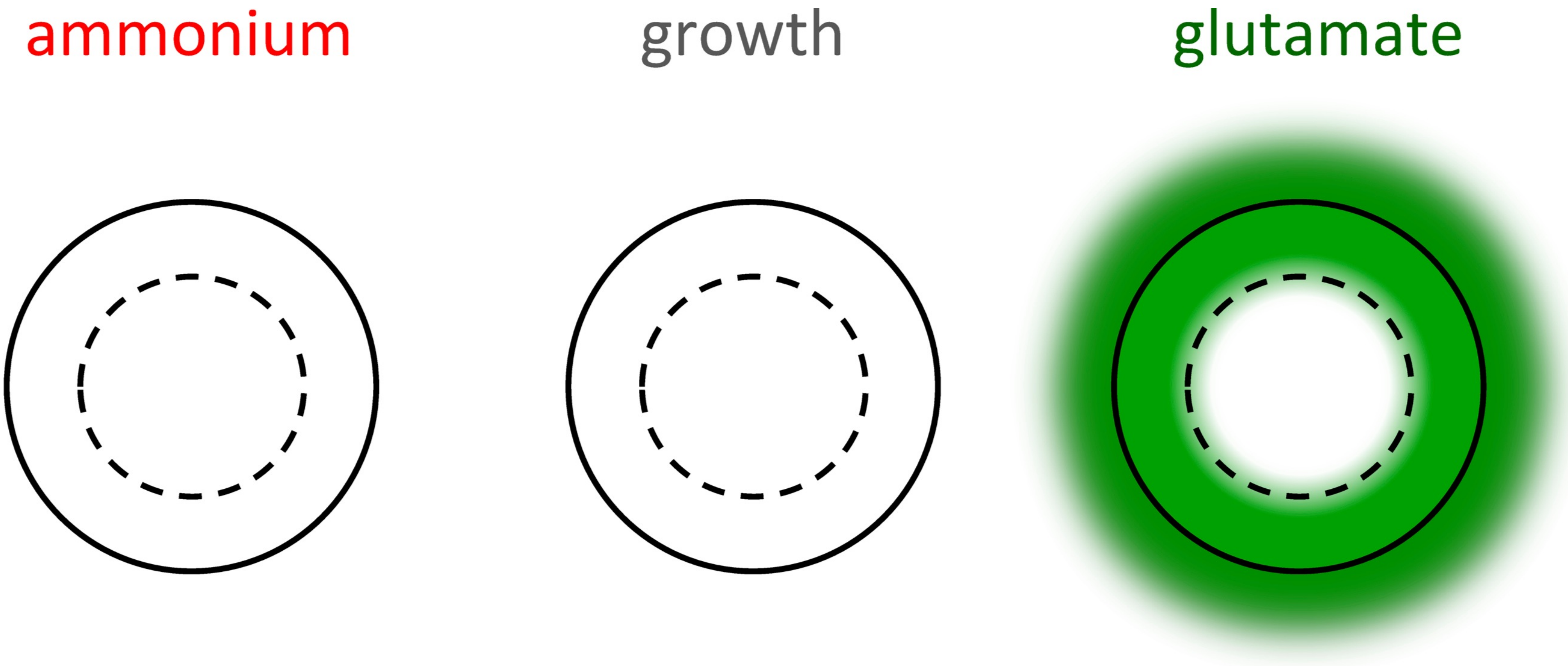
A metabolic tug-of-war between interior and periphery



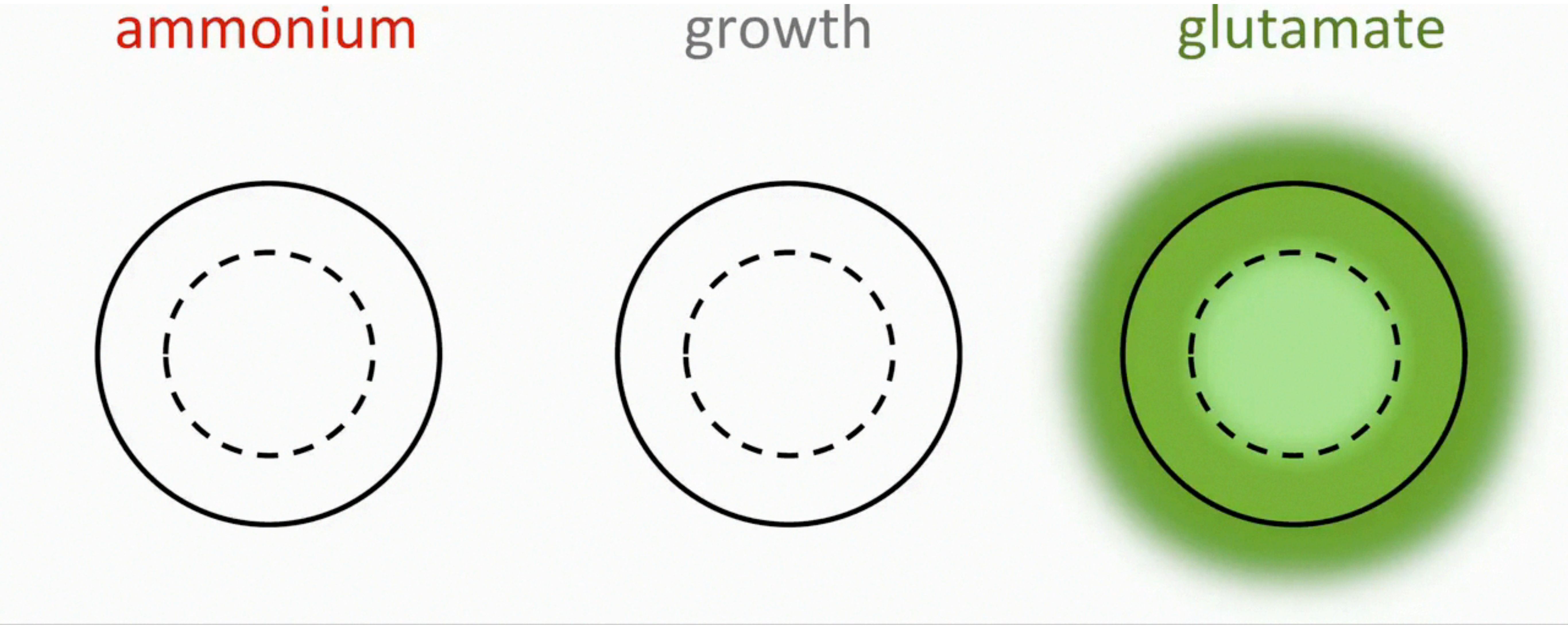
A metabolic tug-of-war between interior and periphery



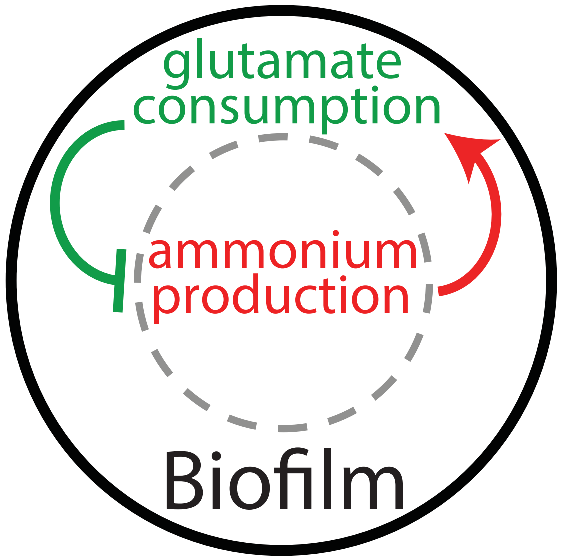
A metabolic tug-of-war between interior and periphery



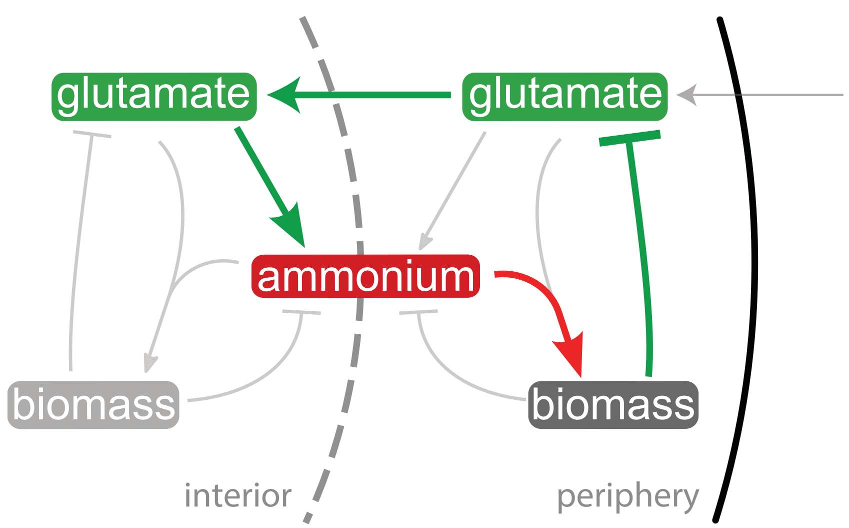
A metabolic tug-of-war between interior and periphery

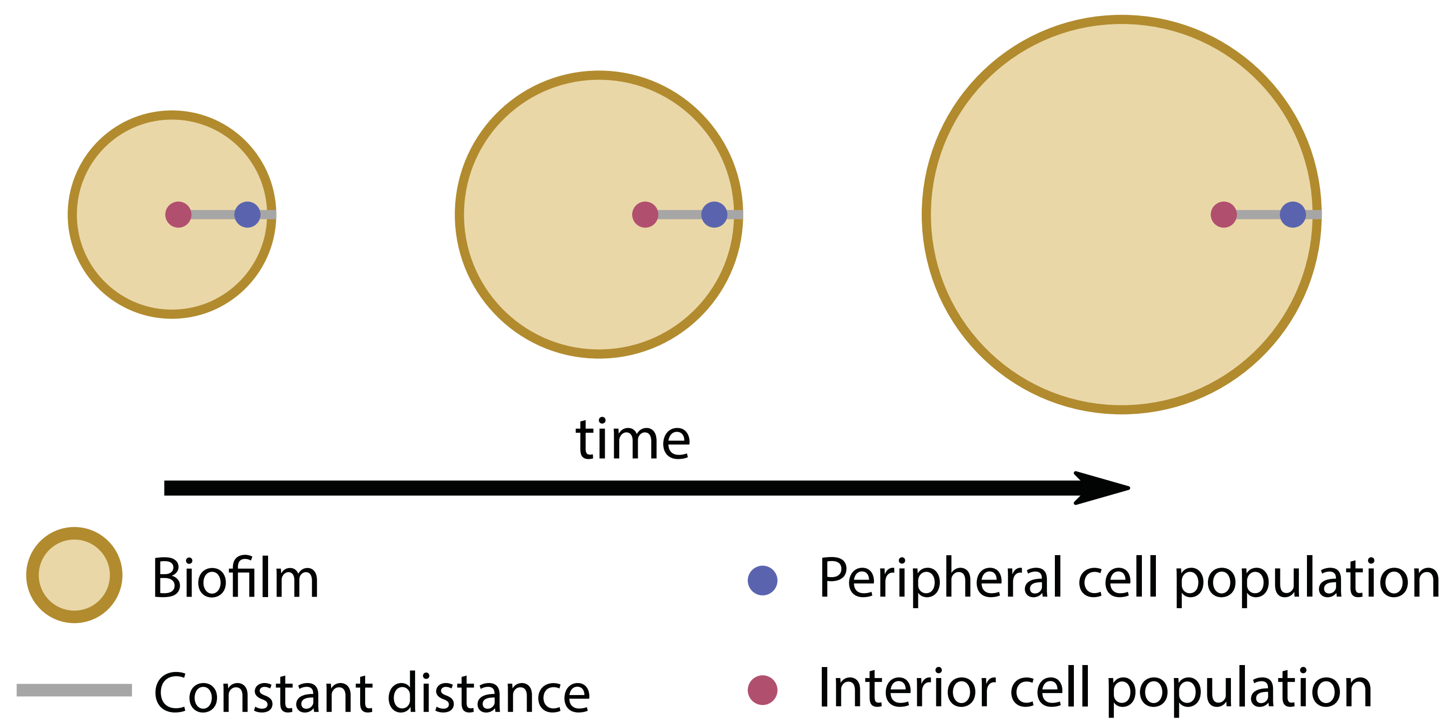


Mathematical model

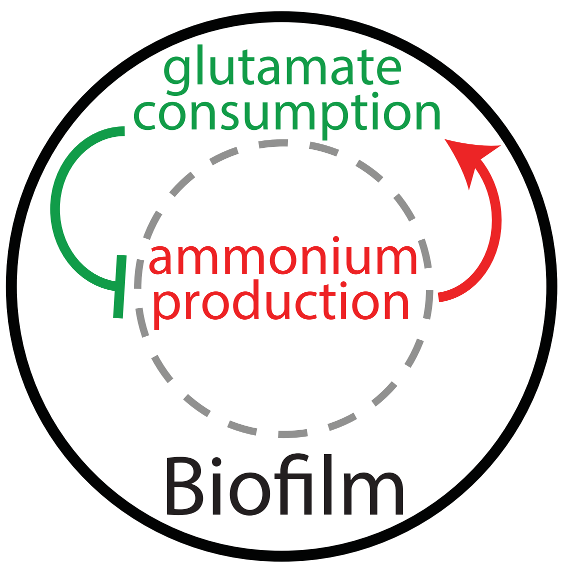


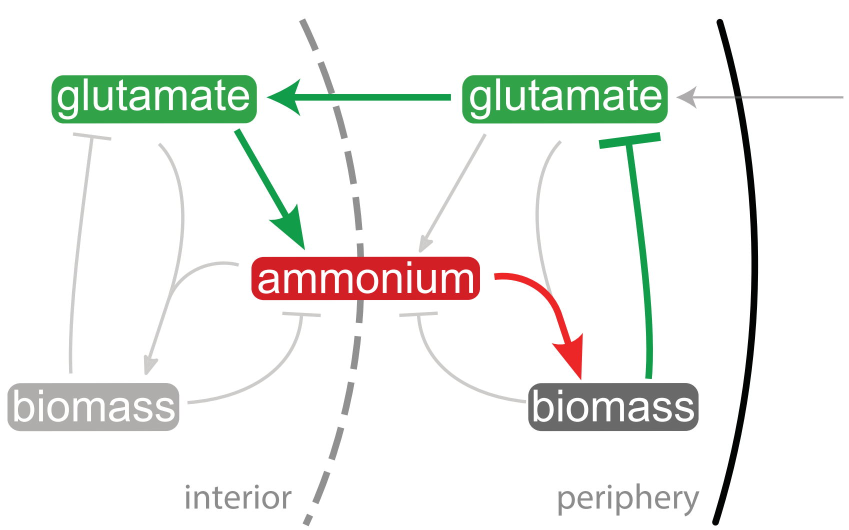
Marçal Gabaldà





Mathematical model





$$\frac{dA}{dt} = \alpha G_i H_i - \delta_A A(r_i + r_p)$$

ammonium

$$\frac{dG_i}{dt} = D(G_p - G_i) - \alpha G_i H_i - \delta_G G_i r_i$$

$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) - \delta_G G_p r_p$$

glutamate

$$\frac{dH_i}{dt} = \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

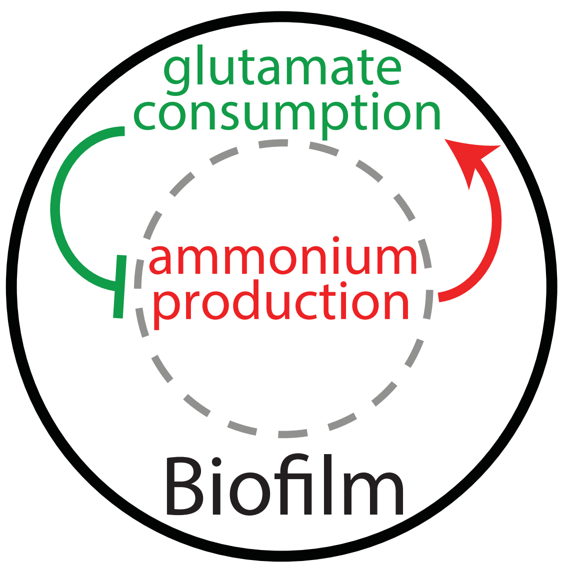
GDH

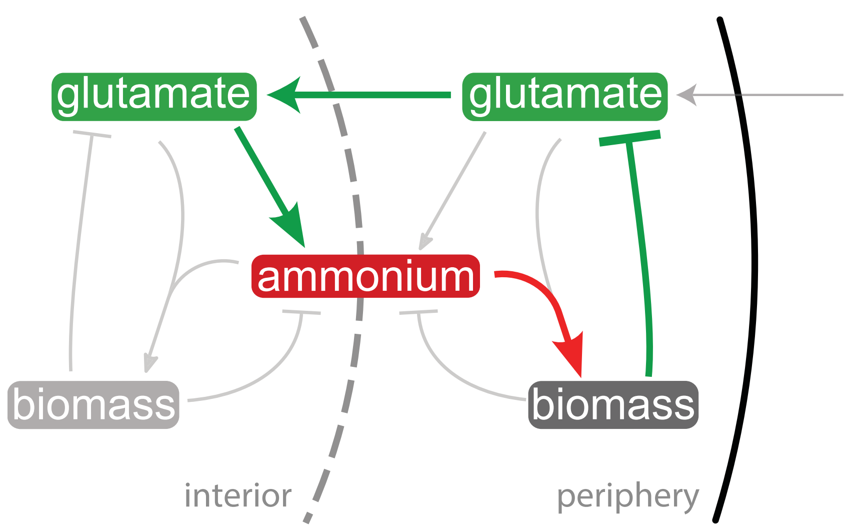
$$\frac{dr_i}{dt} = \beta_r A G_i - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \beta_r A G_p - \gamma_r r_p$$

biomass

Mathematical model





ammonium production

$$\frac{dA}{dt} = \alpha G_i H_i - \delta_A A(r_i + r_p)$$

ammonium

$$\frac{dG_i}{dt} = D(G_p - G_i) - \alpha G_i H_i - \delta_G G_i r_i$$

$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) - \delta_G G_p r_p$$

glutamate

$$\frac{dH_i}{dt} = \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

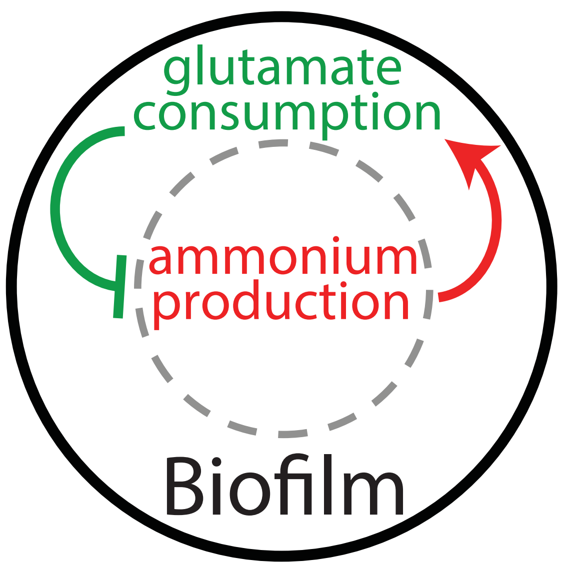
GDH

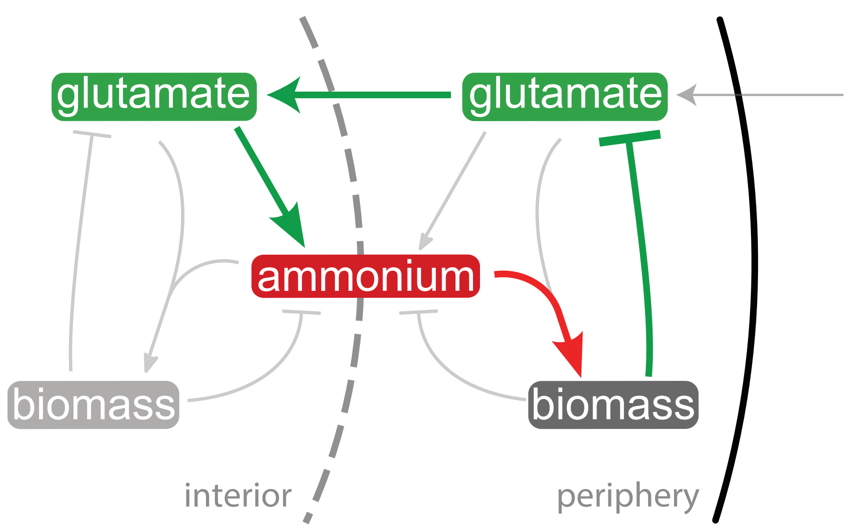
$$\frac{dr_i}{dt} = \beta_r A G_i - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \beta_r A G_p - \gamma_r r_p$$

biomass

Mathematical model





ammonium consumption

$$\frac{dA}{dt} = \alpha G_i H_i \boxed{- \delta_A A(r_i + r_p)}$$

ammonium

$$\frac{dG_i}{dt} = D\left(G_p - G_i\right) - \alpha G_i H_i - \delta_G G_i r_i$$

$$\frac{dG_p}{dt} = D\left(G_i - G_p\right) + D_E\left(G_E - G_p\right) - \delta_G G_p r_p$$

glutamate

$$\frac{dH_i}{dt} = \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

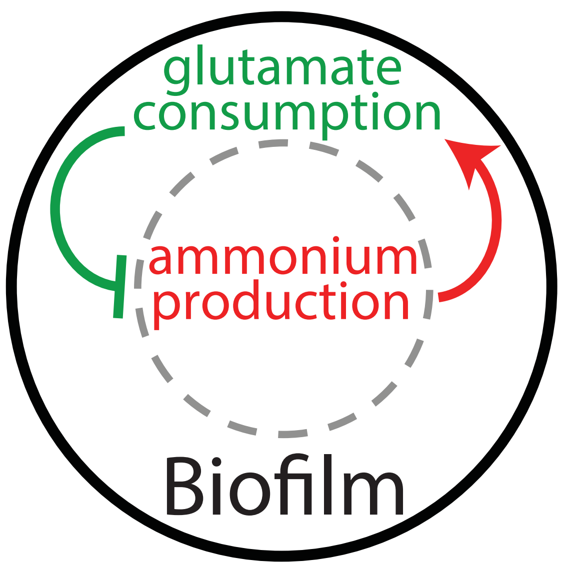
GDH

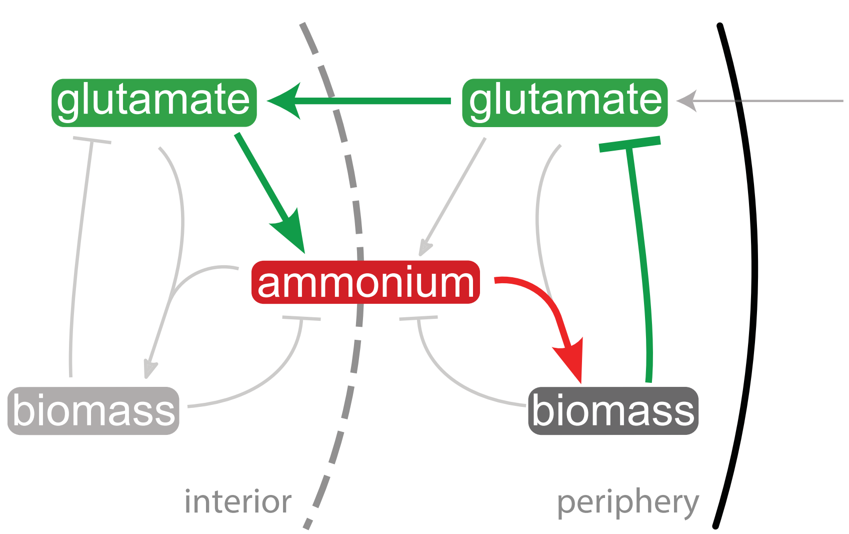
$$\frac{dr_i}{dt} = \beta_r A G_i - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \beta_r A G_p - \gamma_r r_p$$

biomass

Mathematical model





glutamate diffusion

ammonium

$$\frac{dA}{dt} = \alpha G_i H_i - \delta_A A(r_i + r_p)$$

glutamate

$$\frac{dG_i}{dt} = D(G_p - G_i) - \alpha G_i H_i - \delta_G G_i r_i$$

$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) - \delta_G G_p r_p$$

GDH

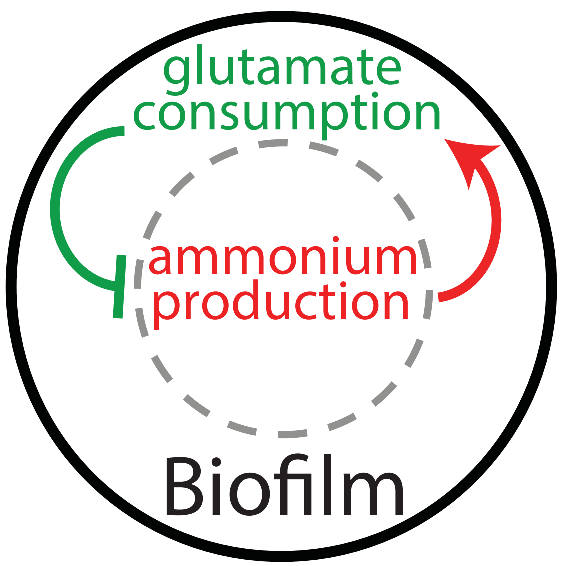
$$\frac{dH_i}{dt} = \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

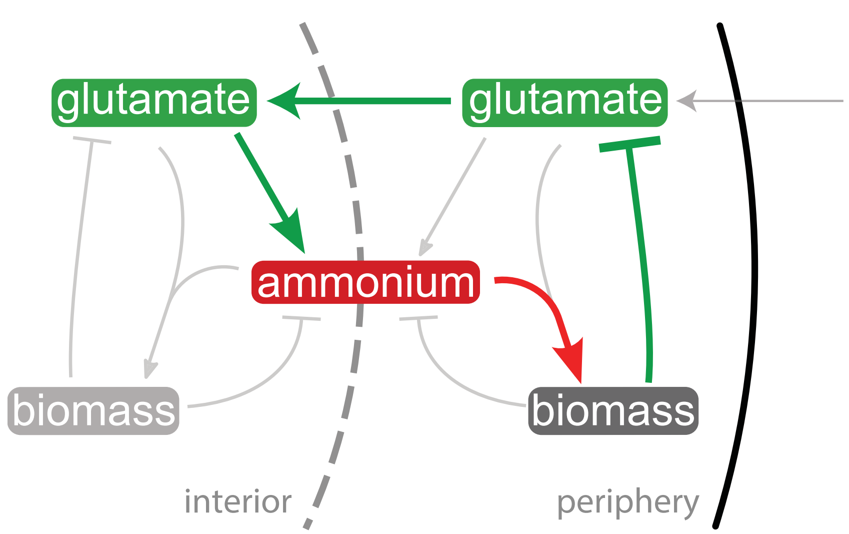
biomass

$$\frac{dr_i}{dt} = \beta_r A G_i - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \beta_r A G_p - \gamma_r r_p$$

Mathematical model





glutamate consumption

$$\frac{dA}{dt} = \alpha G_i H_i - \delta_A A(r_i + r_p)$$

$$\frac{dG_i}{dt} = D(G_p - G_i) - \alpha G_i H_i \boxed{- \delta_G G_i r_i}$$

$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) \boxed{- \delta_G G_p r_p}$$

$$\frac{dH_i}{dt} = \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

$$\frac{dr_i}{dt} = \beta_r A G_i - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \beta_r A G_p - \gamma_r r_p$$

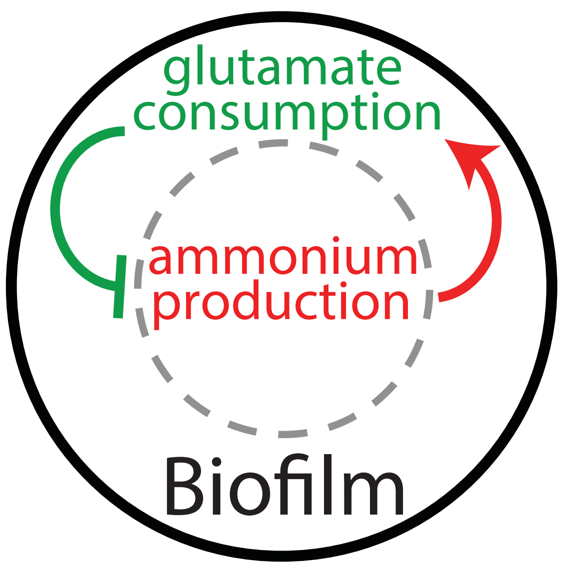
ammonium

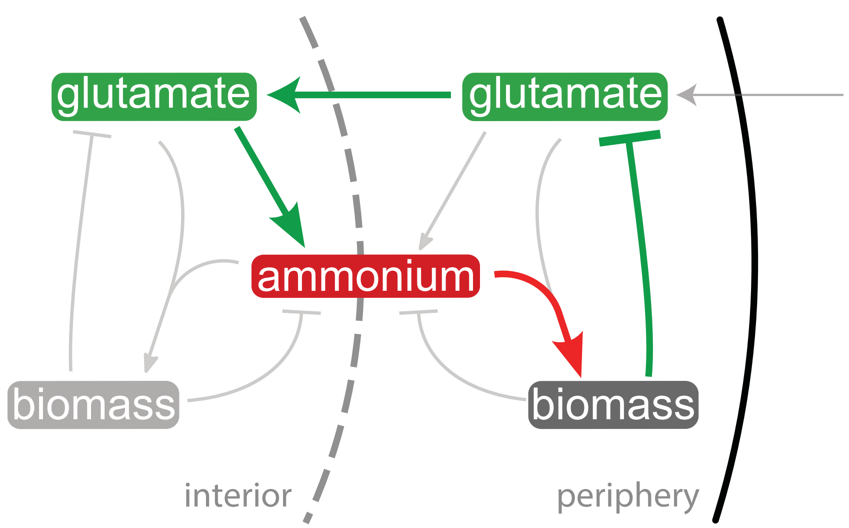
glutamate

GDH

biomass

Mathematical model





biomass
production

$$\frac{dA}{dt} = \alpha G_i H_i - \delta_A A(r_i + r_p)$$

ammonium

$$\frac{dG_i}{dt} = D\left(G_p - G_i\right) - \alpha G_i H_i - \delta_G G_i r_i$$

$$\frac{dG_p}{dt} = D\left(G_i - G_p\right) + D_E\left(G_E - G_p\right) - \delta_G G_p r_p$$

glutamate

$$\frac{dH_i}{dt} = \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

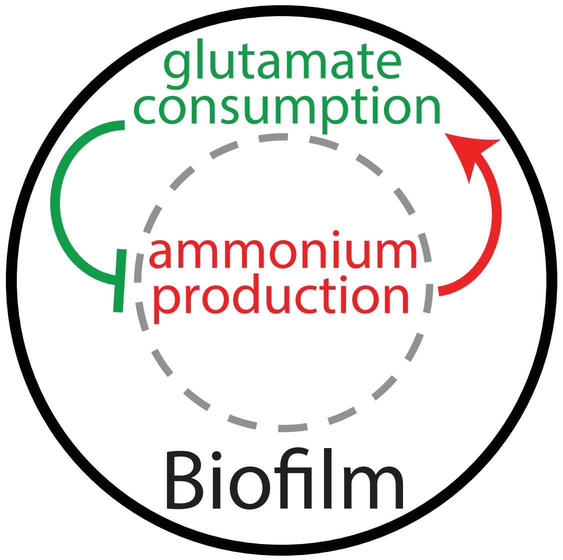
GDH

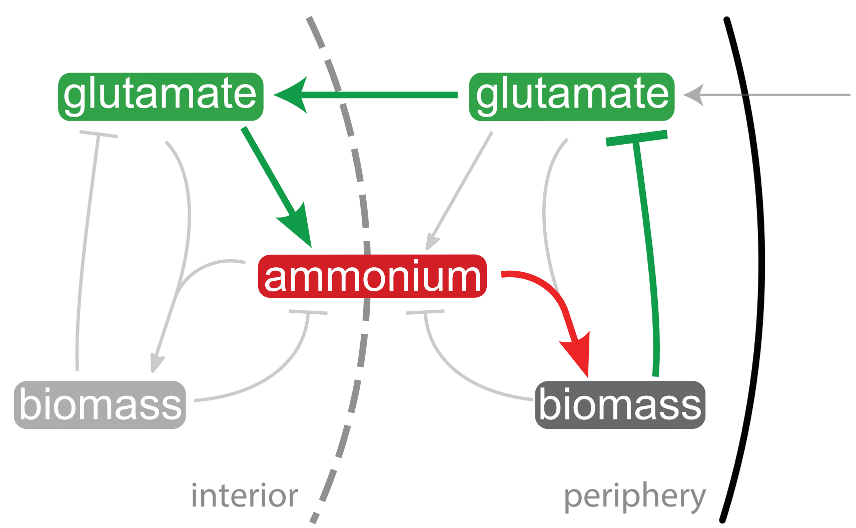
$$\frac{dr_i}{dt} = \boxed{\beta_r A G_i} - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \boxed{\beta_r A G_p} - \gamma_r r_p$$

biomass

Mathematical model





GDH
activation

$$\frac{dA}{dt} = \alpha G_i H_i - \delta_A A(r_i + r_p)$$

$$\frac{dG_i}{dt} = D\left(G_p - G_i\right) - \alpha G_i H_i - \delta_G G_i r_i$$

$$\frac{dG_p}{dt} = D\left(G_i - G_p\right) + D_E\left(G_E - G_p\right) - \delta_G G_p r_p$$

$$\frac{dH_i}{dt} = \boxed{\beta_H \frac{G_i^n}{K_H^n + G_i^n}} - \gamma_H H_i$$

$$\frac{dr_i}{dt} = \beta_r A G_i - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \beta_r A G_p - \gamma_r r_p$$

ammonium

glutamate

GDH

biomass

Measuring population growth

$$\frac{dA}{dt} = \alpha G_i H_i - \delta_A A(r_i + r_p)$$

$$\frac{dG_i}{dt} = D(G_p - G_i) - \alpha G_i H_i - \delta_G G_i r_i$$

$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) - \delta_G G_p r_p$$

$$\frac{dH_i}{dt} = \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

$$\frac{dr_i}{dt} = \beta_r A G_i - \gamma_r r_i$$

$$\frac{dr_p}{dt} = \beta_r A G_p - \gamma_r r_p$$

$$\frac{d\rho_{i,p}}{dt} = \eta r_{i,p} \rho_{i,p} \left(1 - \frac{\rho_{i,p}}{K(G_{i,p})}\right) - \lambda_{i,p} \rho_{i,p}$$

cell density

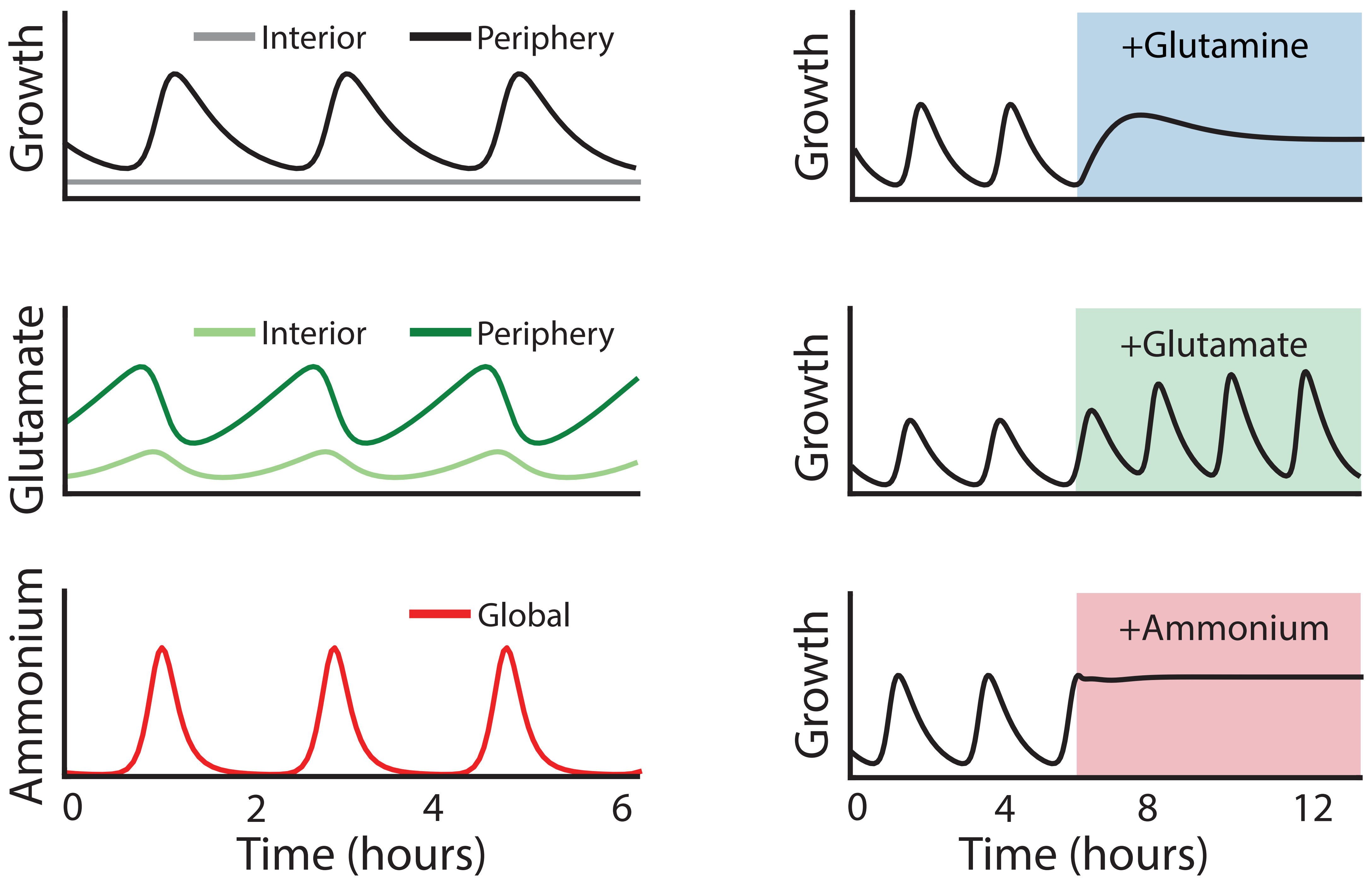
$$K(G) = \frac{G^m}{K_k^m + G^m}$$

carrying capacity

$$\mu_{i,p} = \eta r_{i,p} \rho_{i,p} \left(1 - \frac{\rho_{i,p}}{K(G_{i,p})}\right)$$

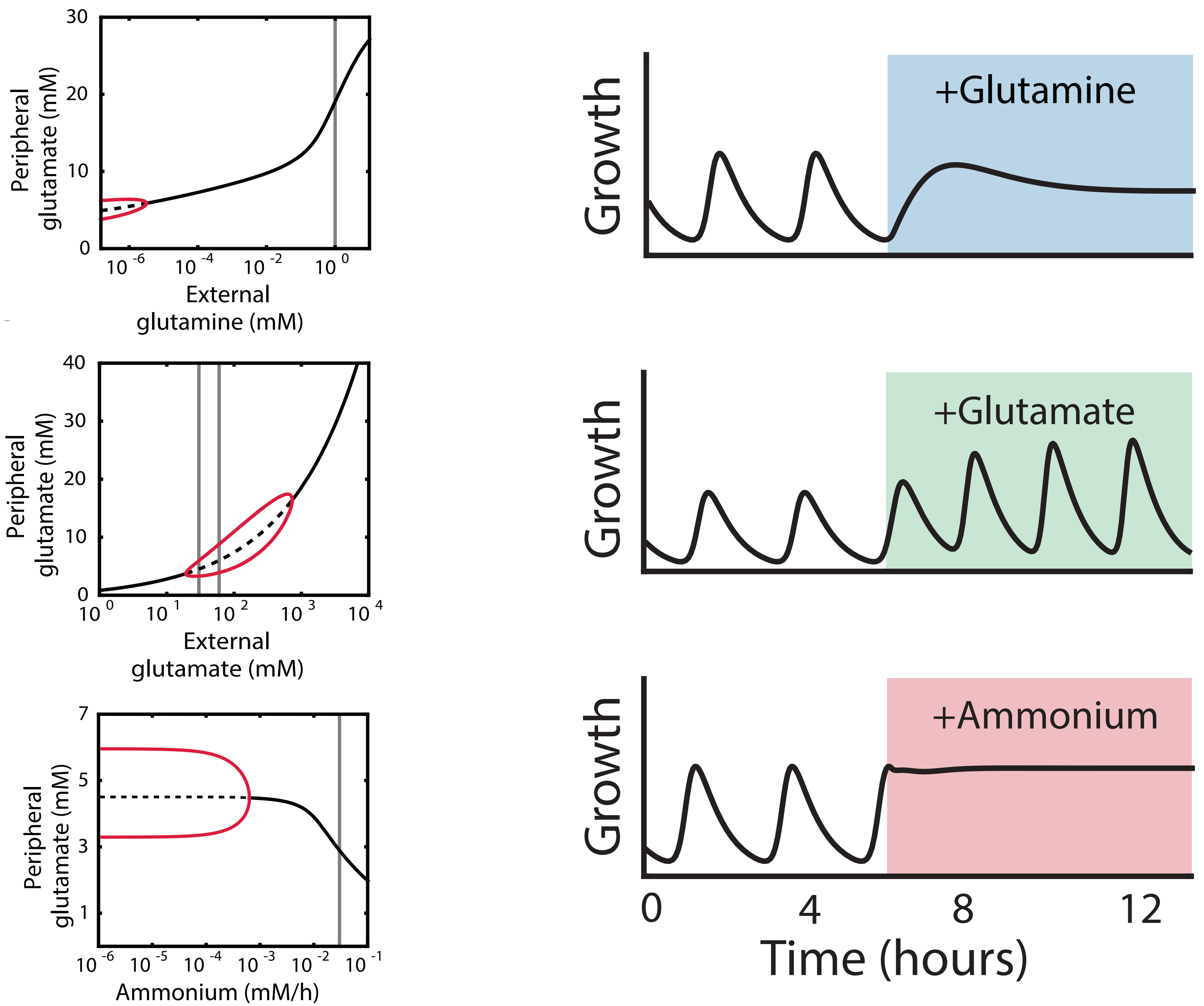
growth rate

The model reproduces the experimental observations



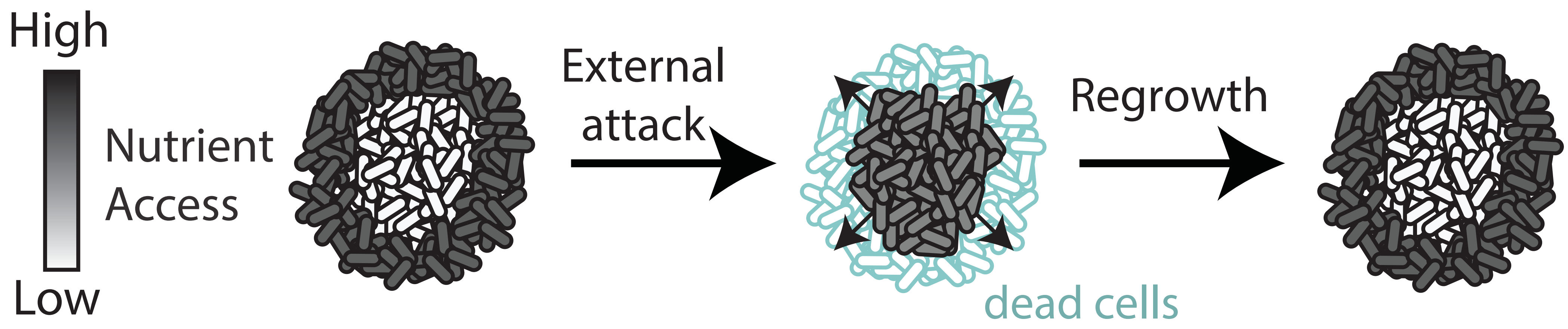
Liu et al, Nature **523**, 550-554 (2015)

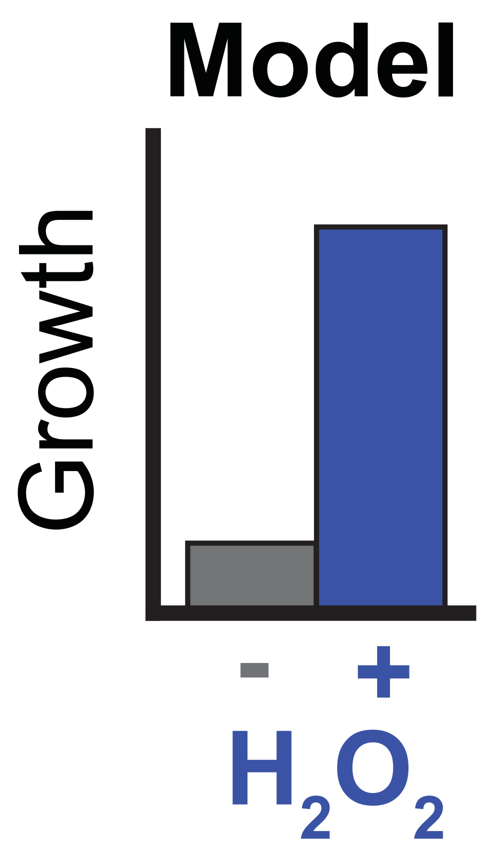
The model reproduces the experimental observations



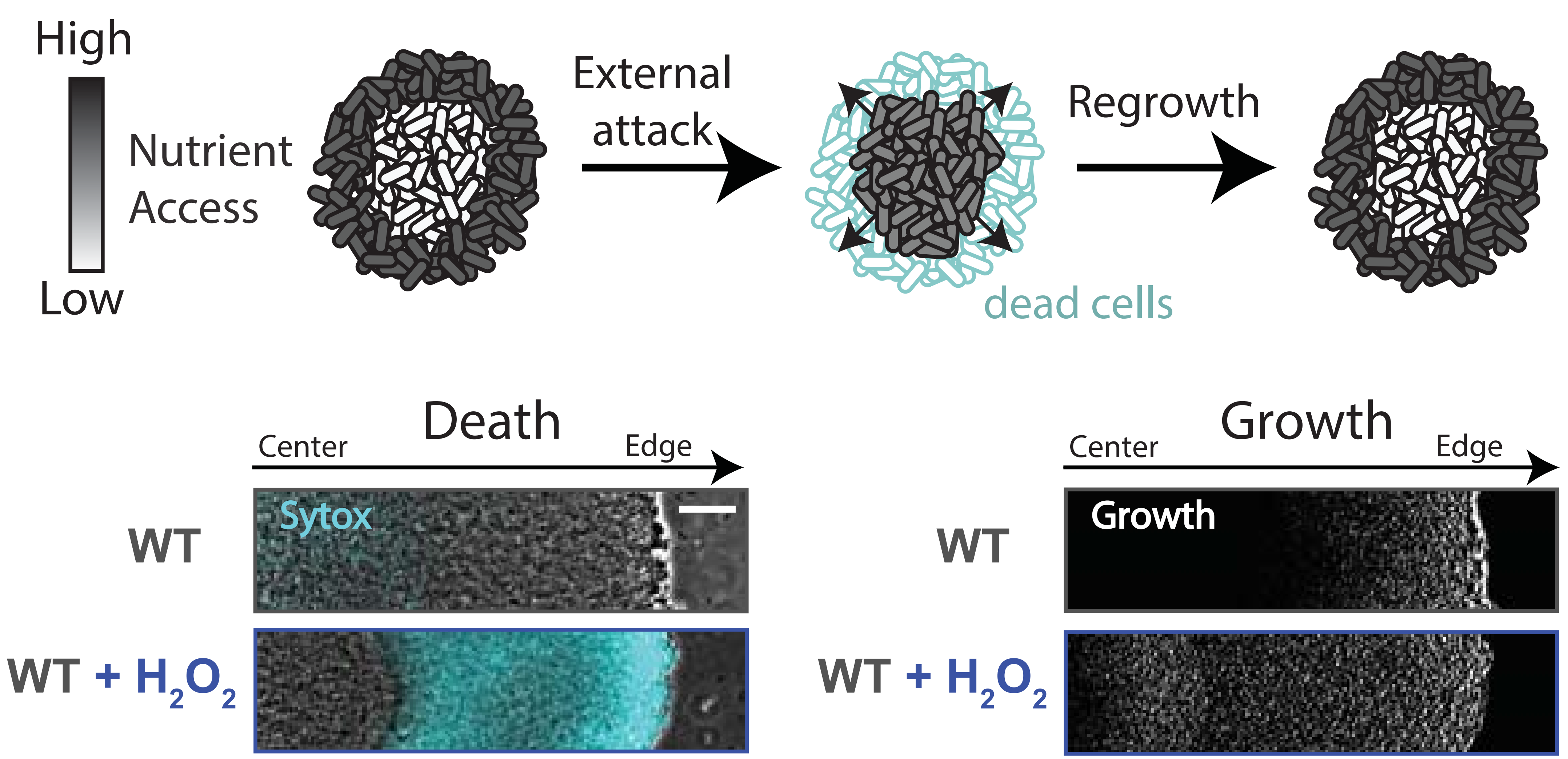
Liu et al, Nature **523**, 550-554 (2015)

Prediction: killing the peripheral cells increases biofilm expansion



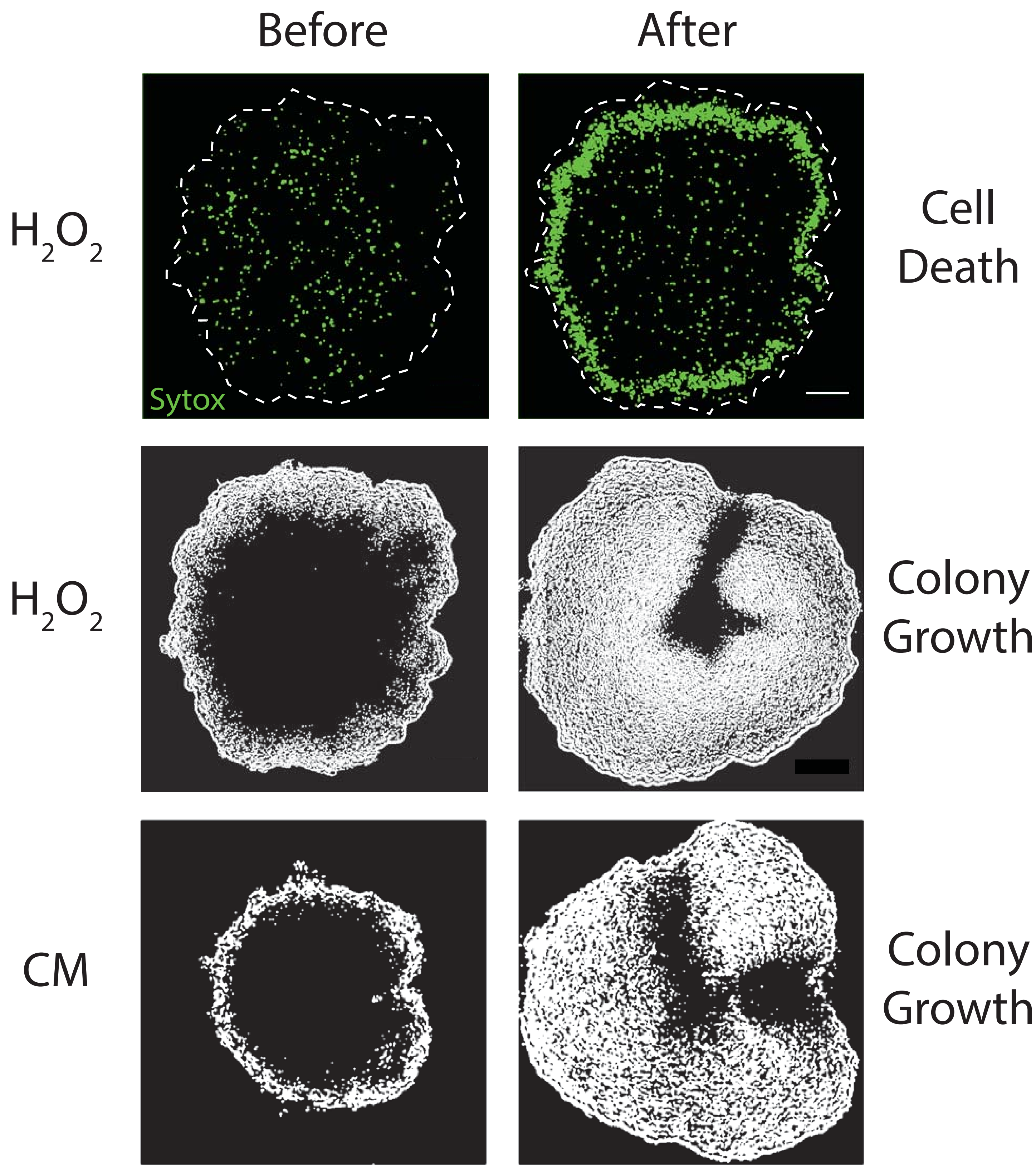


Killing the peripheral cells increases biofilm expansion

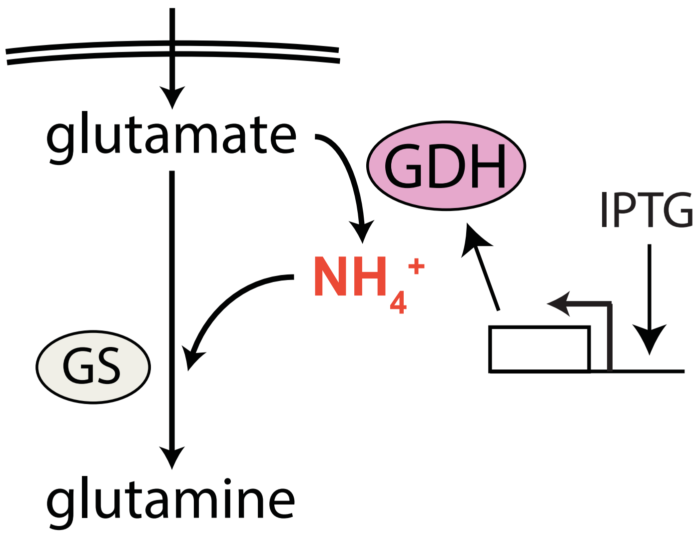


Liu et al, Nature **523**, 550-554 (2015)

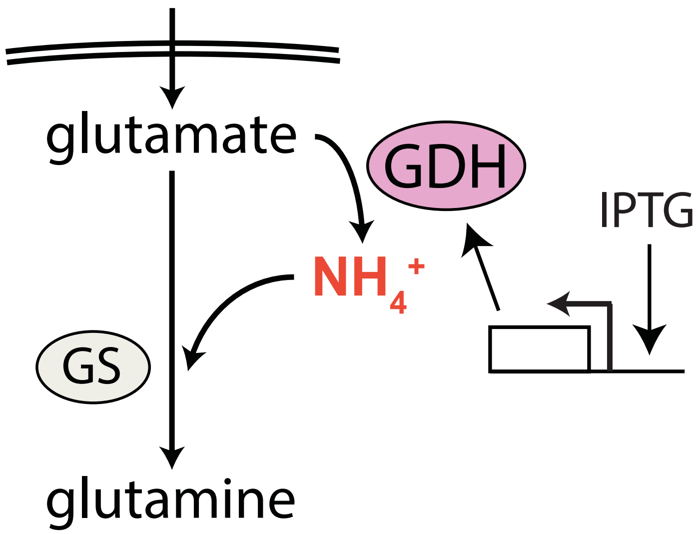
Killing the peripheral cells increases biofilm expansion



Why don’t peripheral cells produce their own ammonium?



Why don't peripheral cells produce their own ammonium?

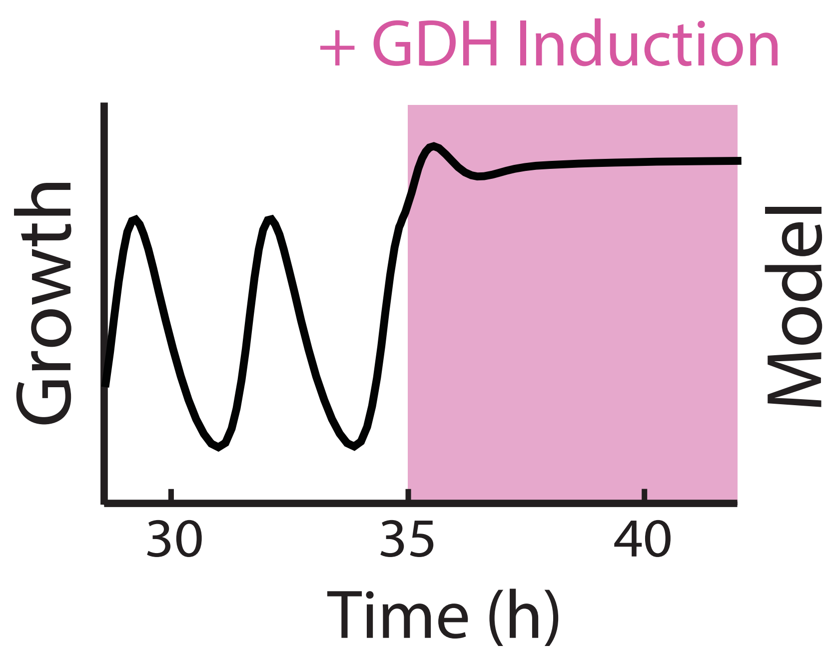


$$\frac{dA}{dt} = \alpha G_i H_i + \boldsymbol{\alpha G_p H_p} - \delta_A A(r_i + r_p)$$

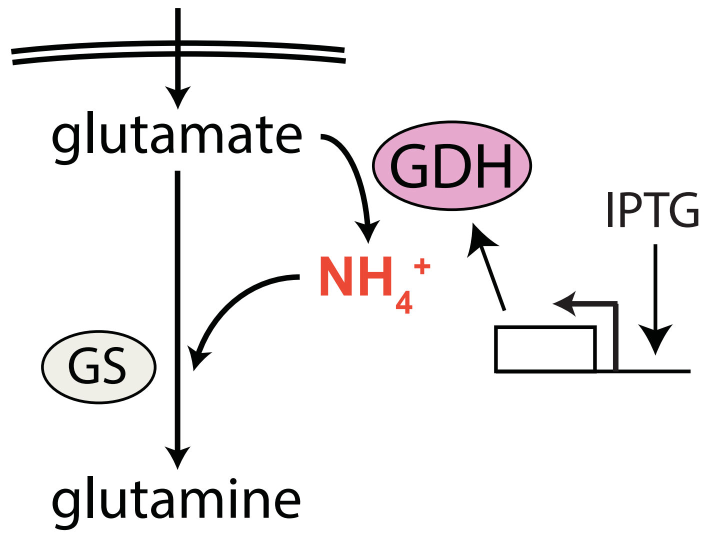
$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) - \boldsymbol{\alpha G_p H_p} - \delta_G G_p r_p$$

$$\frac{dH_i}{dt} = \boldsymbol{\beta_0} + \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

$$\boldsymbol{\frac{dH_p}{dt} = \beta_0 - \gamma_H H_p}$$



Why don't peripheral cells produce their own ammonium?

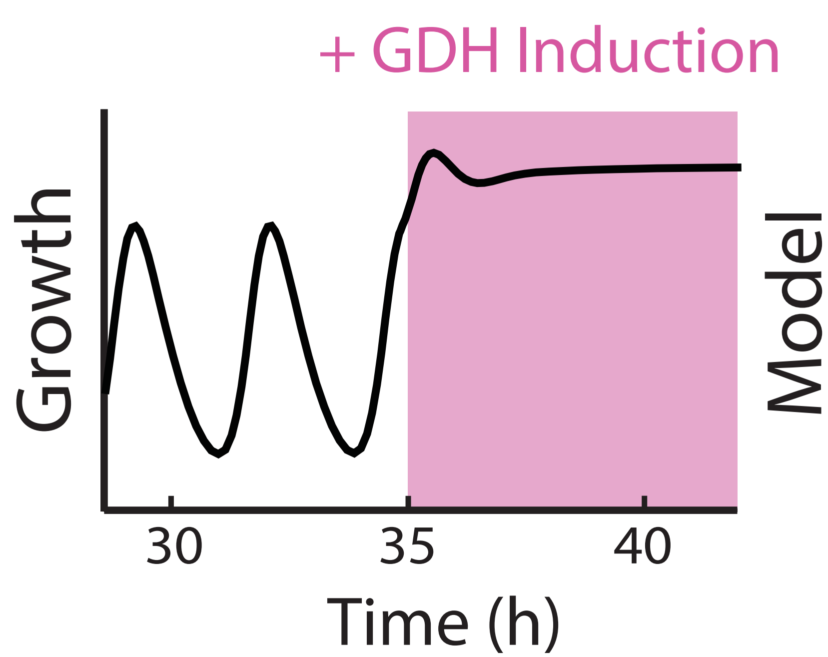


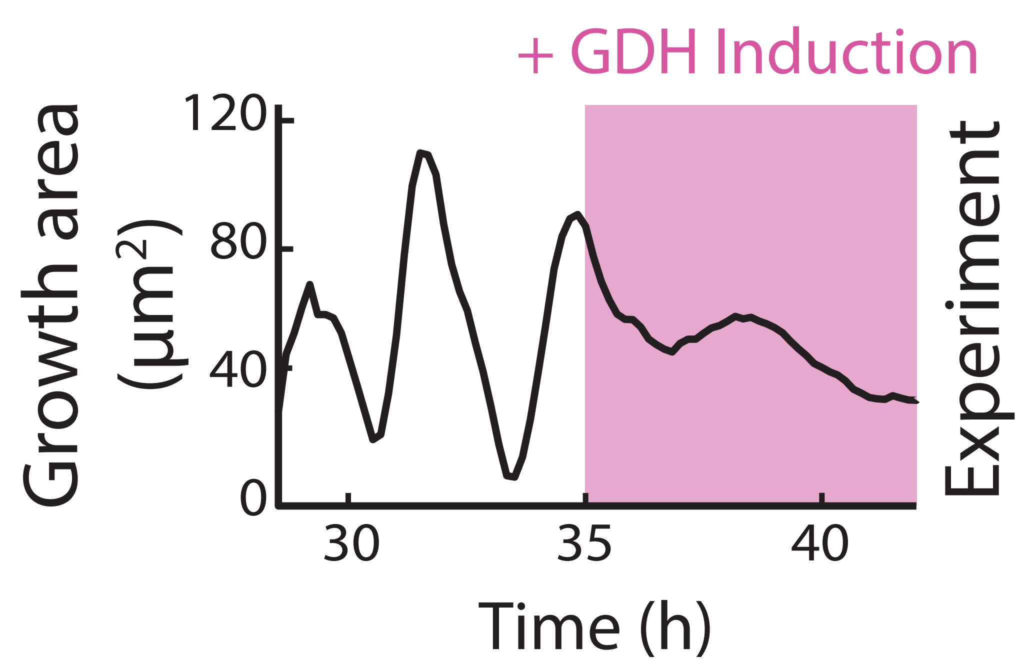
$$\frac{dA}{dt} = \alpha G_i H_i + \boldsymbol{\alpha G_p H_p} - \delta_A A(r_i + r_p)$$

$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) - \boldsymbol{\alpha G_p H_p} - \delta_G G_p r_p$$

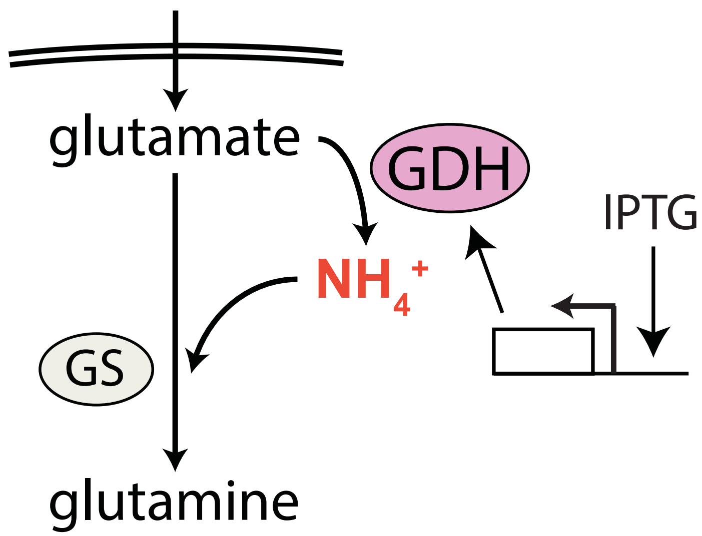
$$\frac{dH_i}{dt} = \boldsymbol{\beta_0} + \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

$$\boldsymbol{\frac{dH_p}{dt} = \beta_0 - \gamma_H H_p}$$





Why don't peripheral cells produce their own ammonium?



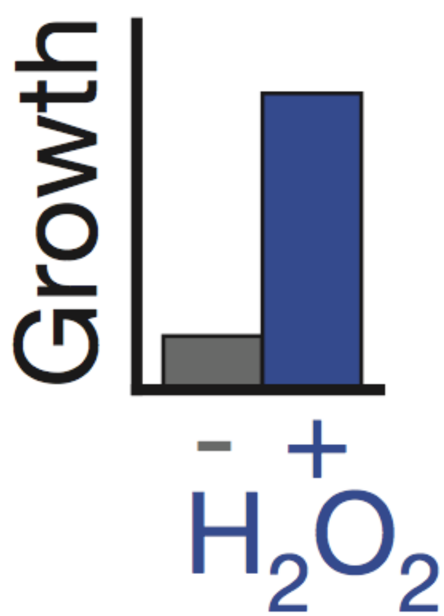
$$\frac{dA}{dt} = \alpha G_i H_i + \boldsymbol{\alpha G_p H_p} - \delta_A A(r_i + r_p)$$

$$\frac{dG_p}{dt} = D(G_i - G_p) + D_E(G_E - G_p) - \boldsymbol{\alpha G_p H_p} - \delta_G G_p r_p$$

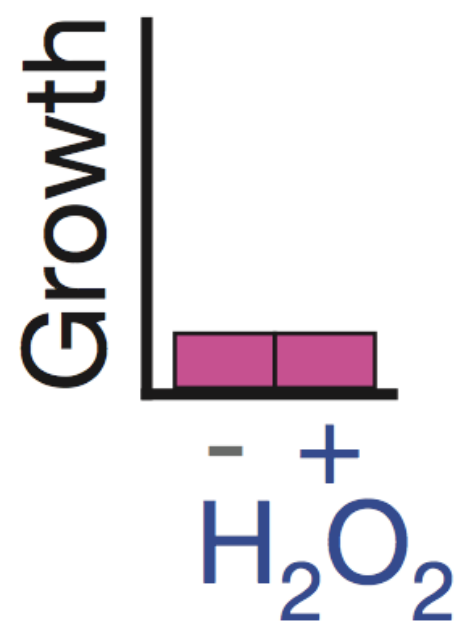
$$\frac{dH_i}{dt} = \boldsymbol{\beta_0} + \beta_H \frac{G_i^n}{K_H^n + G_i^n} - \gamma_H H_i$$

$$\boldsymbol{\frac{dH_p}{dt} = \beta_0 - \gamma_H H_p}$$

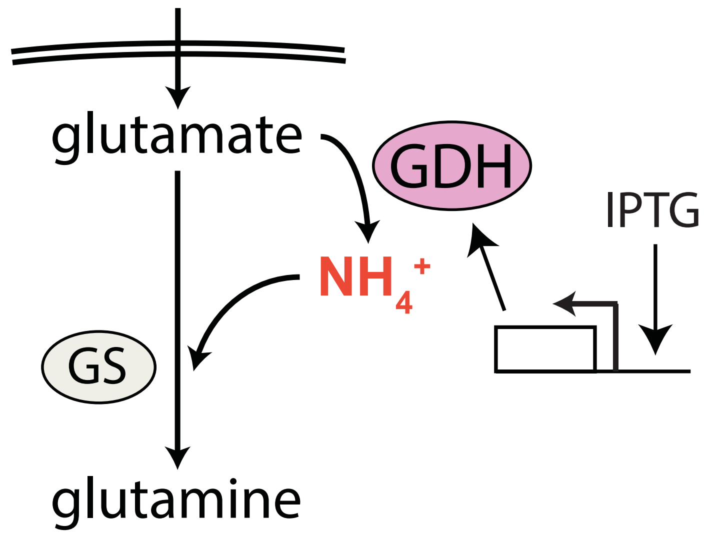
Wild type

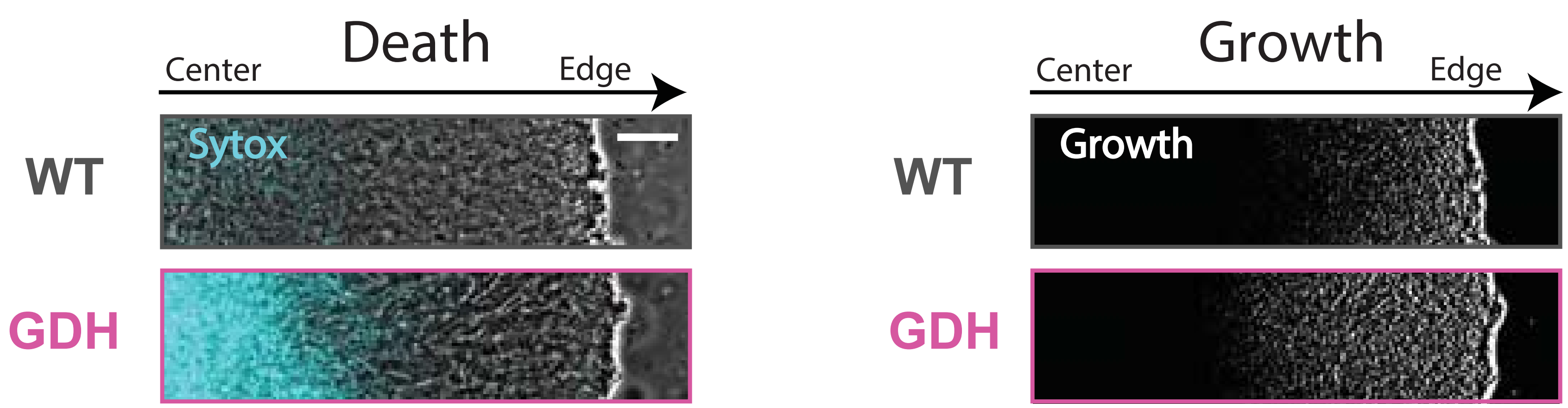


+ GDH induction

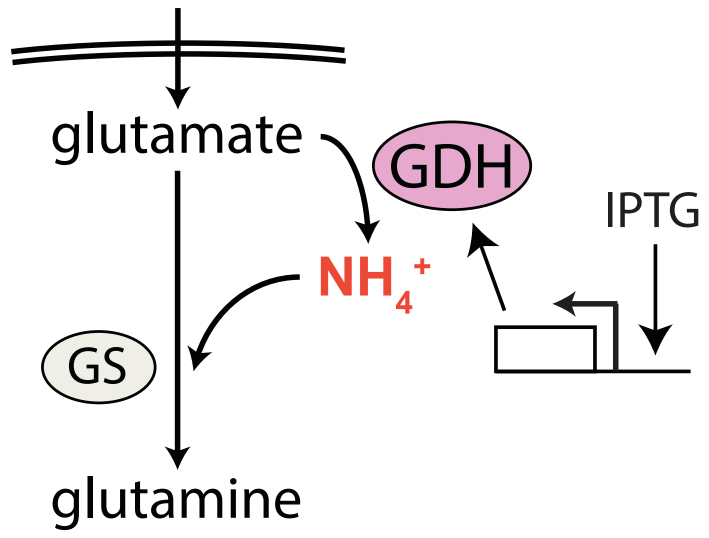


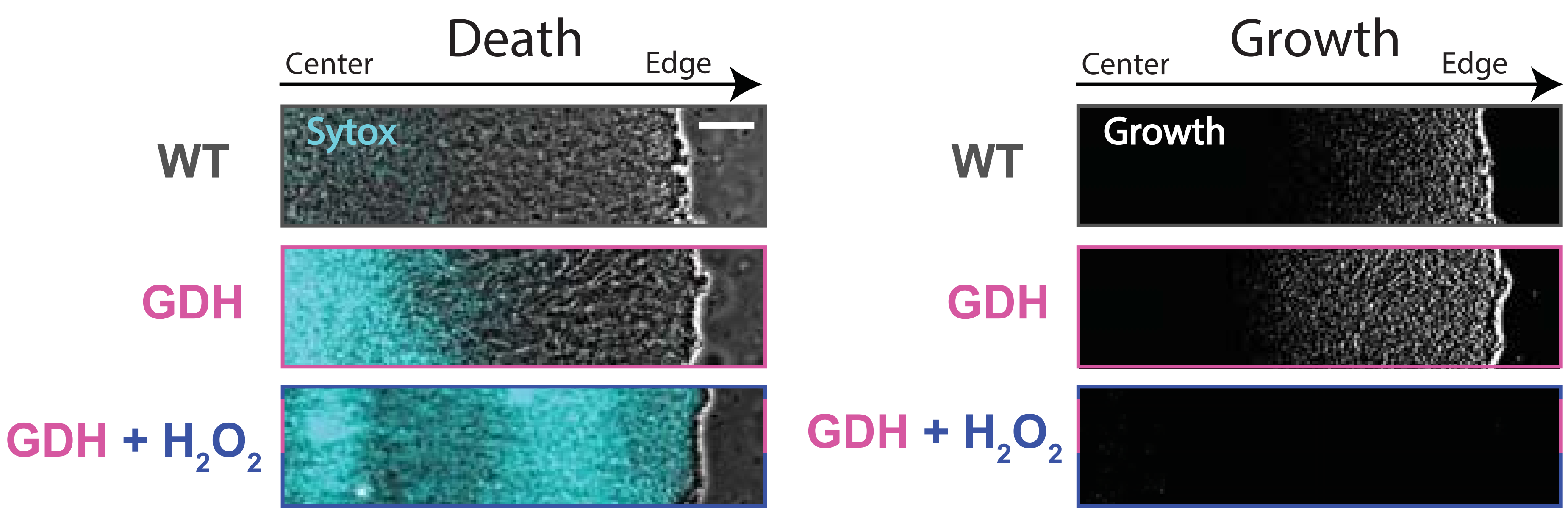
Why don't peripheral cells produce their own ammonium?



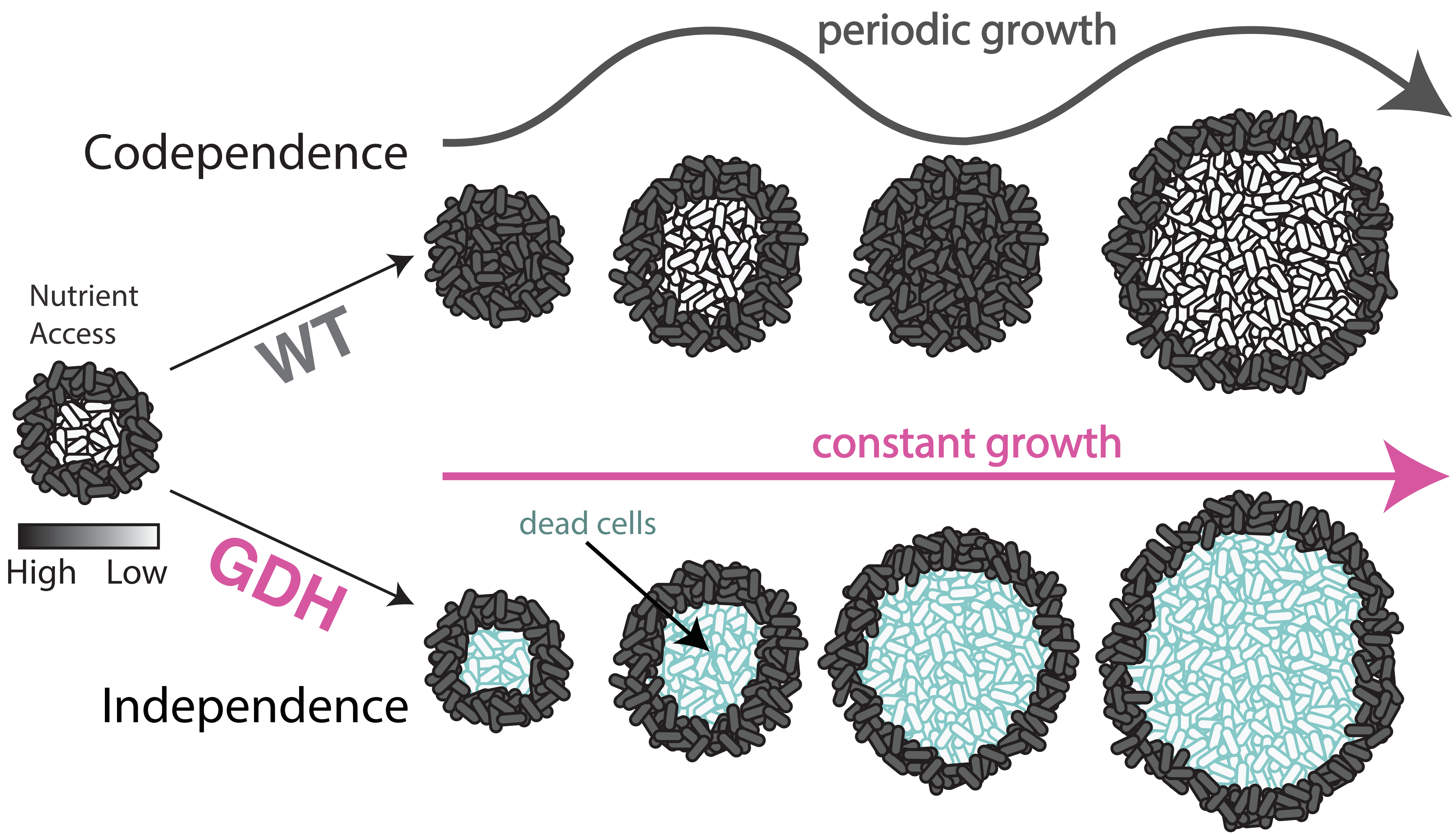


A strategy to eliminate biofilms: starve the interior first





A strategy to eliminate biofilms: starve the interior first

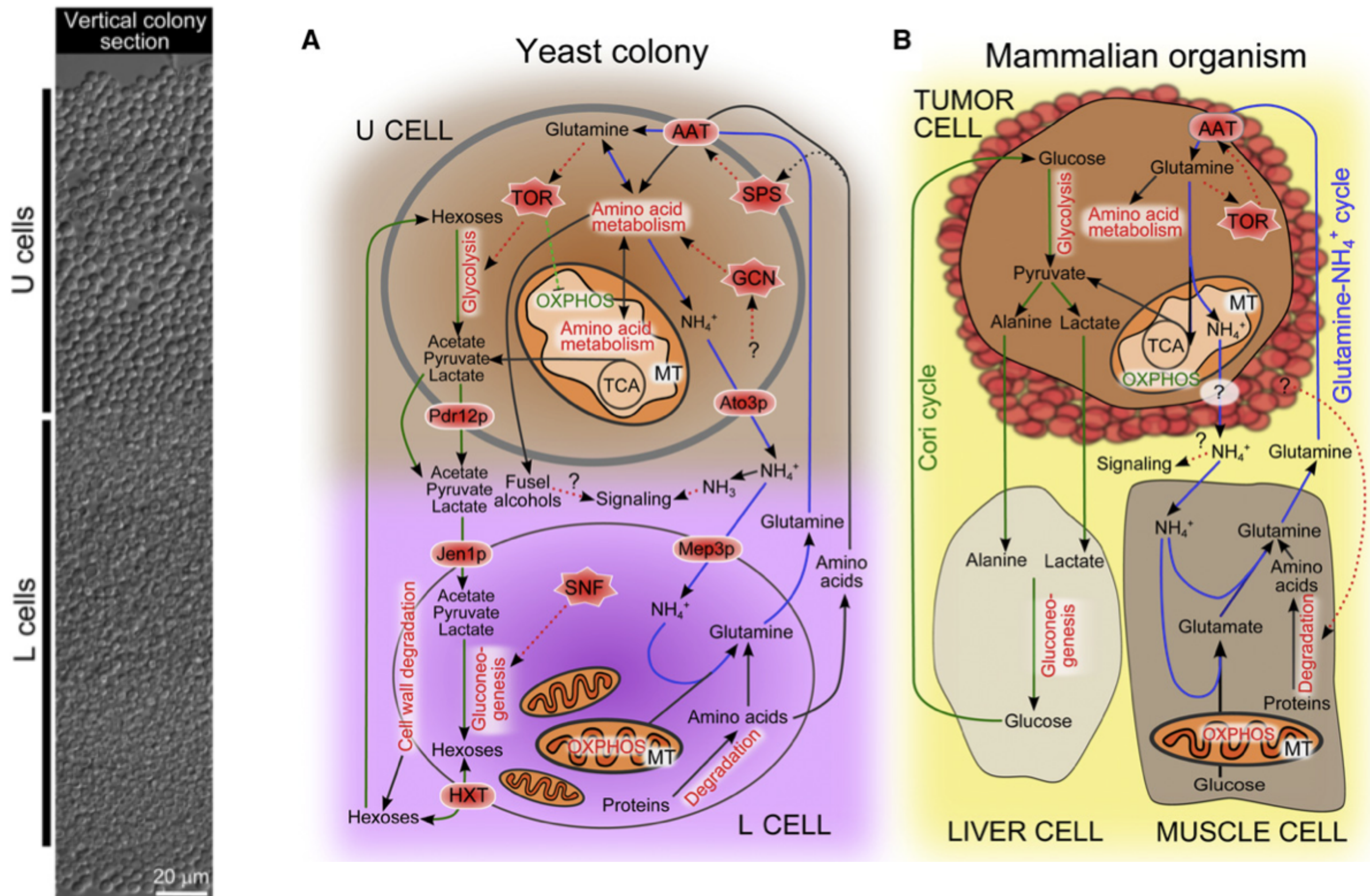


Liu et al, Nature **523**, 550-554 (2015)

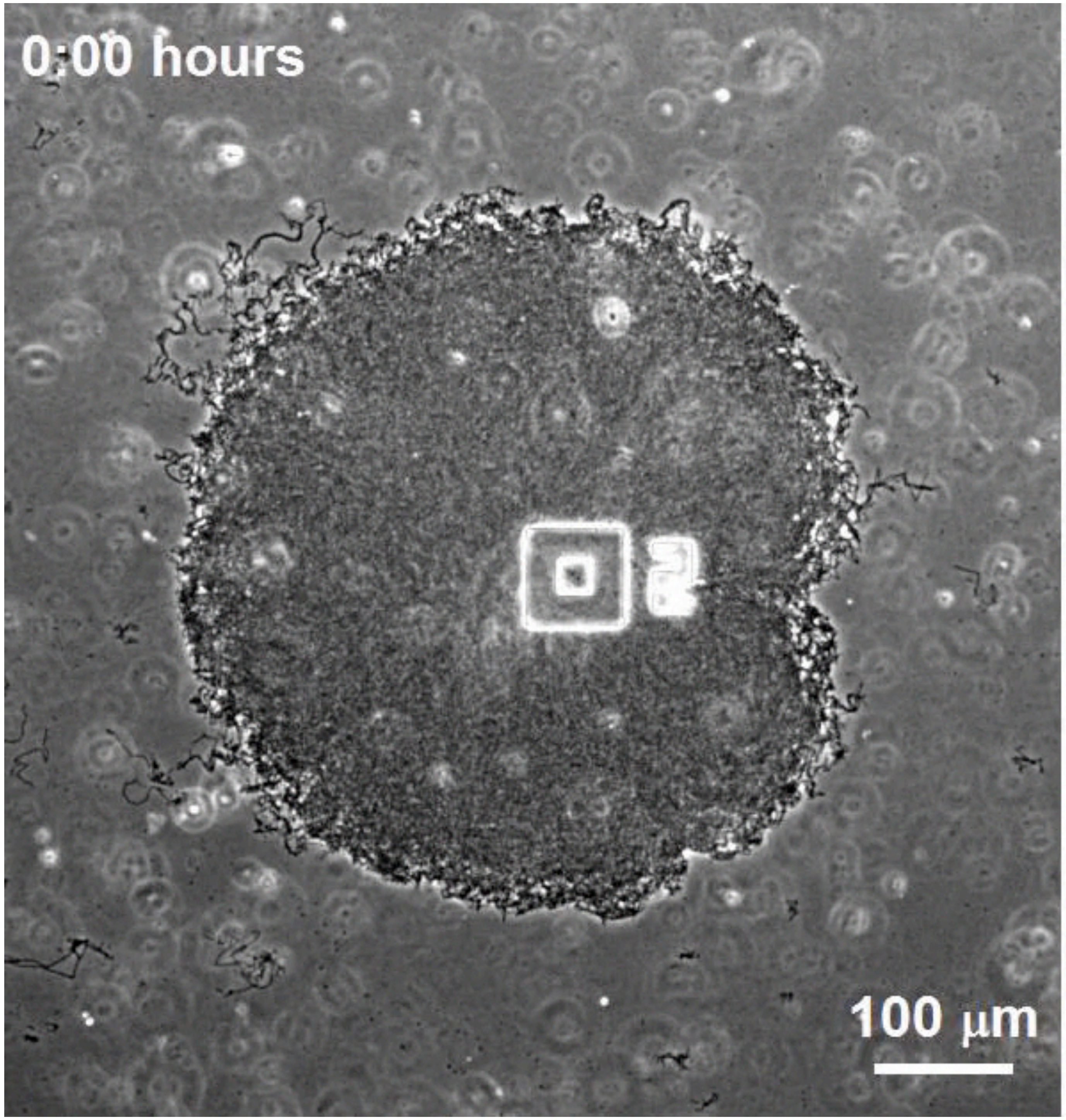
Molecular Cell
Article

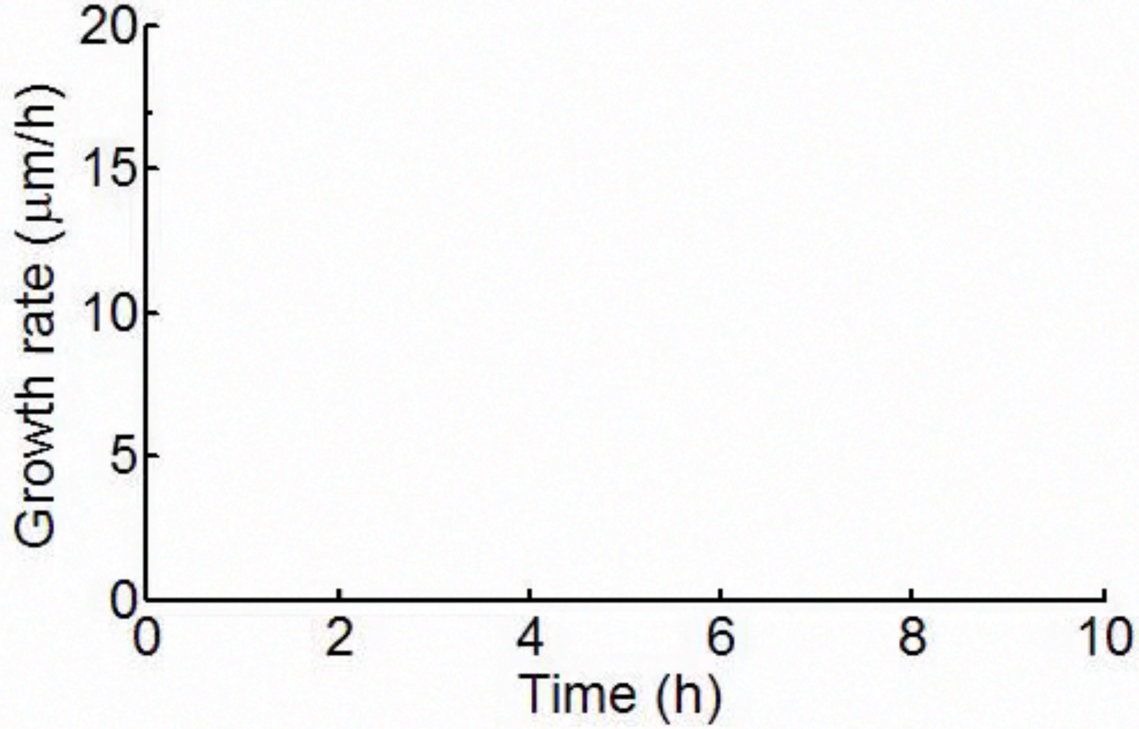
Cell Differentiation within a Yeast Colony: Metabolic and Regulatory Parallels with a Tumor-Affected Organism

Michal Čáp,[1] Luděk Štěpánek,[1] Karel Harant,[1,2] Libuše Váchová,[2] and Zdena Palková[1,*]



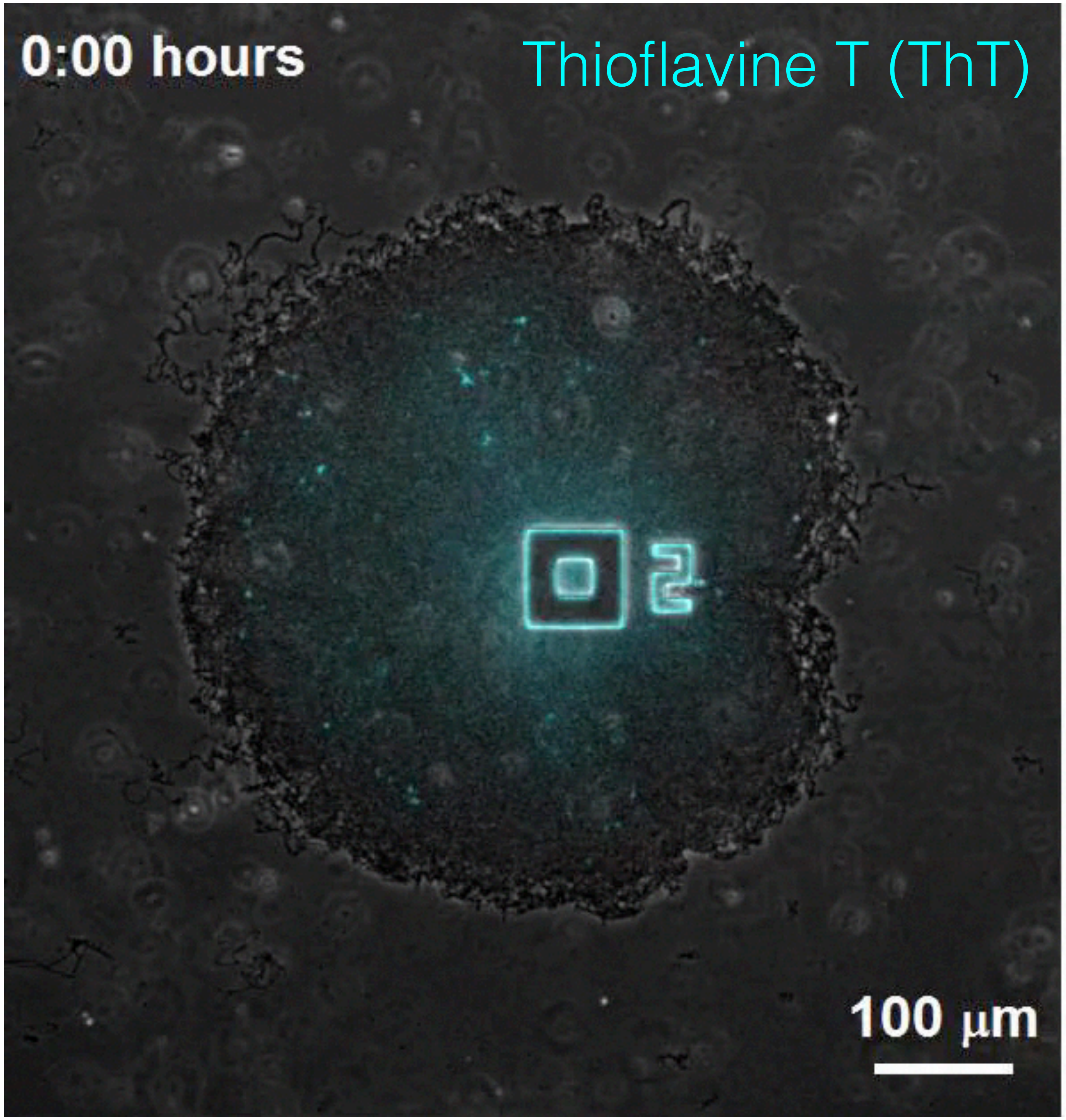
Beyond growth oscillations

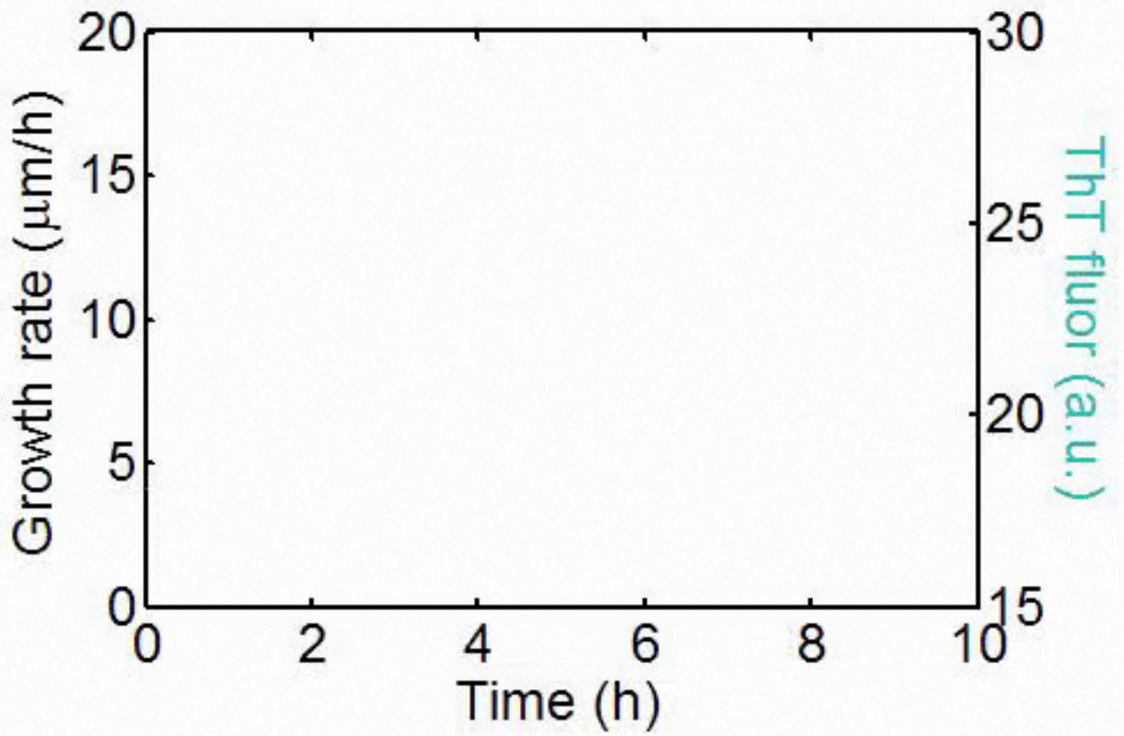




Arthur Prindle

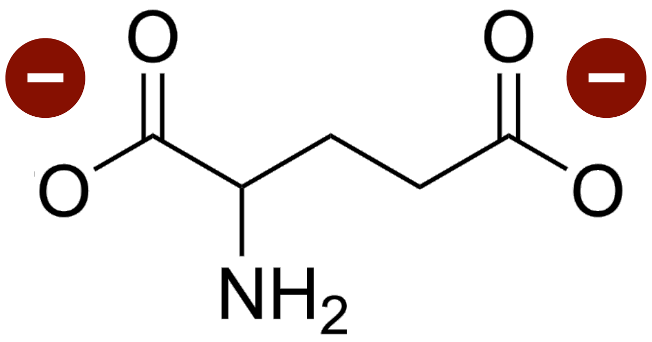
Beyond growth oscillations



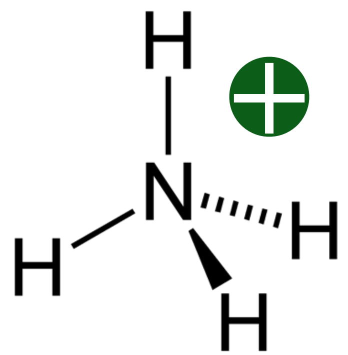


Arthur Prindle

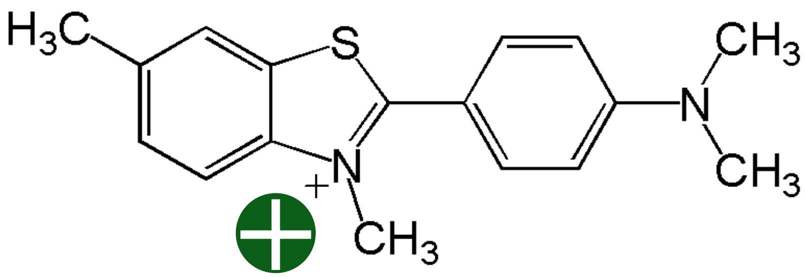
Our key metabolites are charged molecules



glutamate

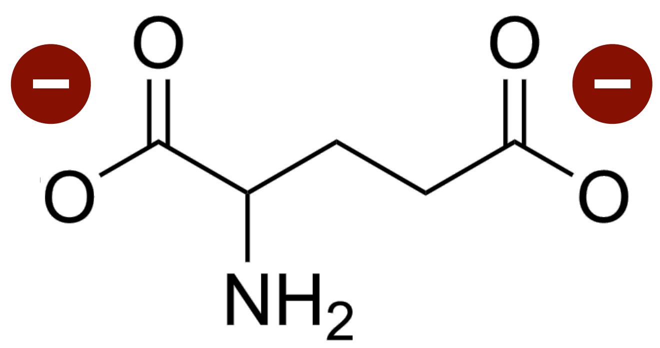


ammonium

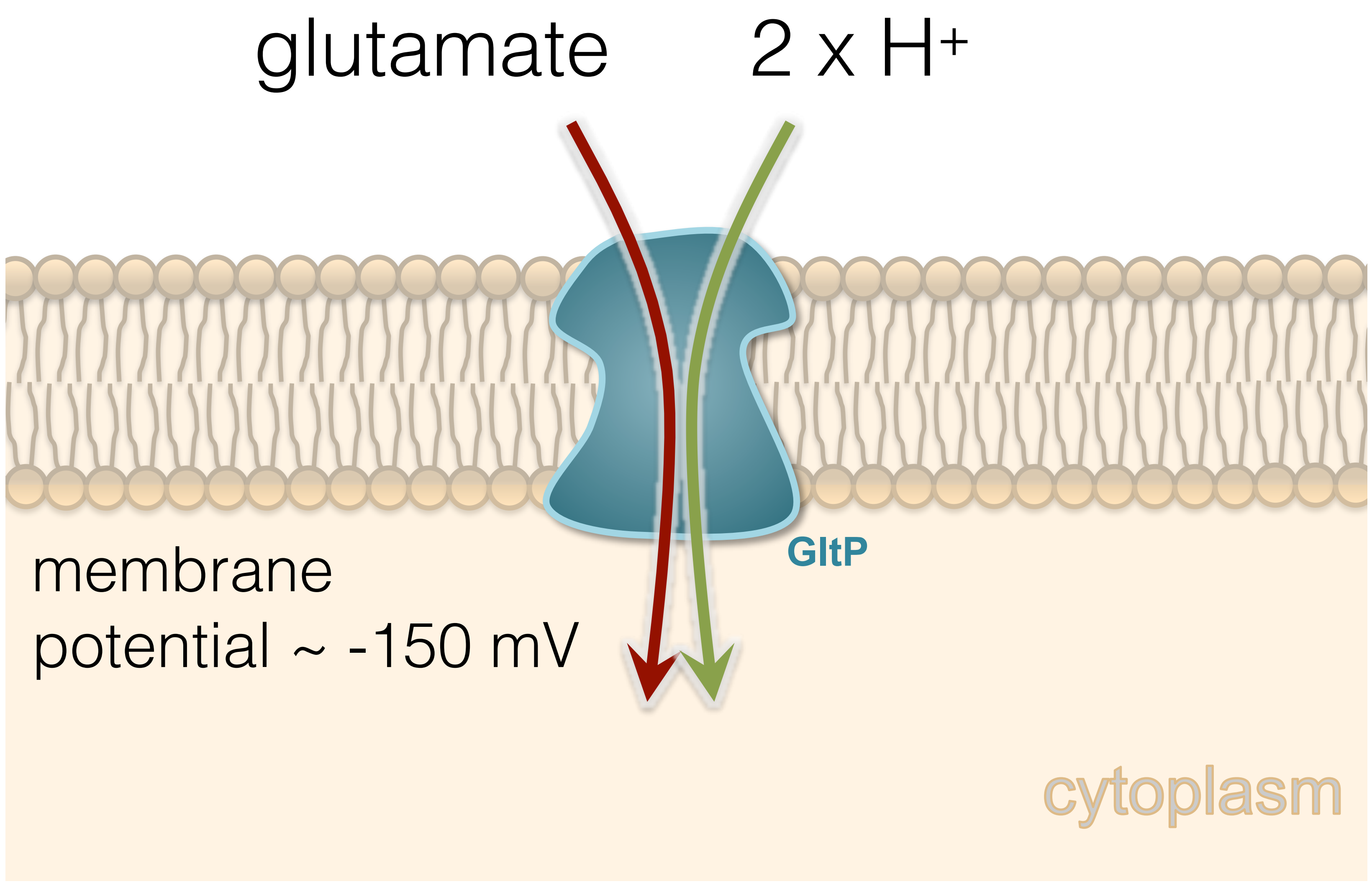


Thioflavine T (ThT)

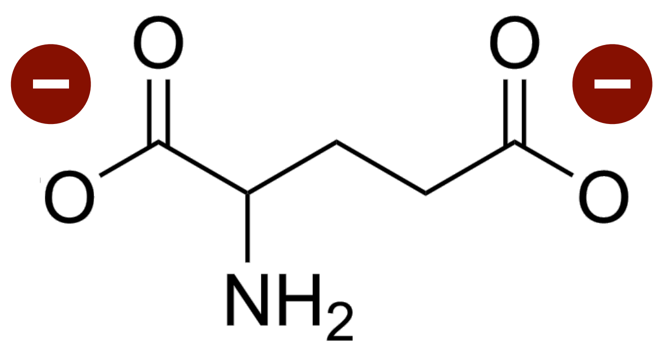
Our key metabolites are charged molecules



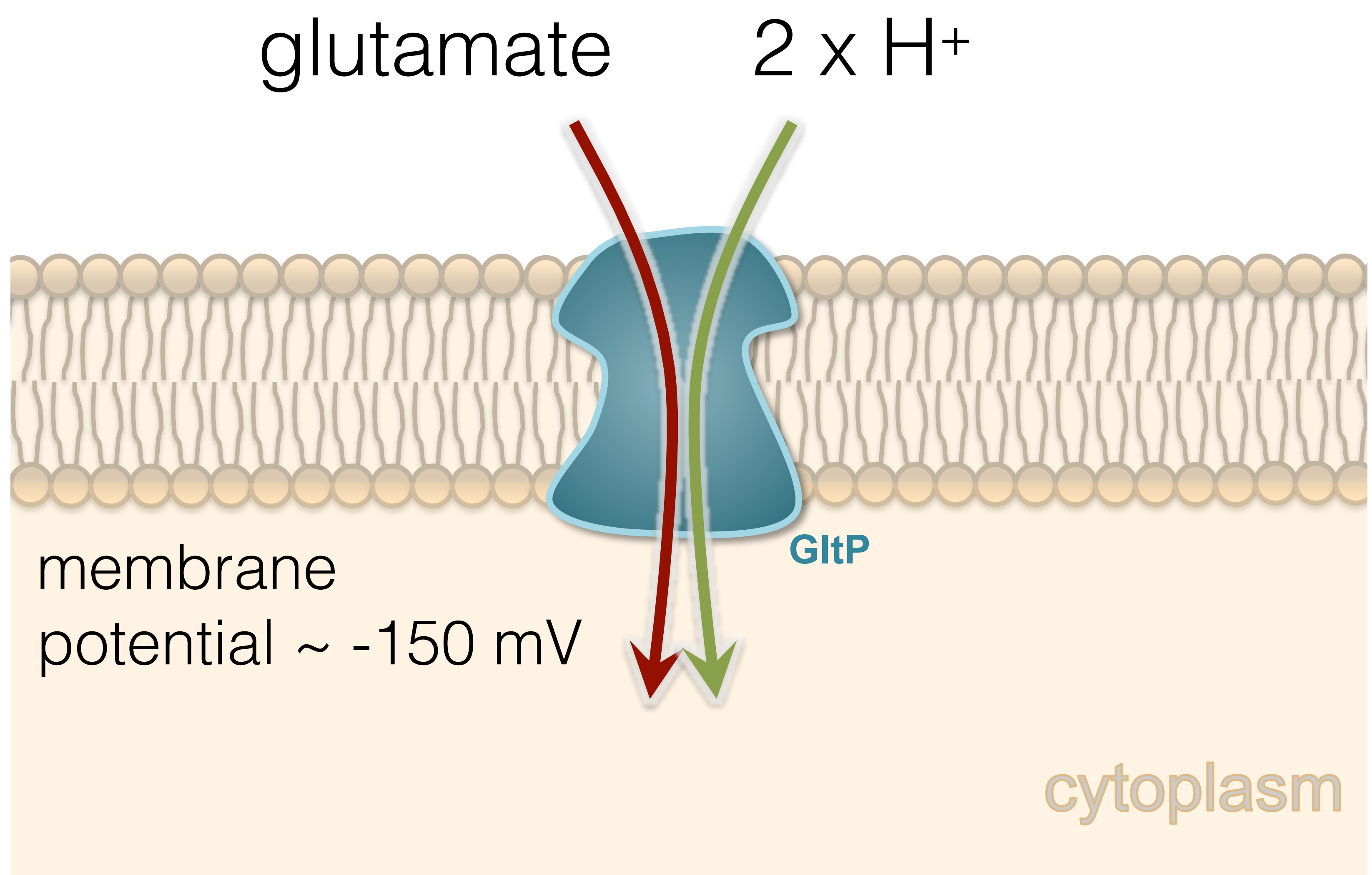
glutamate



Membrane potential affects the metabolic state

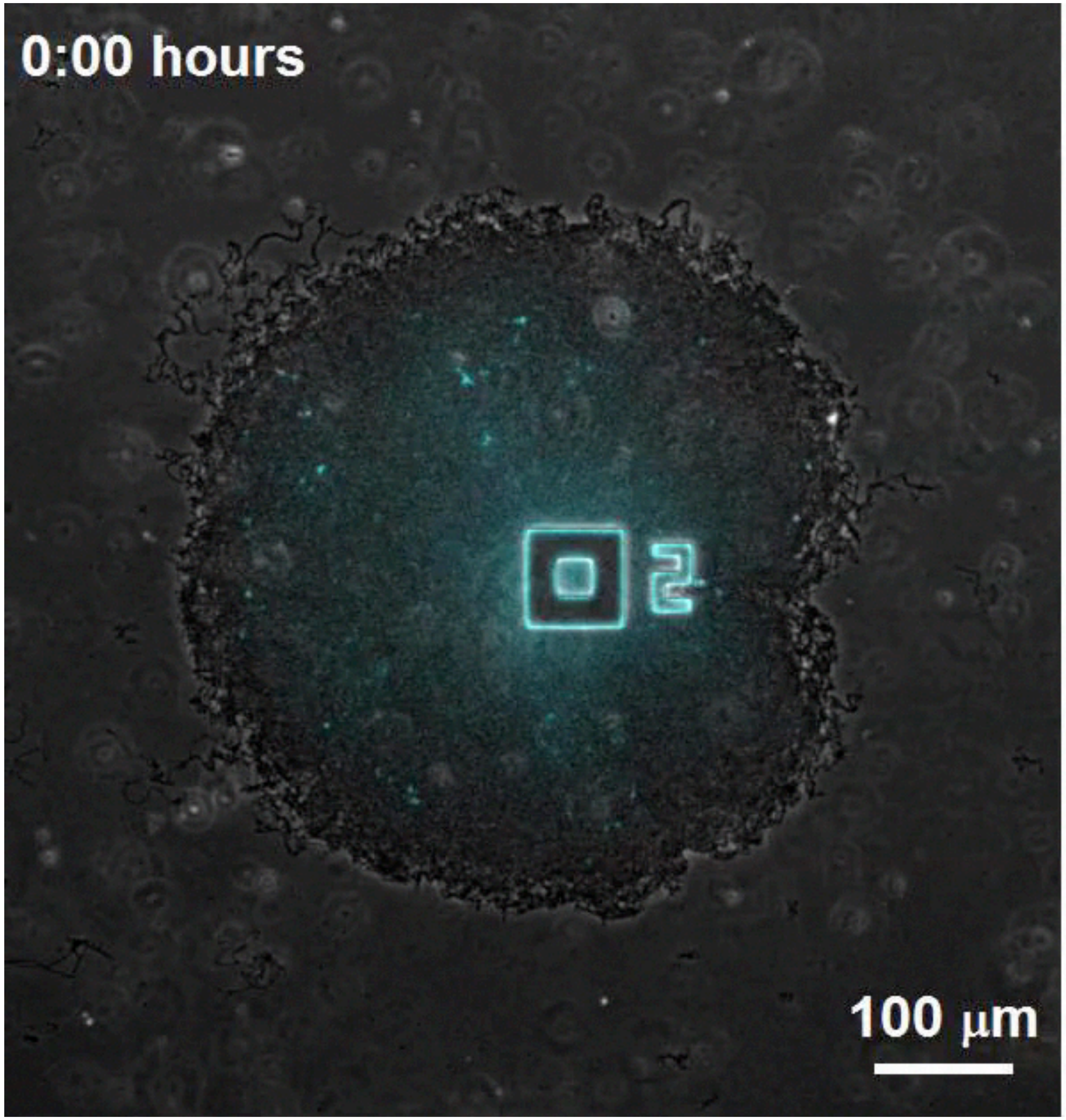


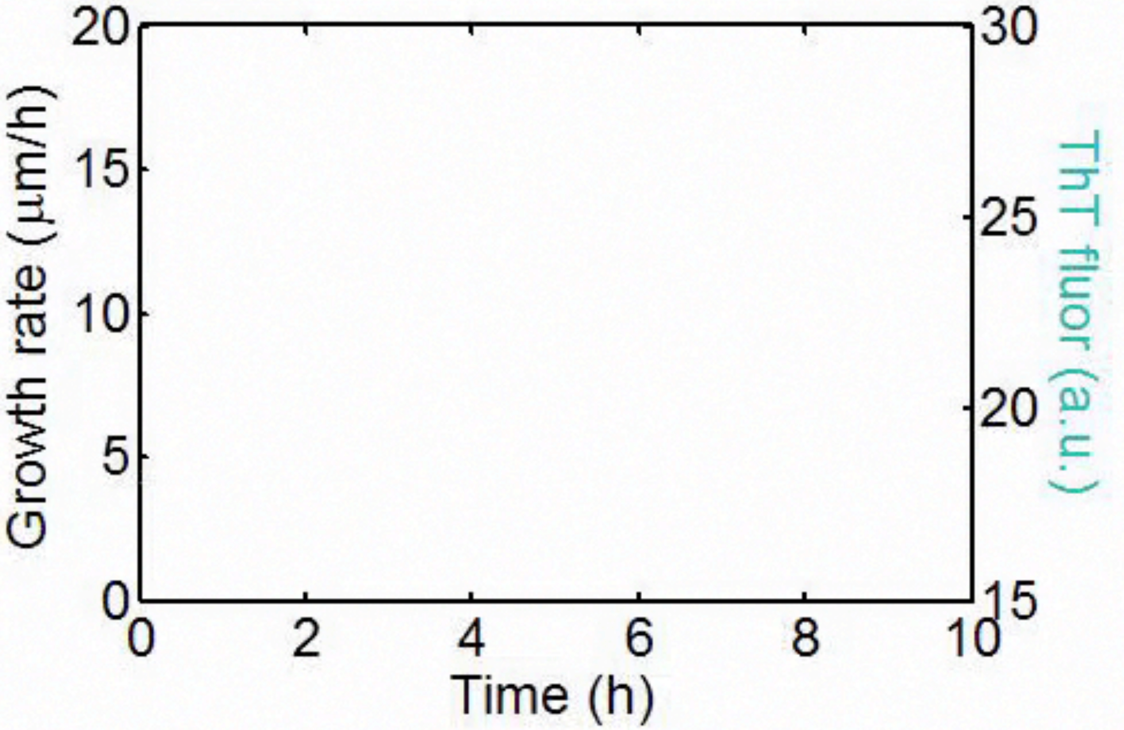
glutamate

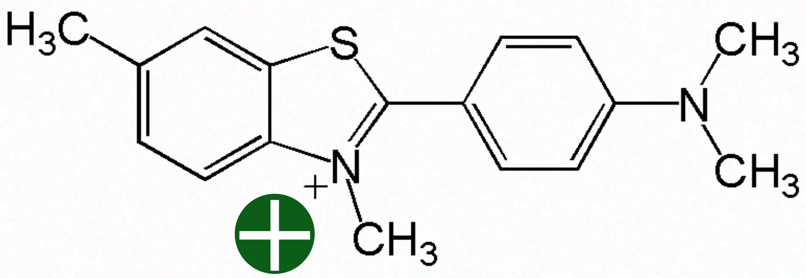


→ glutamate uptake is reduced if the cell depolarizes

ThT oscillations reflect membrane potential oscillations



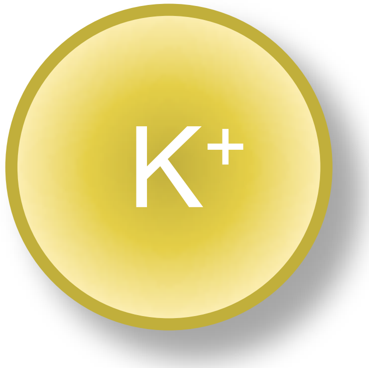




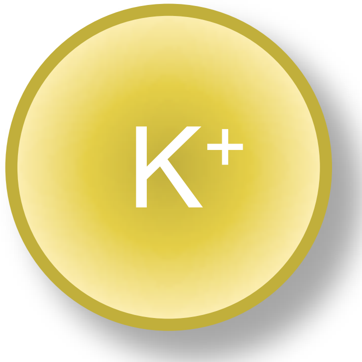
Thioflavine T (ThT)

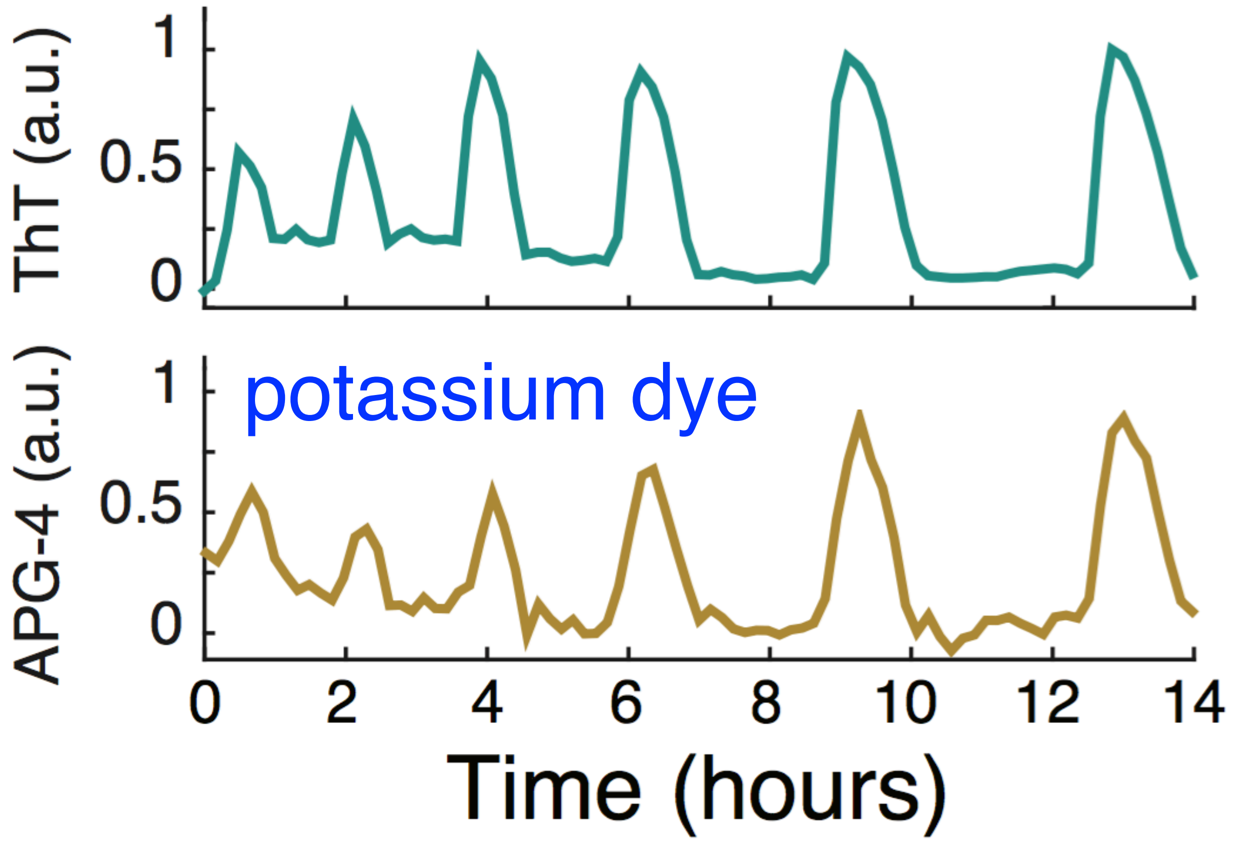
(high when cell is hyperpolarized)

What ions are involved in the membrane potential oscillations?

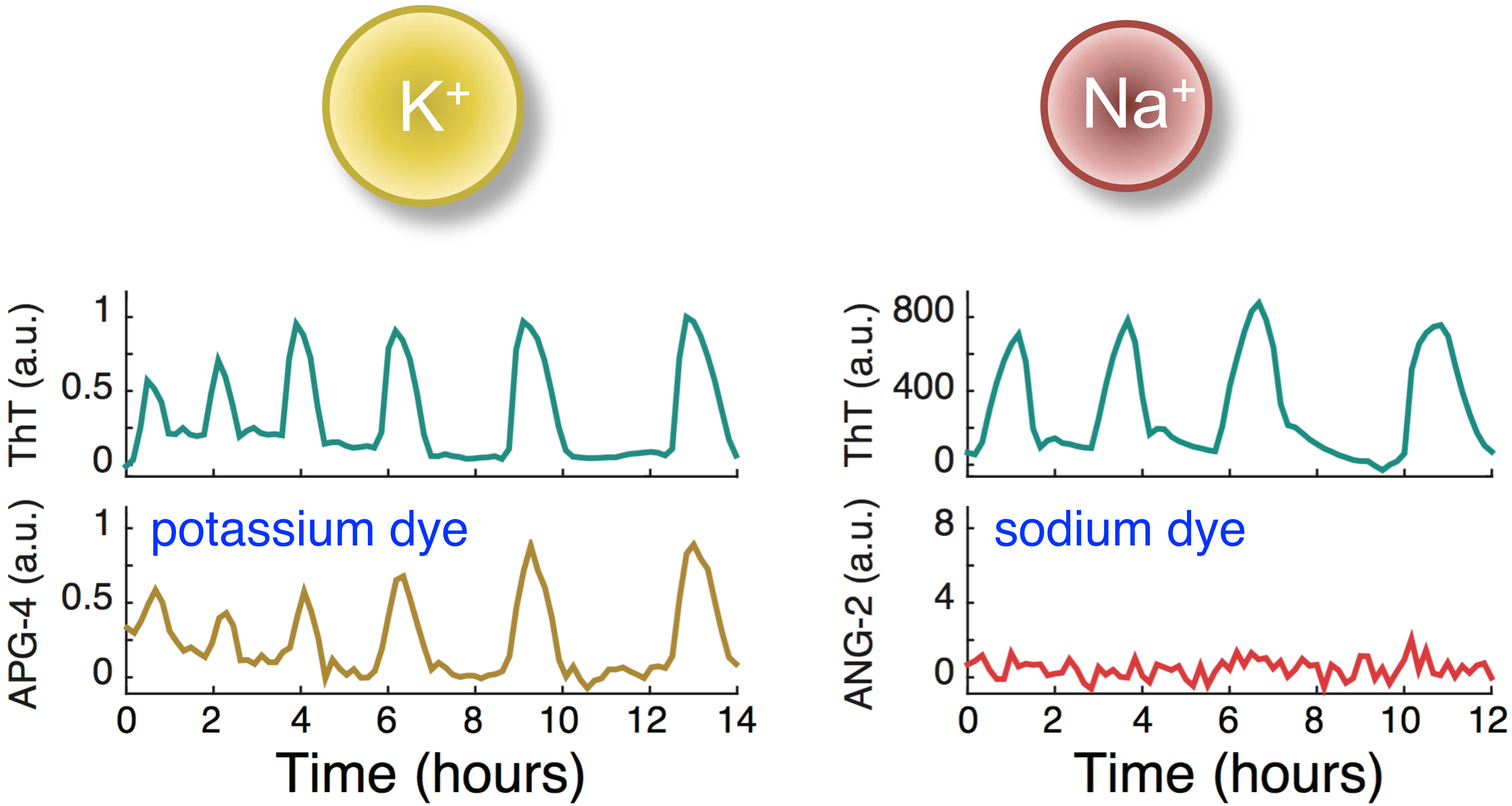


What ions are involved in the membrane potential oscillations?

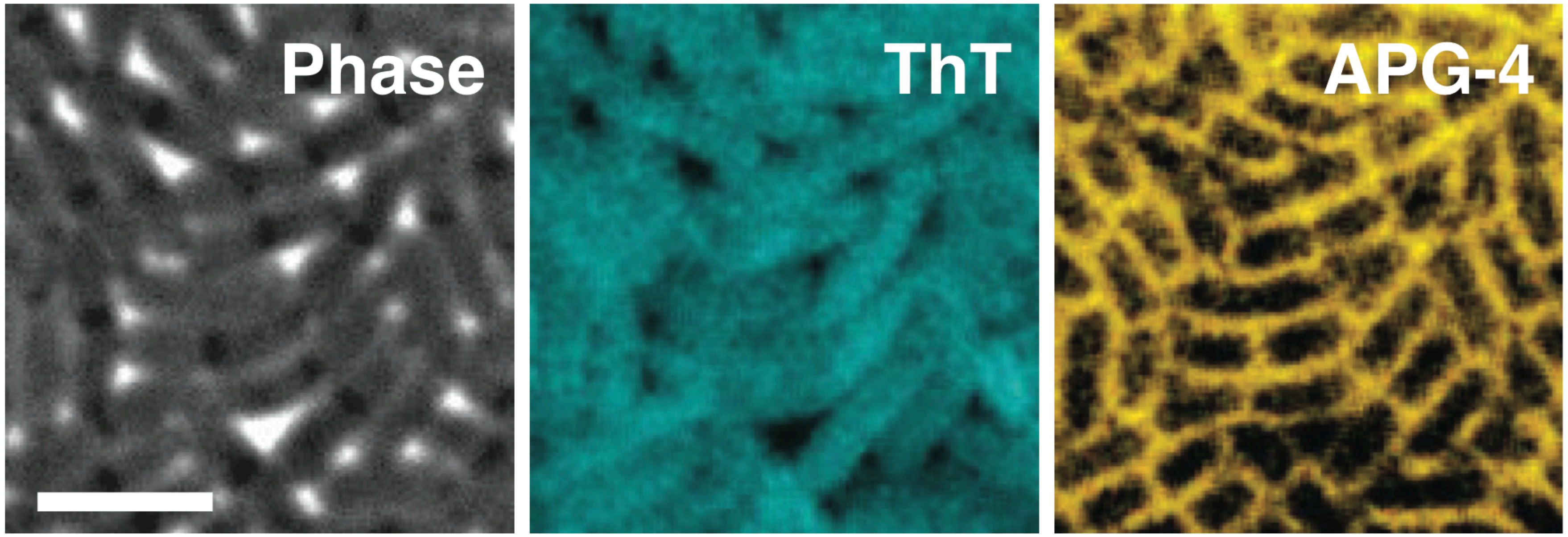


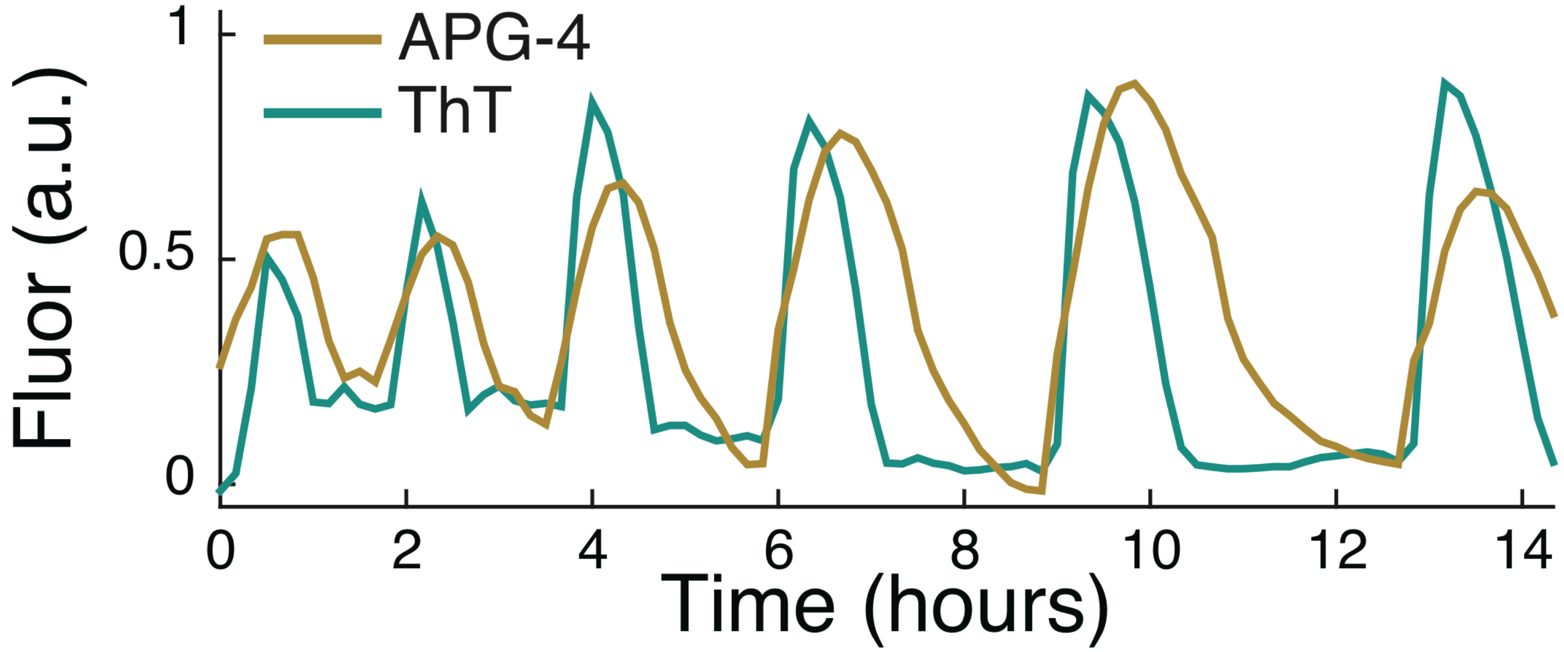


What ions are involved in the membrane potential oscillations?

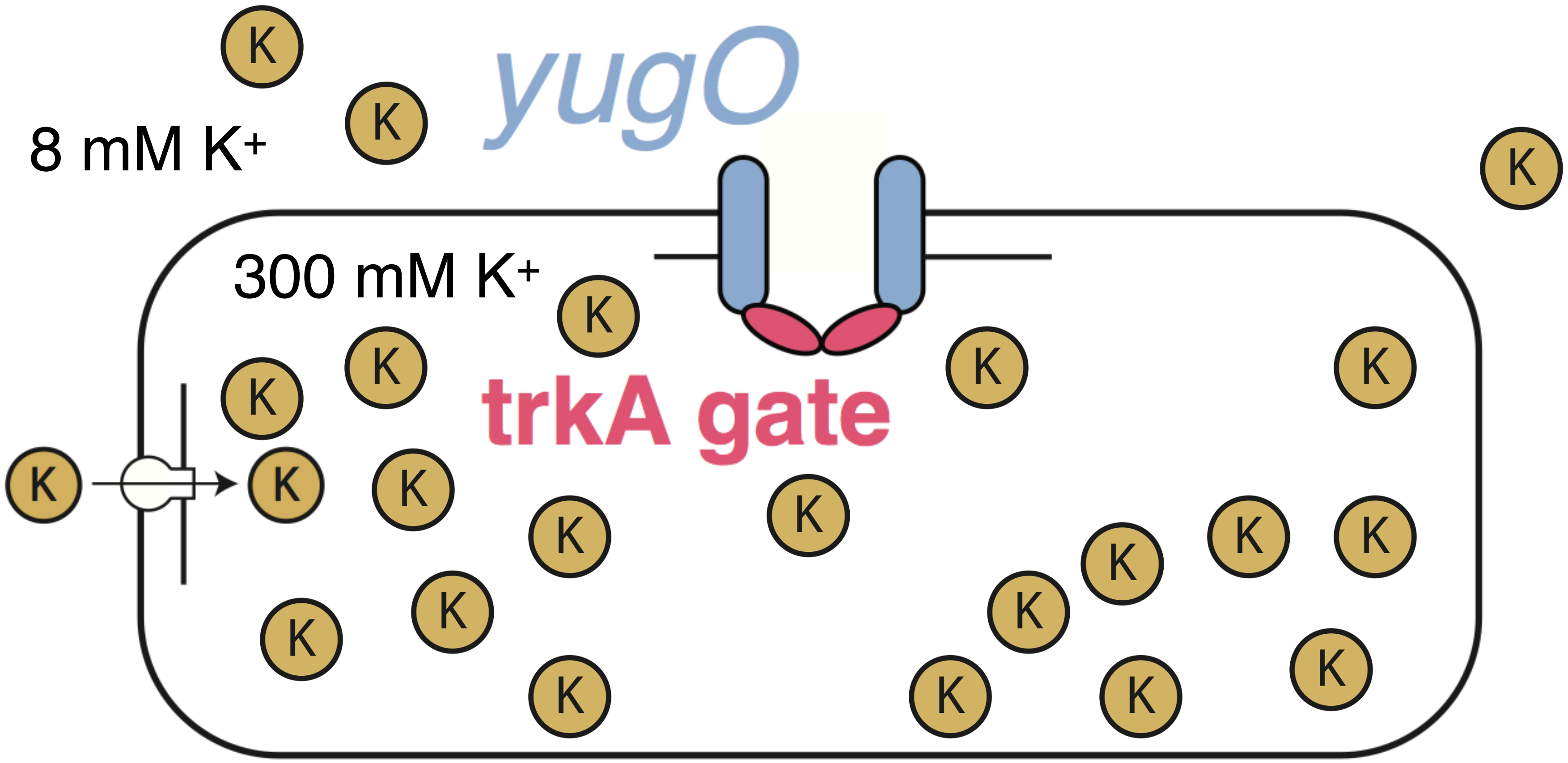


Dynamics of extracellular potassium

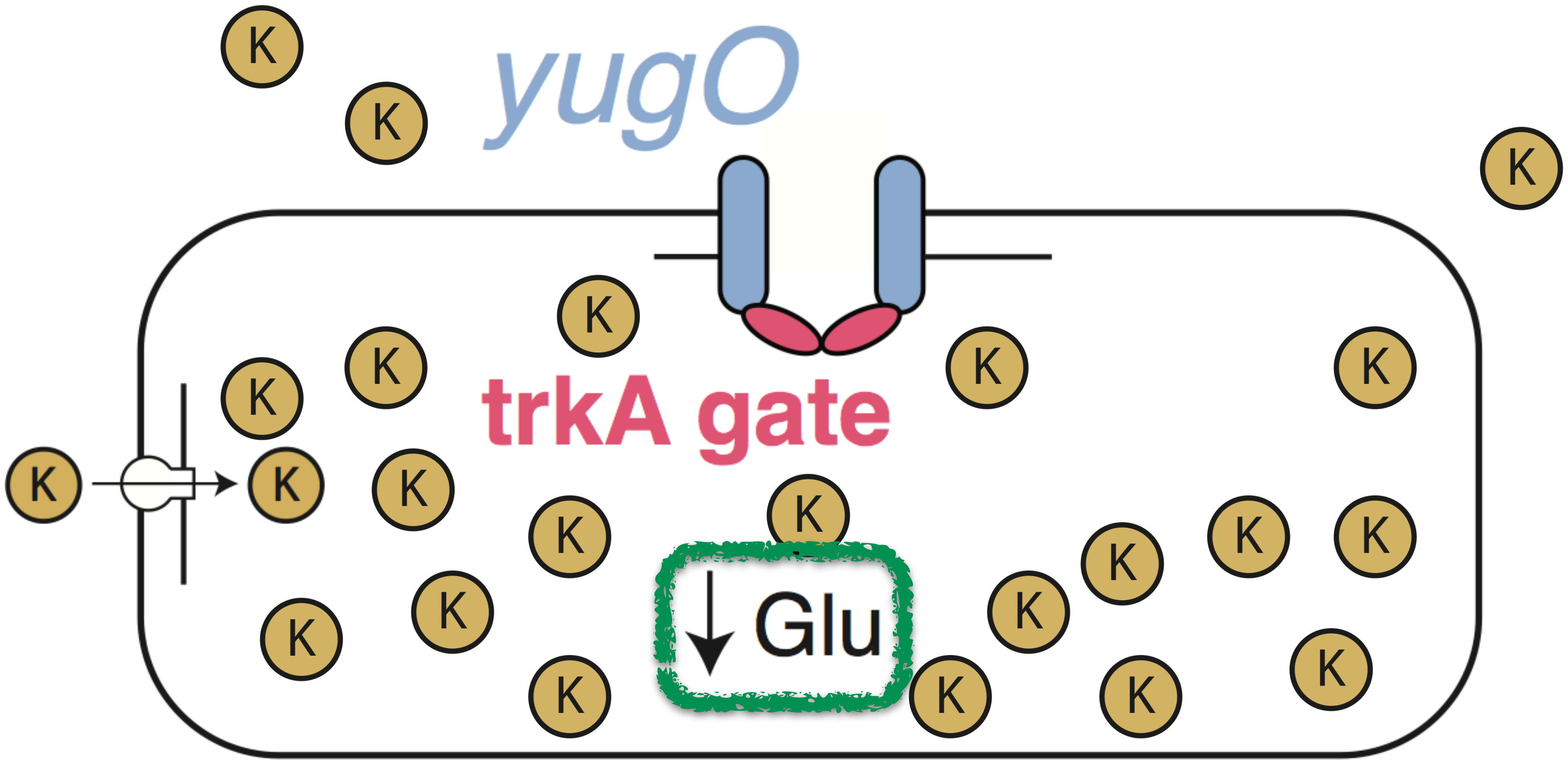




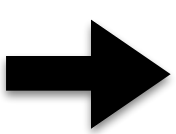
Potassium is concentrated inside the cell



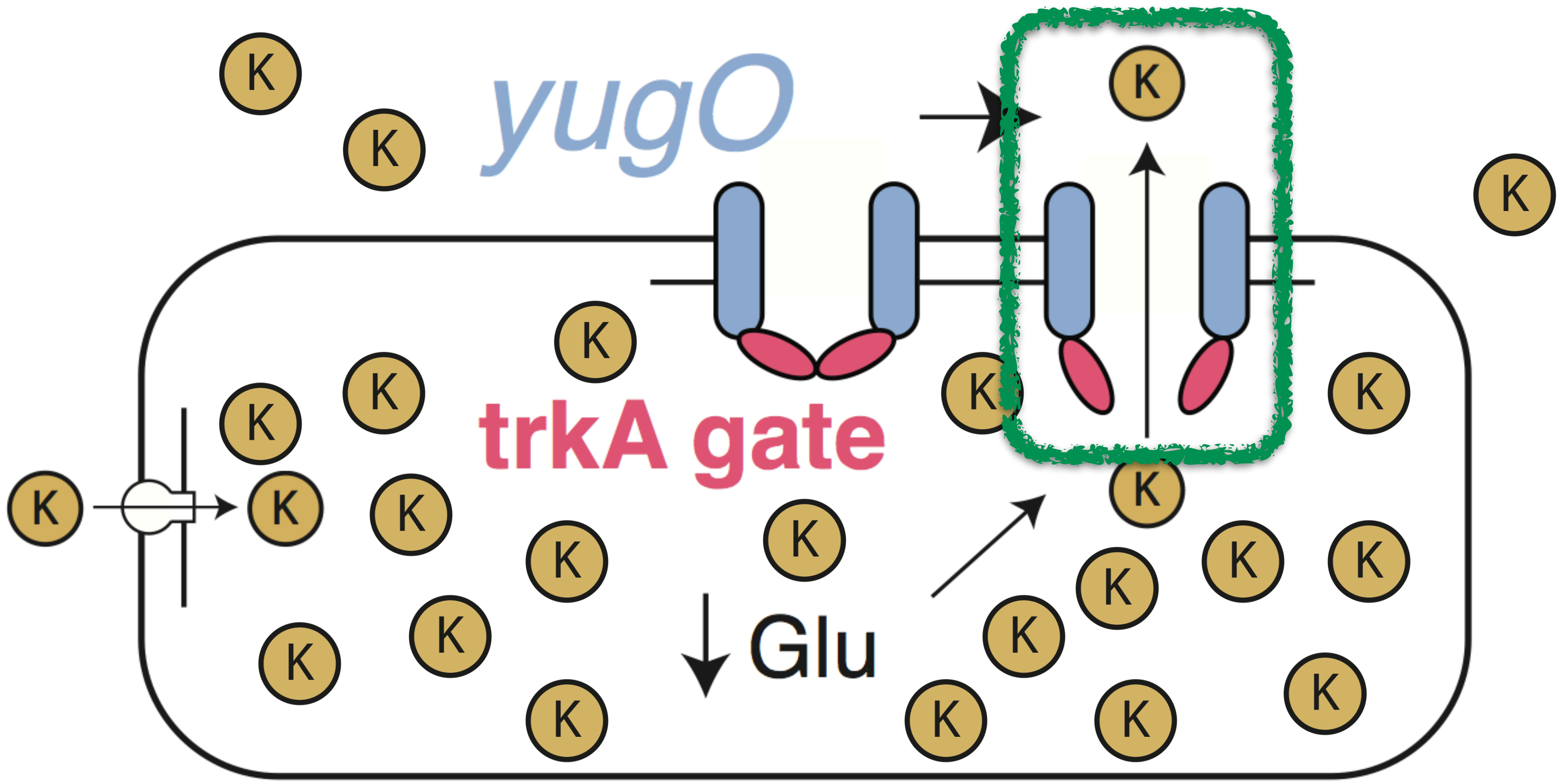
Potassium is released via a stress-gated ion channel



glutamate decrease

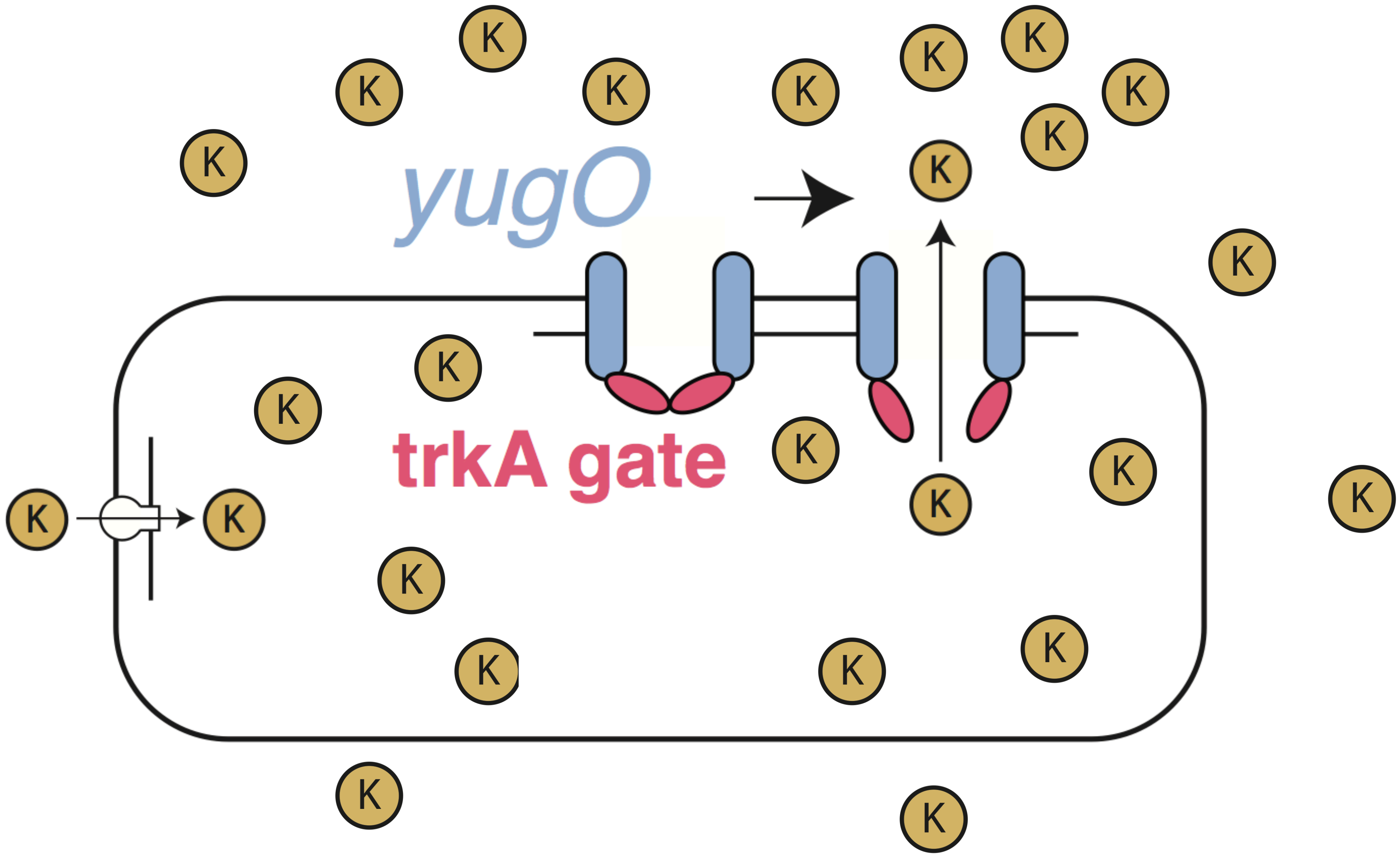


Potassium is released via a stress-gated ion channel



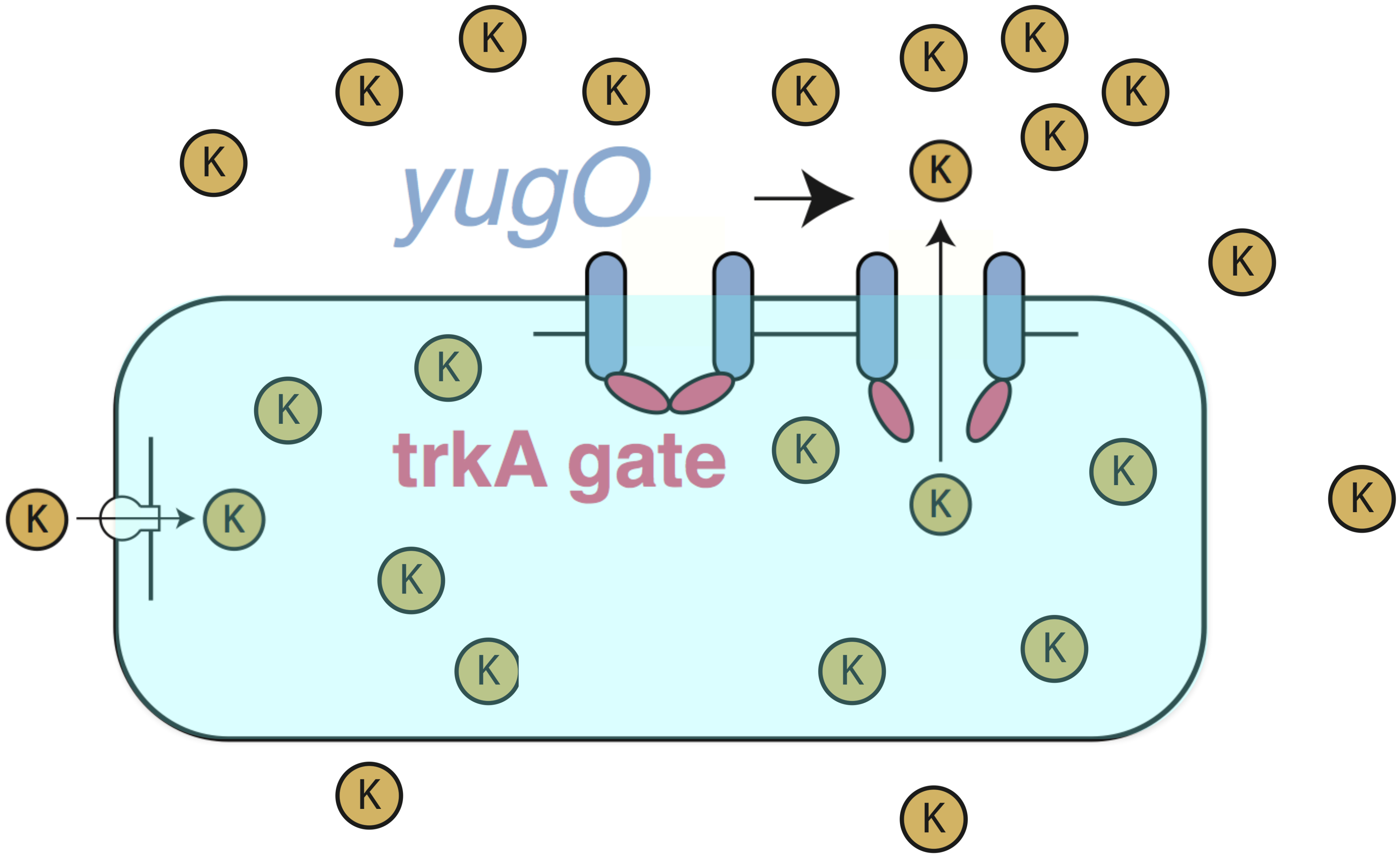
glutamate decrease ➡ channel opens ➡

Potassium is released via a stress-gated ion channel



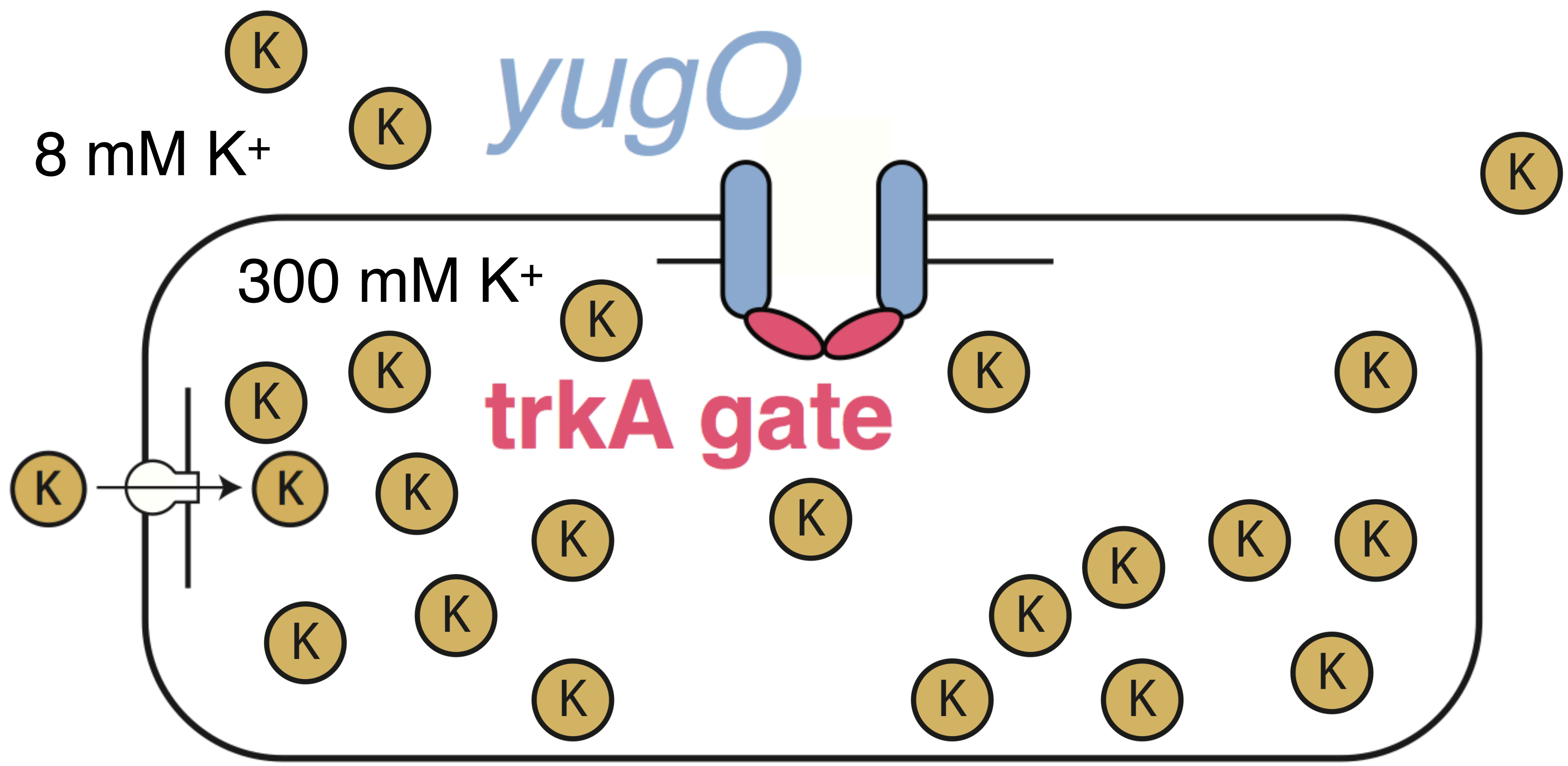
glutamate decrease ➡ channel opens ➡ potassium released ➡

Potassium release hyperpolarizes the cell



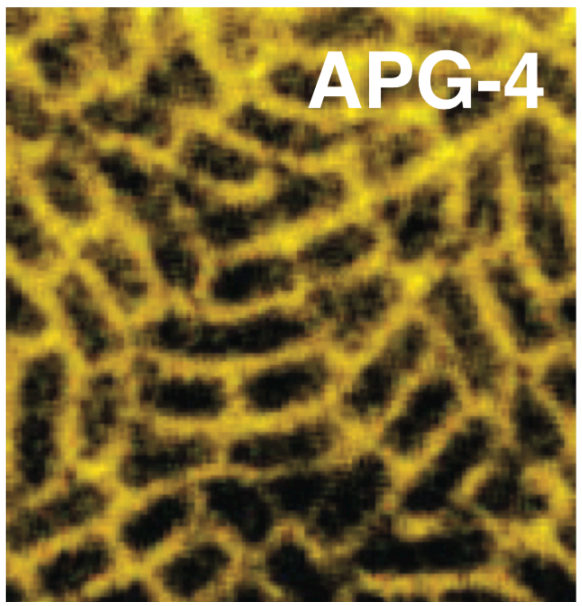
glutamate decrease → channel opens → potassium released → cell hyperpolarizes (high ThT) →

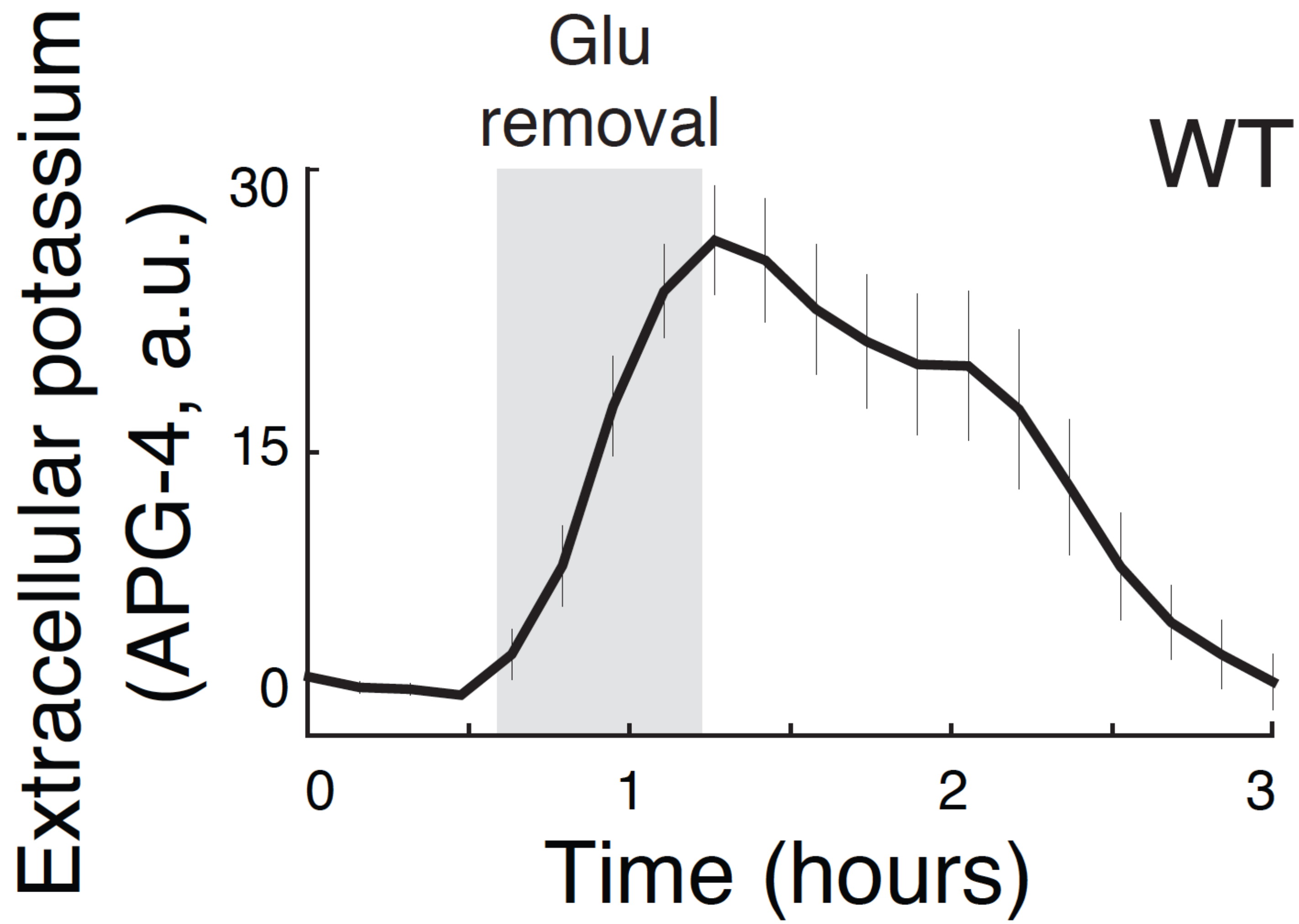
Hyperpolarization allows glutamate uptake again



glutamate decrease → channel opens → potassium released → cell hyperpolarizes (high ThT) → glutamate uptake

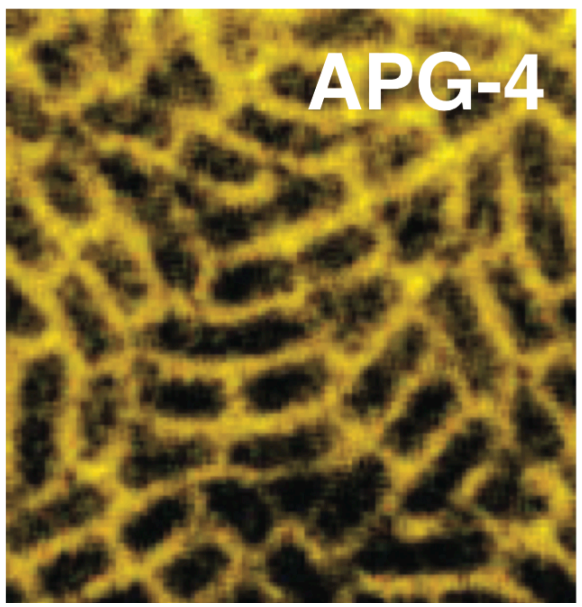
Testing the mechanism: glutamate removal triggers potassium release

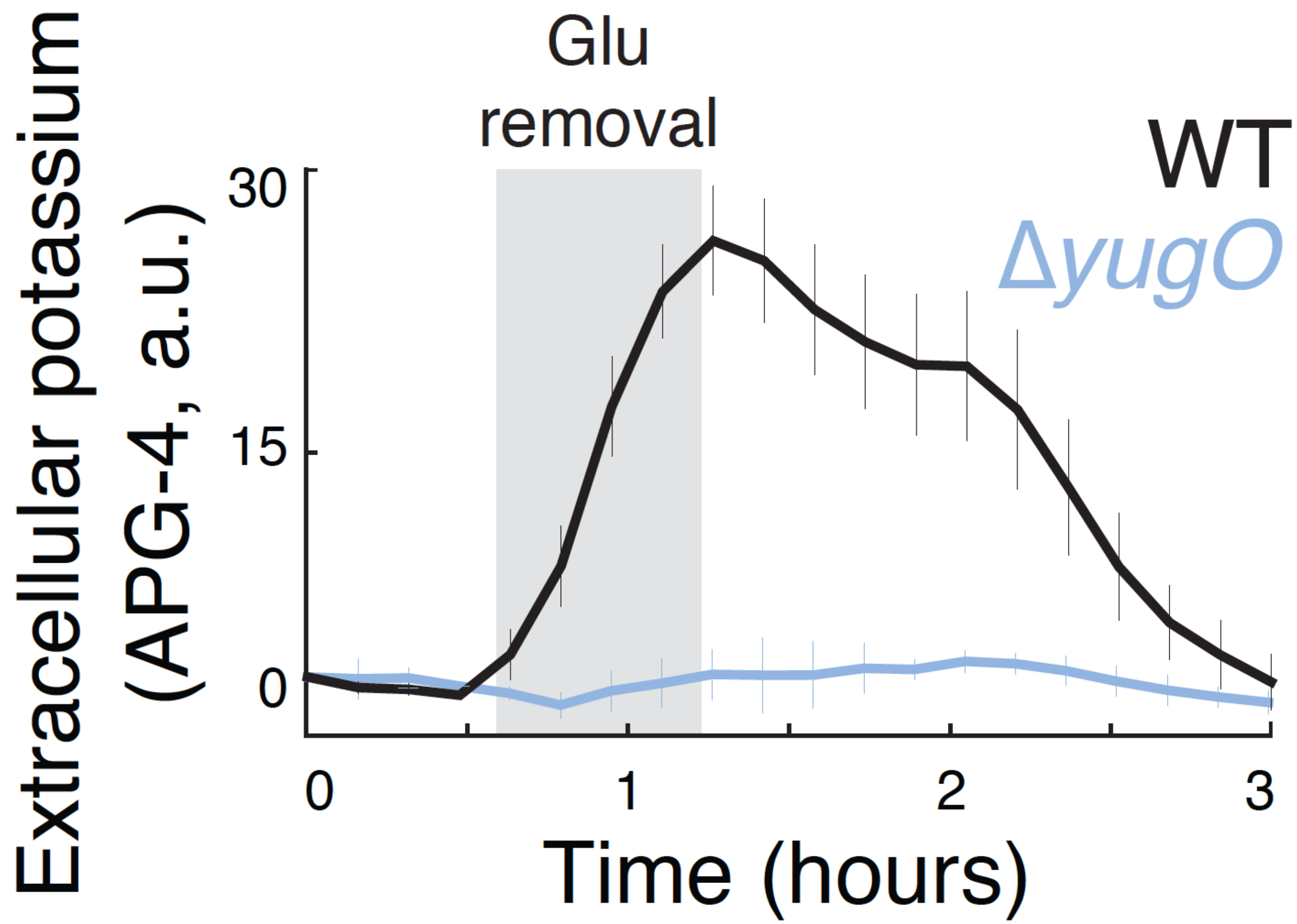




glutamate decrease → channel opens → potassium released → cell hyperpolarizes (high ThT) → glutamate uptake

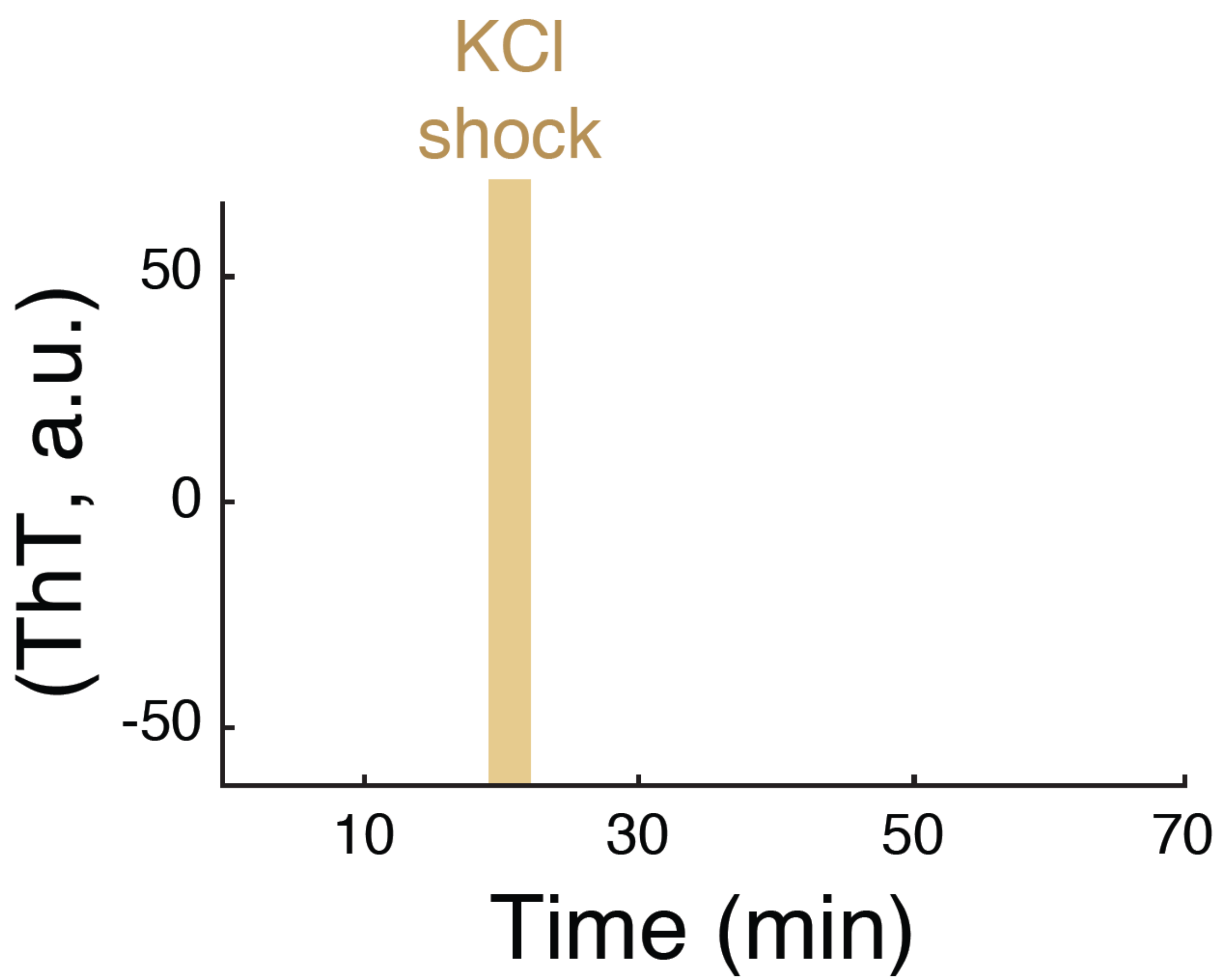
Testing the mechanism: channel opening leads to potassium release



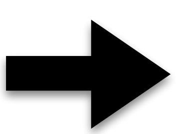


glutamate decrease → channel opens → potassium released → cell hyperpolarizes (high ThT) → glutamate uptake

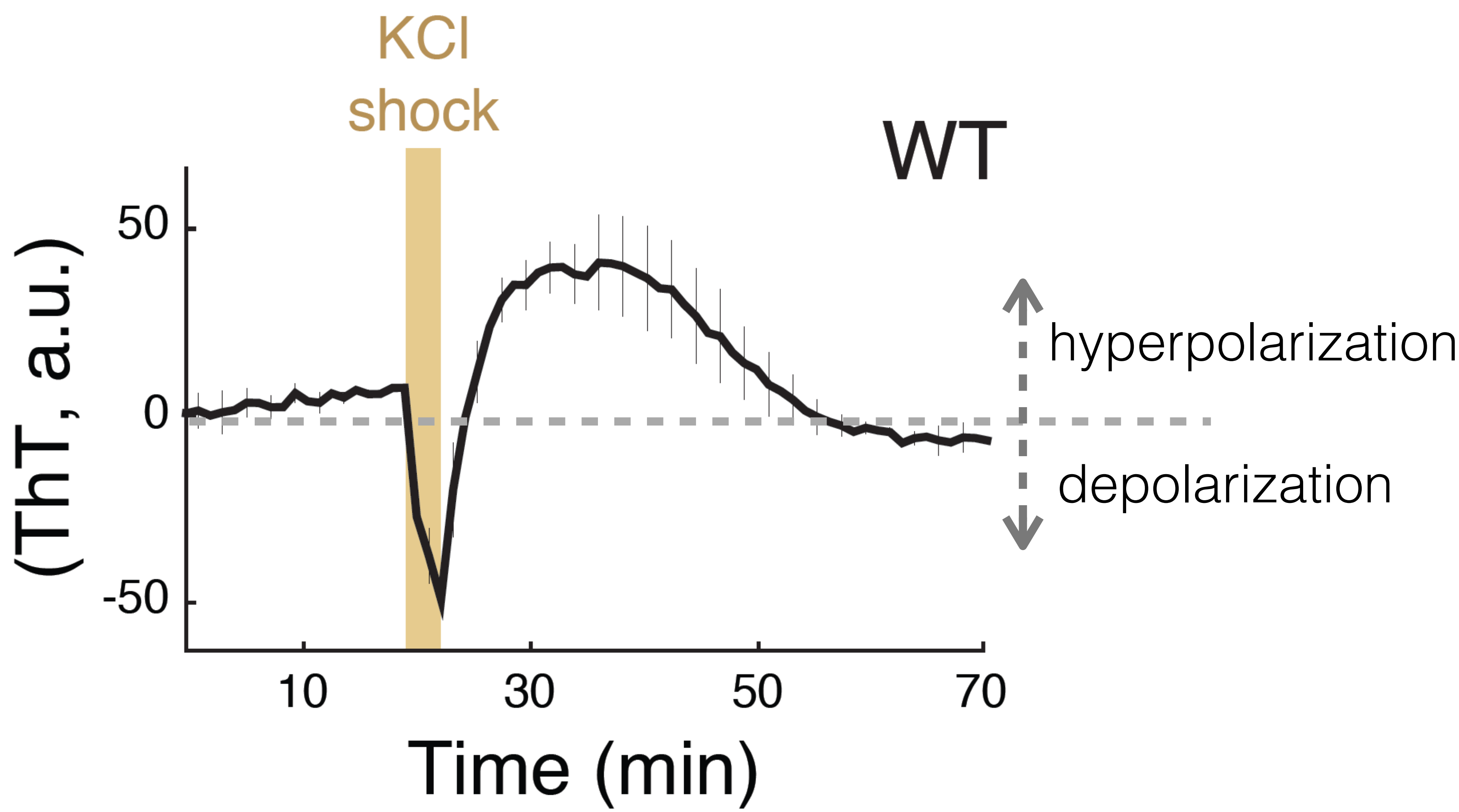
Potassium exposure also triggers potassium release



potassium exposure

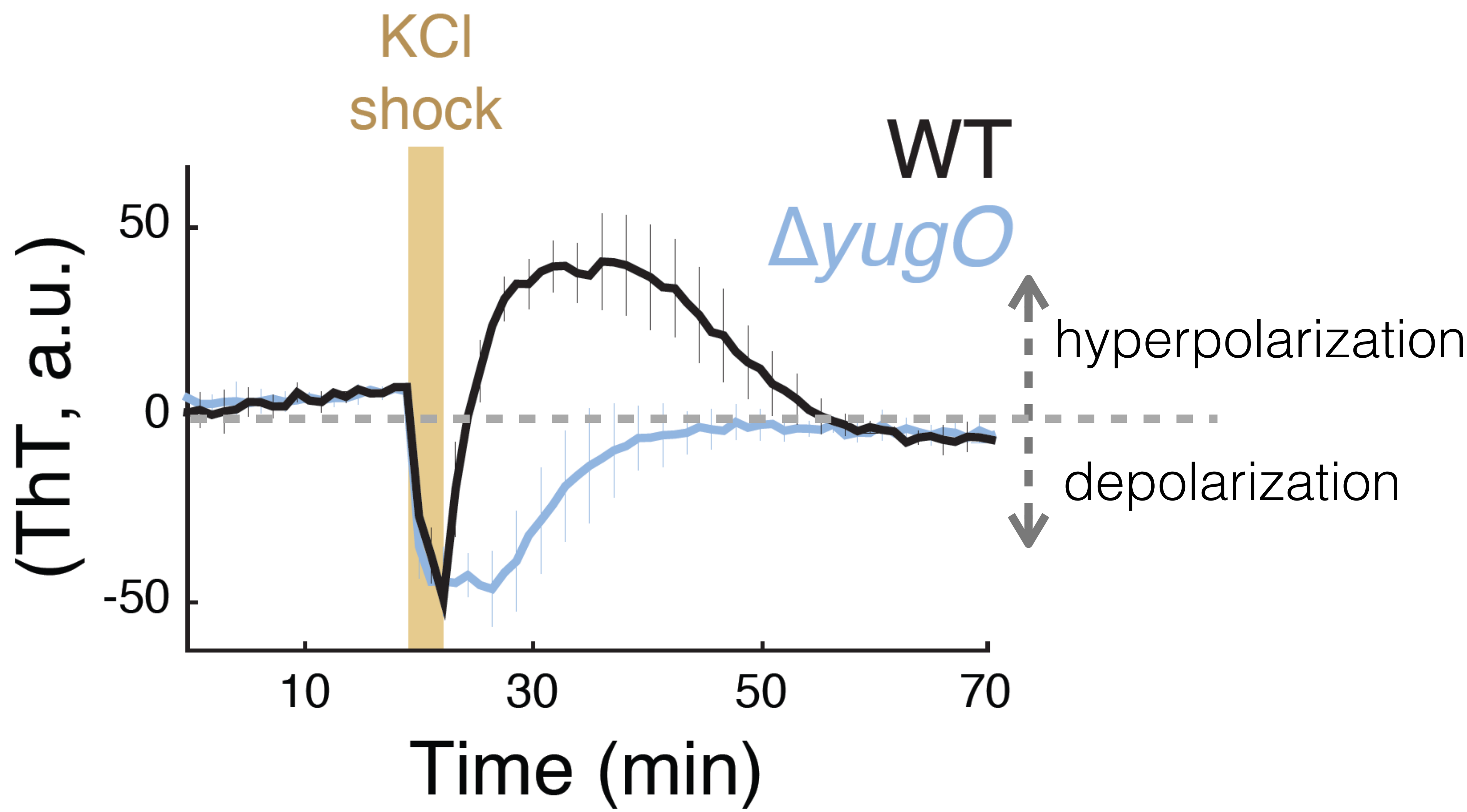


Potassium exposure also triggers potassium release



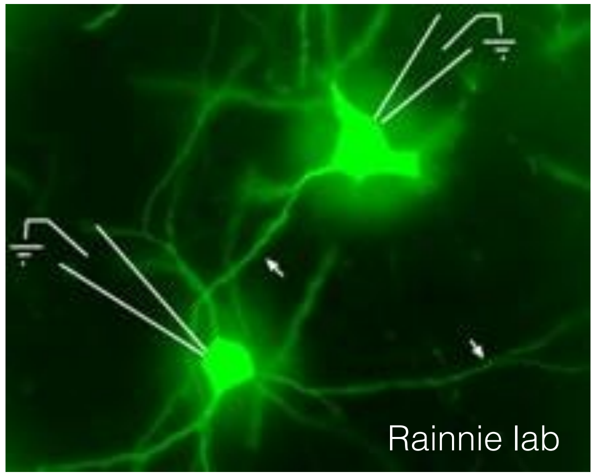
potassium exposure → cell depolarizes (low ThT) → channel opens → potassium released → cell hyperpolarizes (high ThT)

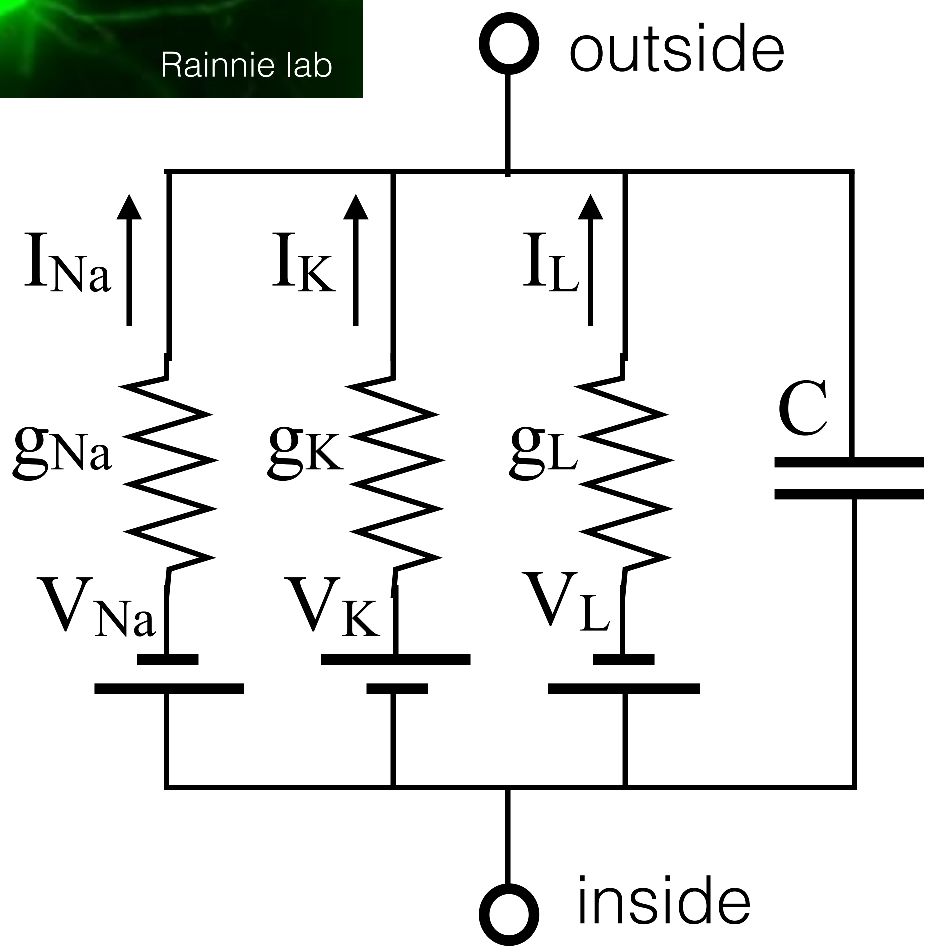
Potassium exposure also triggers potassium release



potassium exposure → cell depolarizes (low ThT) → channel opens → potassium released → cell hyperpolarizes (high ThT)

Hodgkin-Huxley model of neuronal electrophysiology





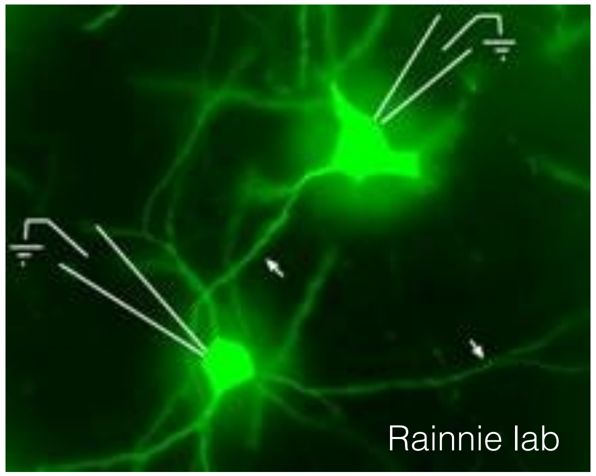
$$C\frac{dV}{dt} = \underbrace{-g_{\rm Na}m^3h(V-V_{\rm Na})}_{\text{sodium current}} \underbrace{-\, g_{\rm K}n^4(V-V_{\rm K})}_{\text{potassium current}} \underbrace{-\, g_{\rm L}(V-V_{\rm L})}_{\text{leak current}}$$

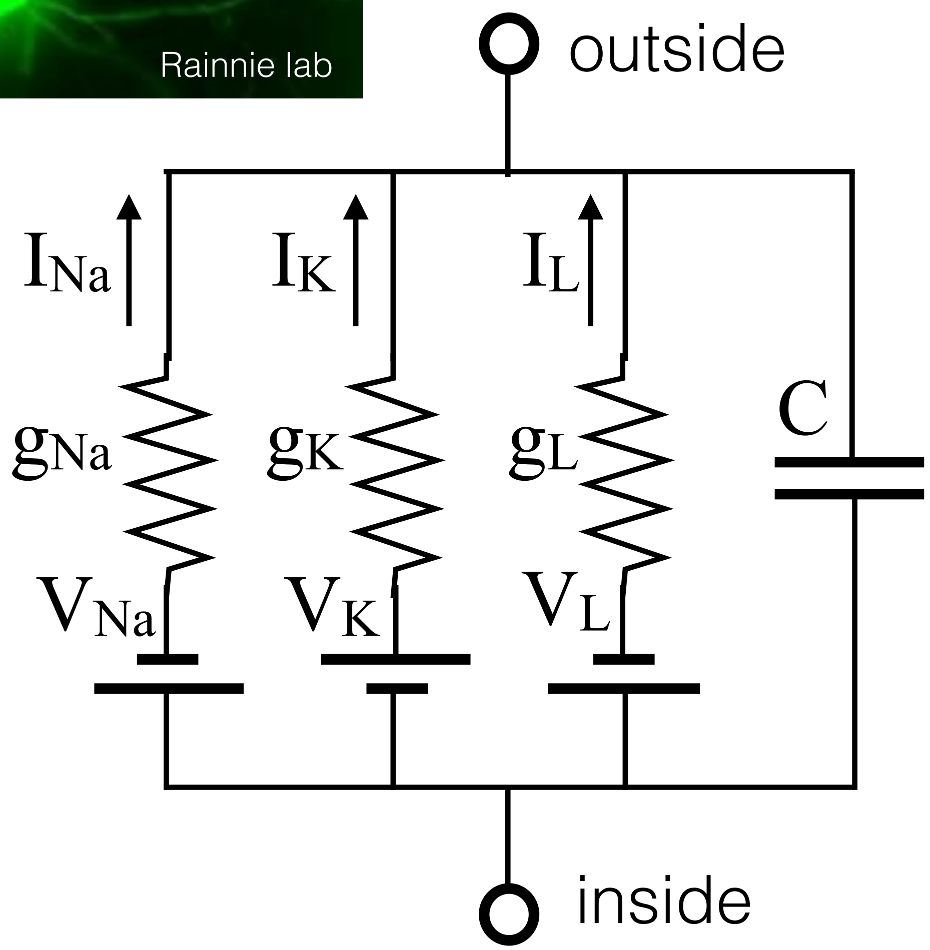
sodium current

potassium current

leak current

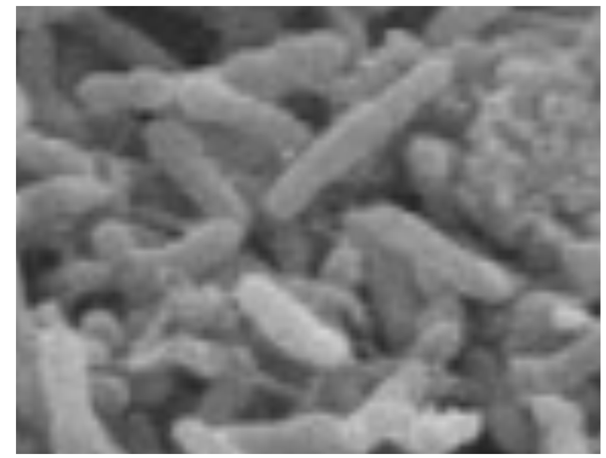
Hodgkin-Huxley model of neuronal electrophysiology

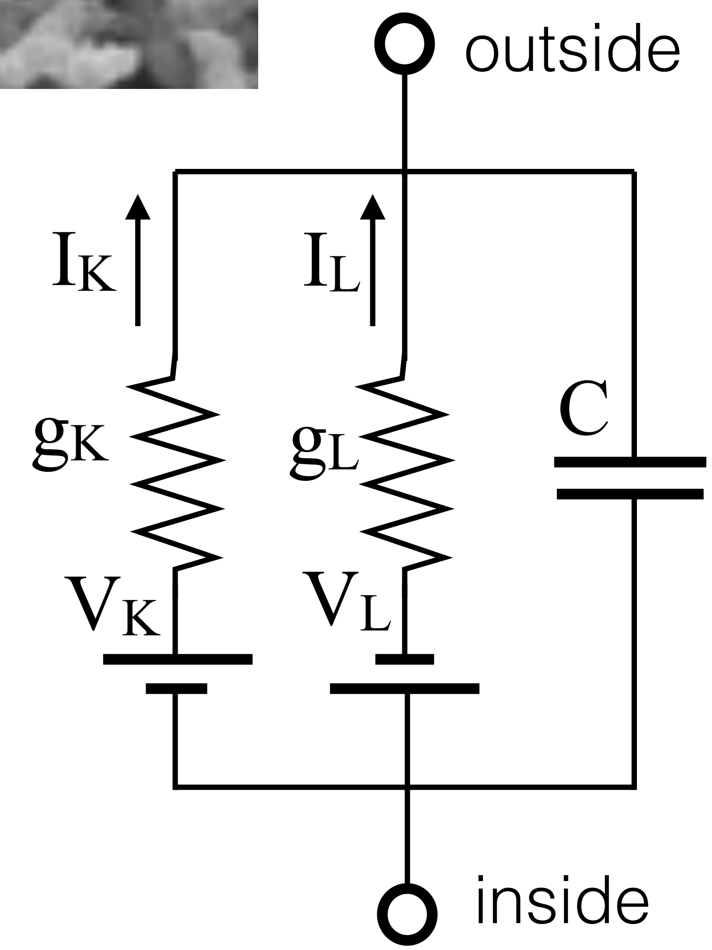




$$C\frac{dV}{dt} = \underbrace{-g_{Na}m^3h(V - V_{Na})}_{\text{sodium current}} - \underbrace{g_K n^4(V - V_K)}_{\text{potassium current}} - \underbrace{g_L(V - V_L)}_{\text{leak current}}$$

K-channel model of bacterial electrophysiology

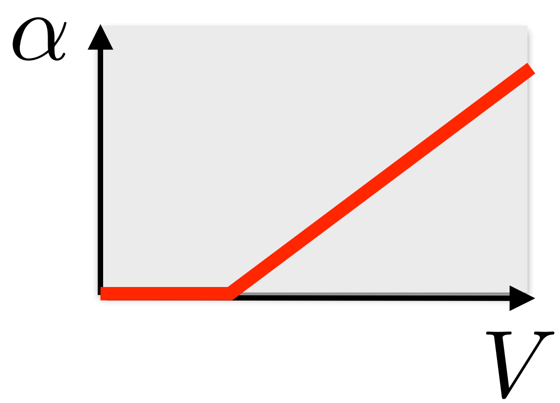




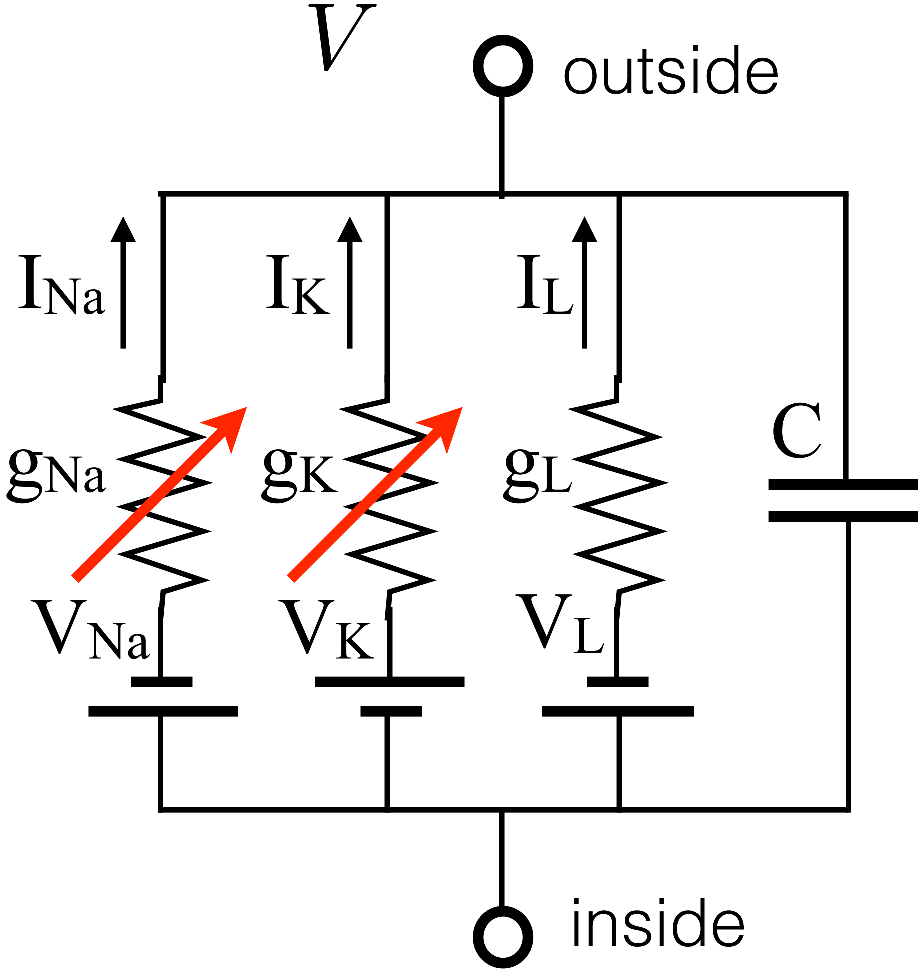
$$C\frac{dV}{dt} = \underbrace{-g_K n^4(V - V_K)}_{\text{potassium current}} - \underbrace{g_L(V - V_L)}_{\text{leak current}}$$

Hodgkin-Huxley model of neuronal electrophysiology

K-channel model of bacterial electrophysiology

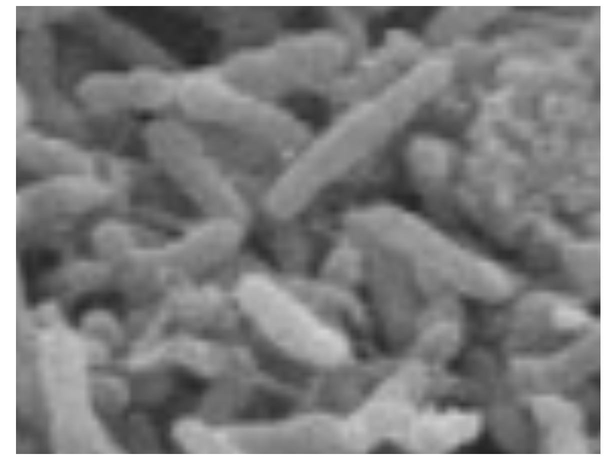


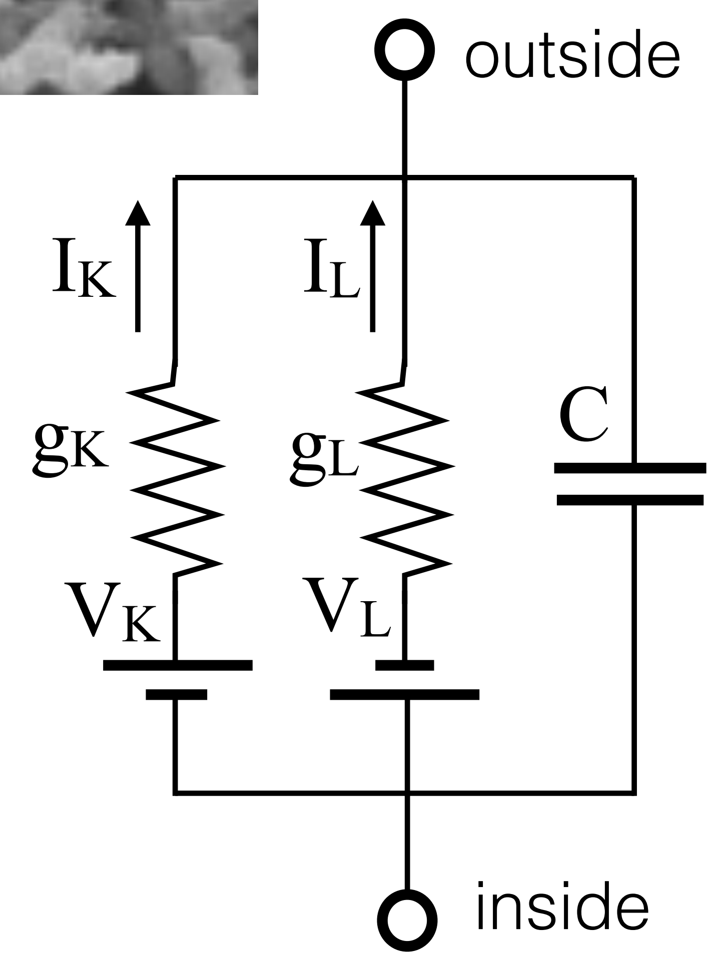
voltage-gated conductance



$$C\frac{dV}{dt} = -g_{\mathrm{Na}}\underline{m^3 h}(V - V_{\mathrm{Na}}) - g_{\mathrm{K}}\underline{n^4}(V - V_{\mathrm{K}}) - g_{\mathrm{L}}(V - V_{\mathrm{L}})$$

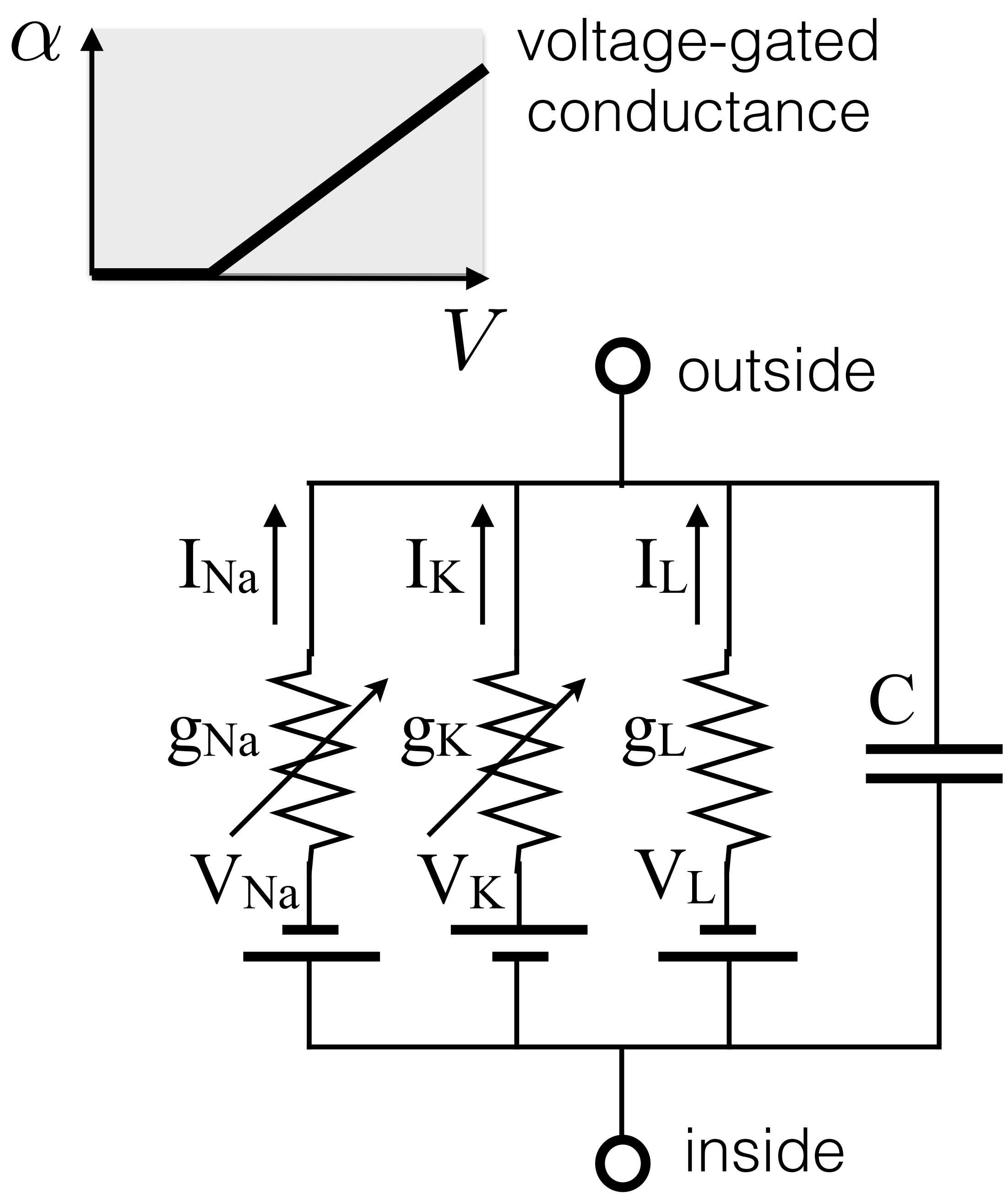
$$\frac{dn}{dt} = \alpha(V)(1-n) - \beta(V)n$$





$$C\frac{dV}{dt} = \underbrace{-g_{\mathrm{K}}n^4(V - V_{\mathrm{K}})}_{\text{potassium current}} \underbrace{- g_{\mathrm{L}}(V - V_{\mathrm{L}})}_{\text{leak current}}$$

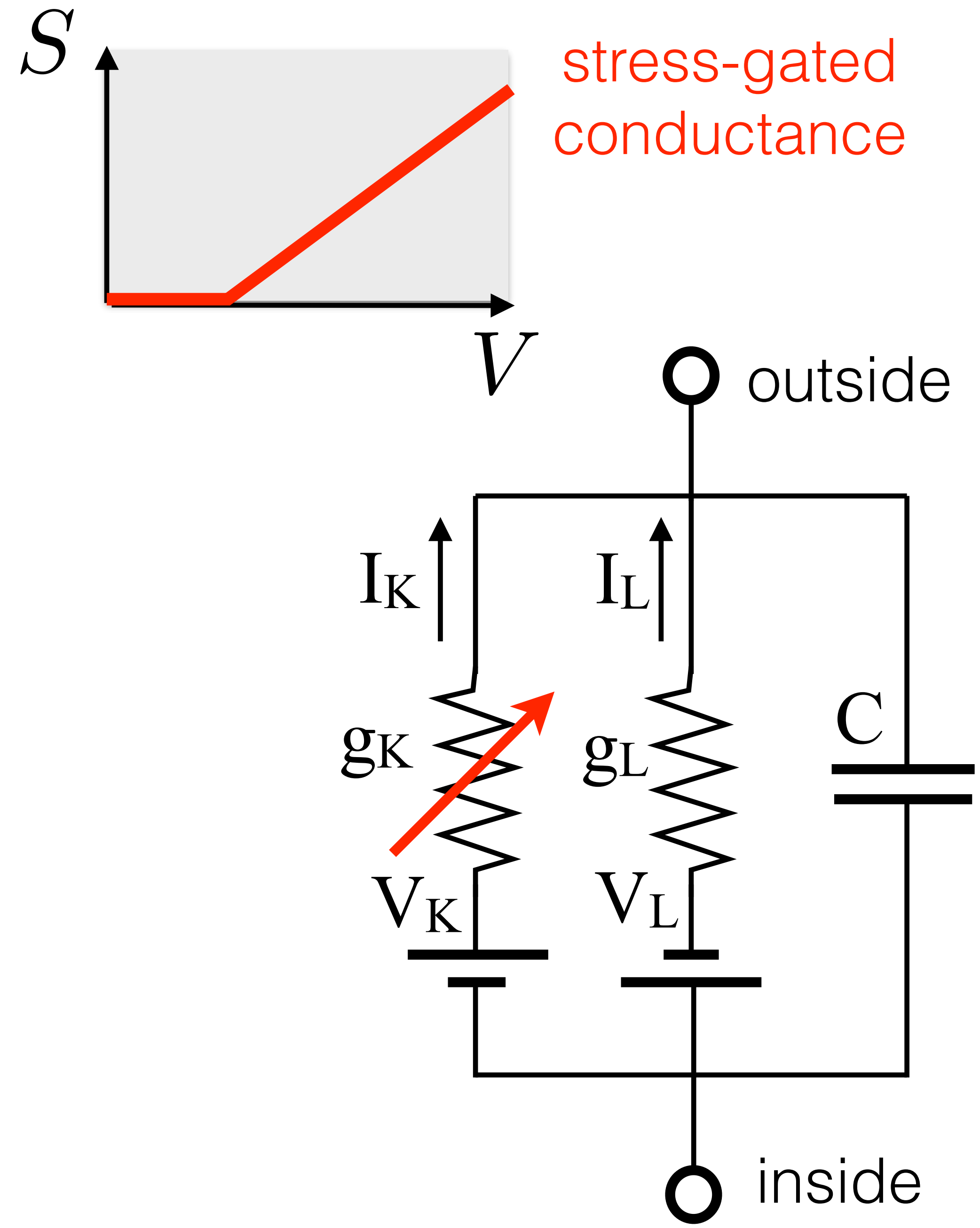
Hodgkin-Huxley model of neuronal electrophysiology



$$C\frac{dV}{dt} = -g_{\mathrm{Na}}m^3h(V - V_{\mathrm{Na}}) - g_{\mathrm{K}}n^4(V - V_{\mathrm{K}}) - g_{\mathrm{L}}(V - V_{\mathrm{L}})$$

$$\frac{dn}{dt} = \alpha(V)(1-n) - \beta(V)n$$

K-channel model of bacterial electrophysiology



$$C\frac{dV}{dt} = -g_{\mathrm{K}}\underline{n^4}(V - V_{\mathrm{K}}) - g_{\mathrm{L}}(V - V_{\mathrm{L}})$$

$$\frac{dn}{dt} = \alpha(S)(1-n) - \beta n$$

K-channel model of bacterial electrophysiology

membrane potential
$$\frac{dV}{dt} = -g_K n^4 (V - V_K) - g_L (V - V_L)$$

opening probability
$$\frac{dn}{dt} = \alpha(S)(1-n) - \beta n$$

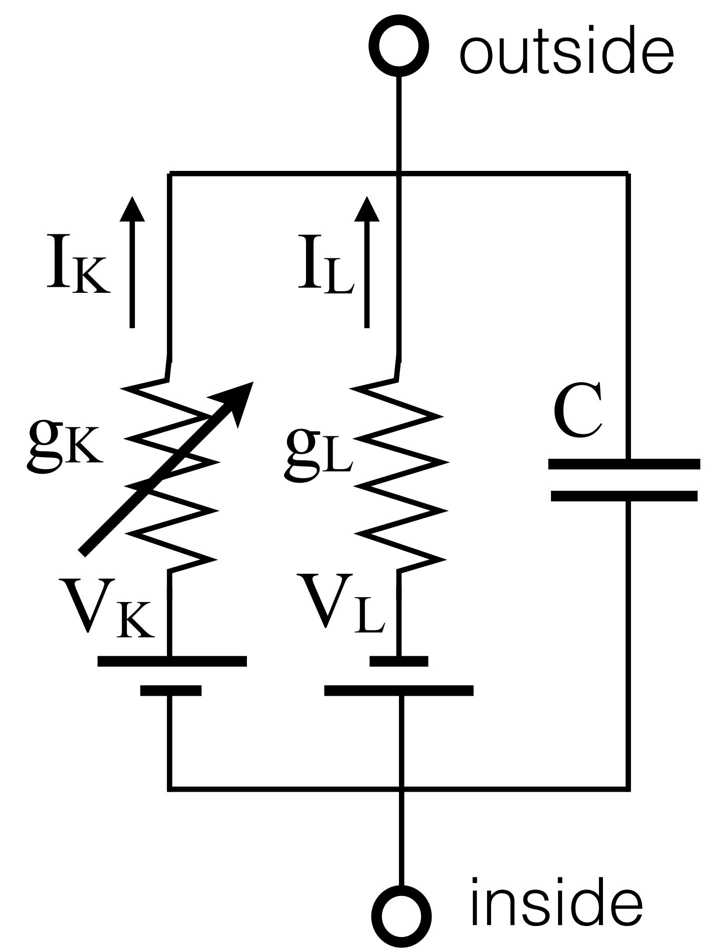
stress gating
$$\alpha(S) = \frac{\alpha_0 S^m}{S_{th}^m + S^m}$$

stress
$$\frac{dS}{dt} = \frac{\alpha_s (V_{th} - V)}{\exp\left(\frac{V_{th} - V}{\sigma}\right) - 1} - \gamma_s S$$

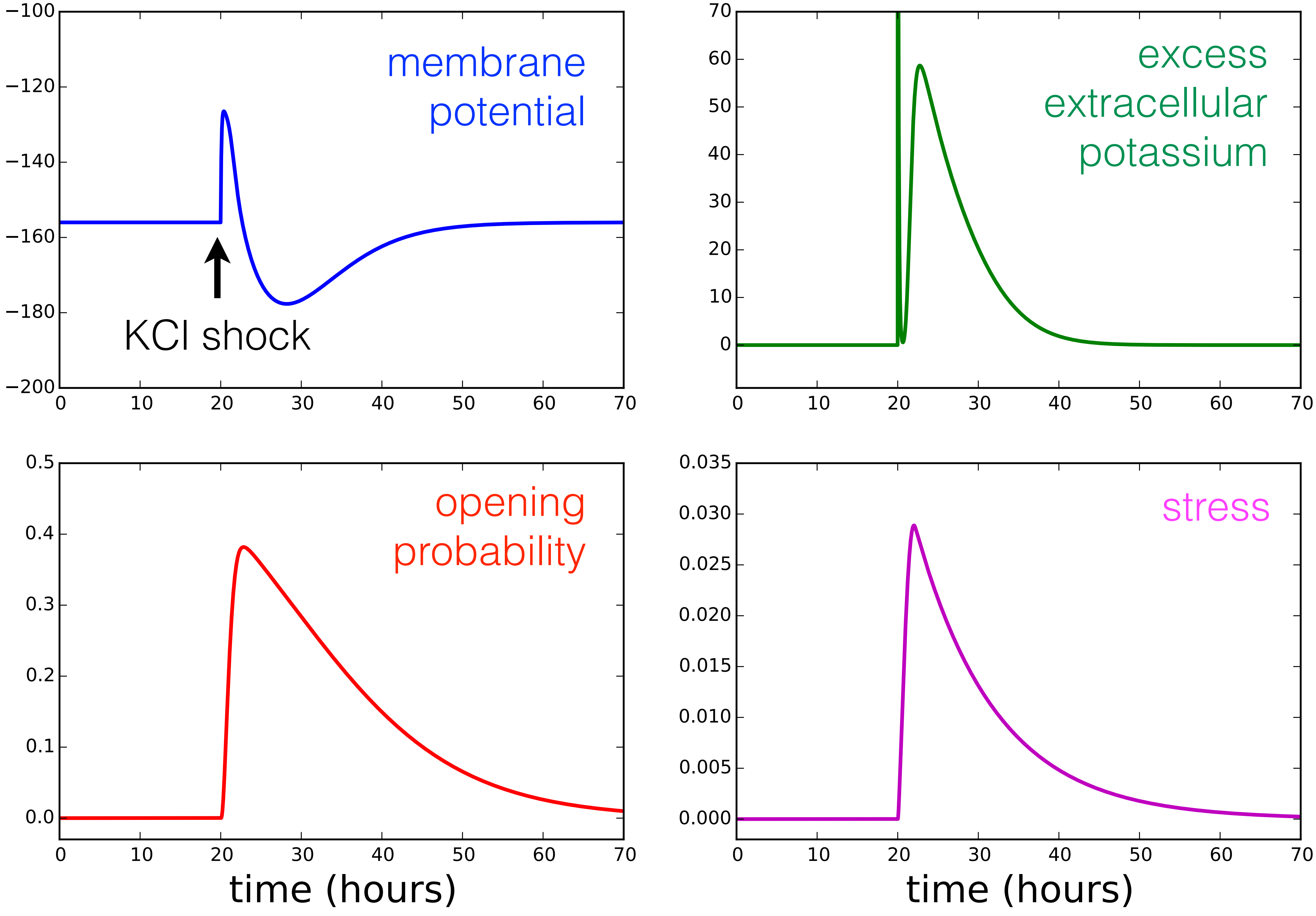
Nernst potentials
$$V_K = V_{K0} + \delta_K E$$
$$V_L = V_{L0} + \delta_L E$$

excess extracellular potassium
$$\frac{dE}{dt} = F g_K n^4 (V - V_K) - \gamma_e E$$

voltage sensor
$$\frac{dT}{dt} = \alpha_t (V_{L0} - V) - \gamma_t T$$

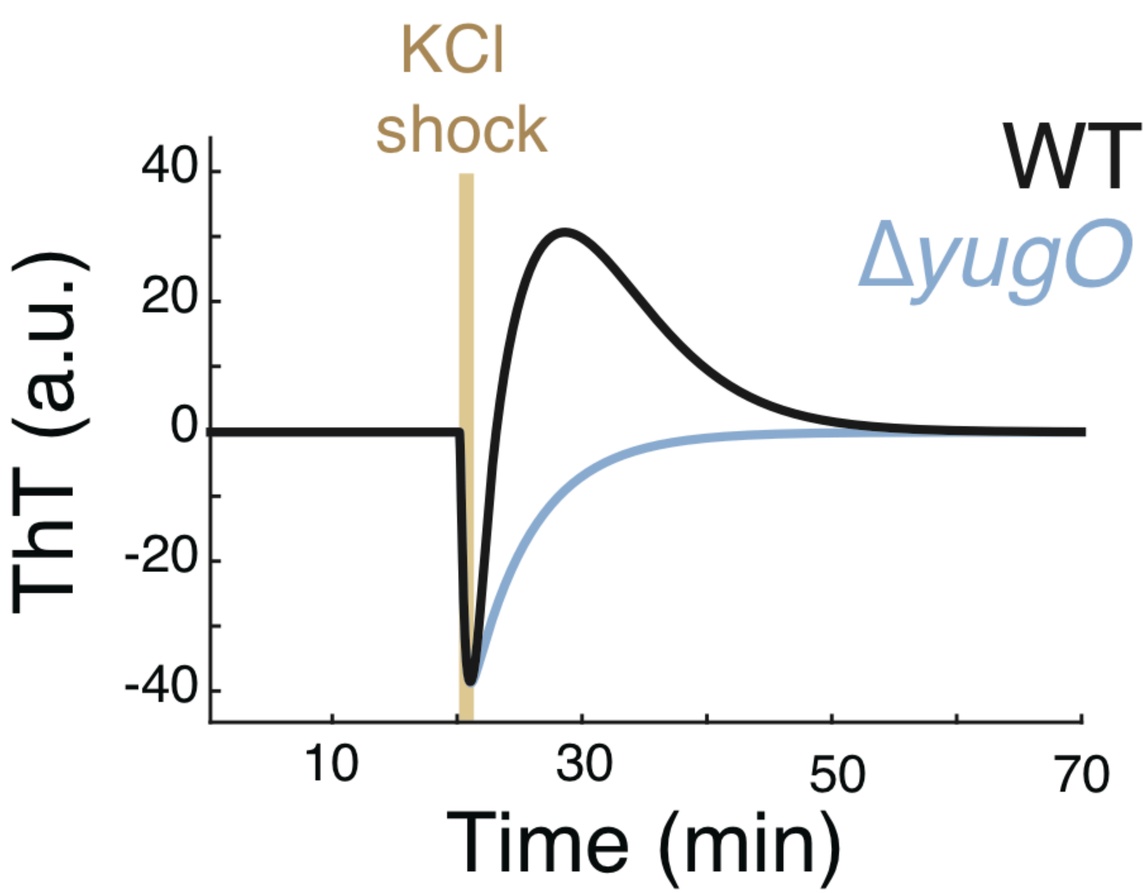


Modeling results

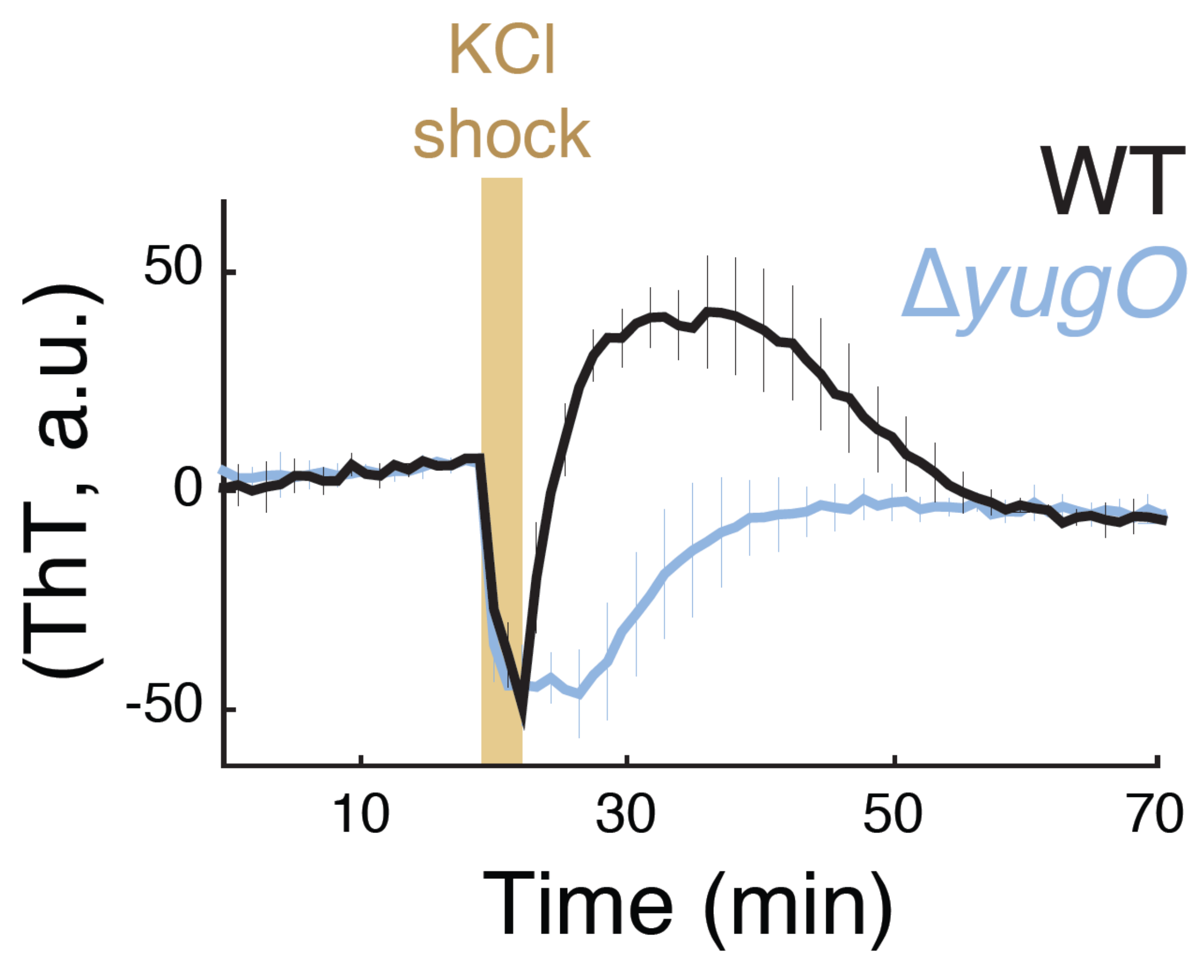


Comparison with experiments

Model

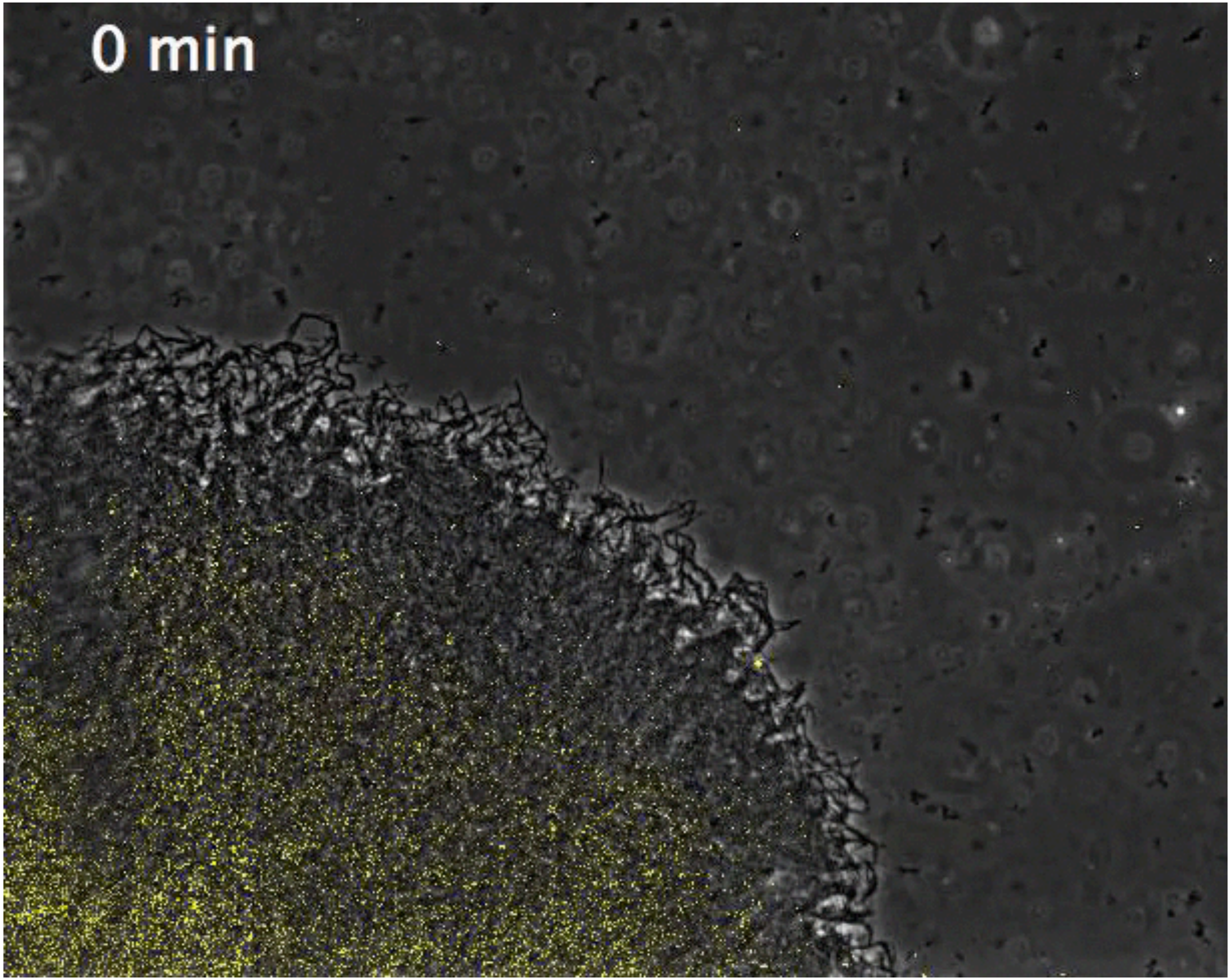


Experiment

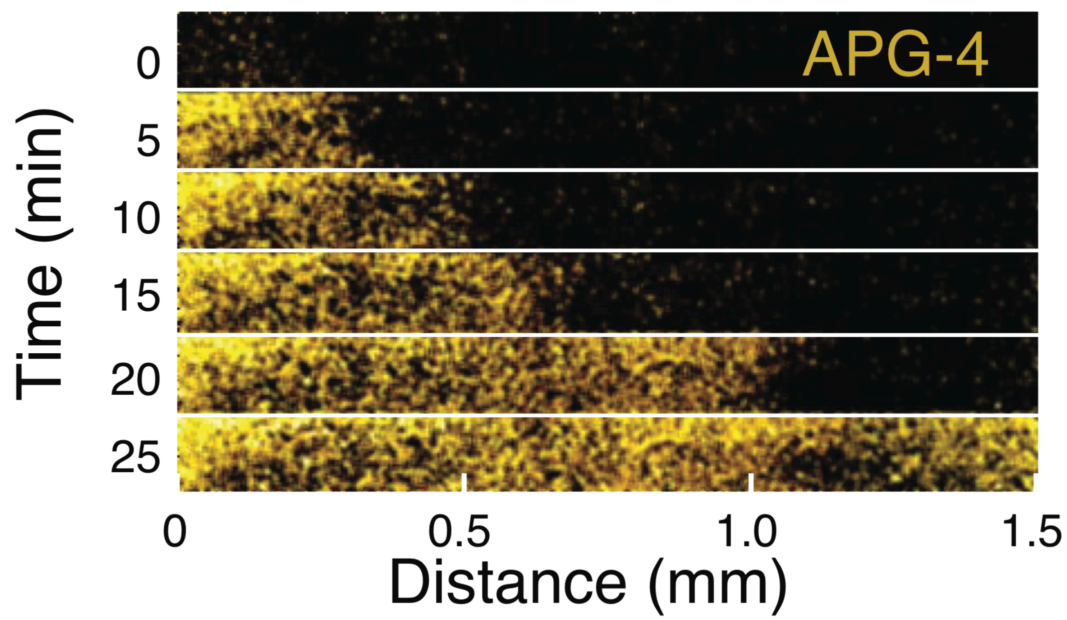


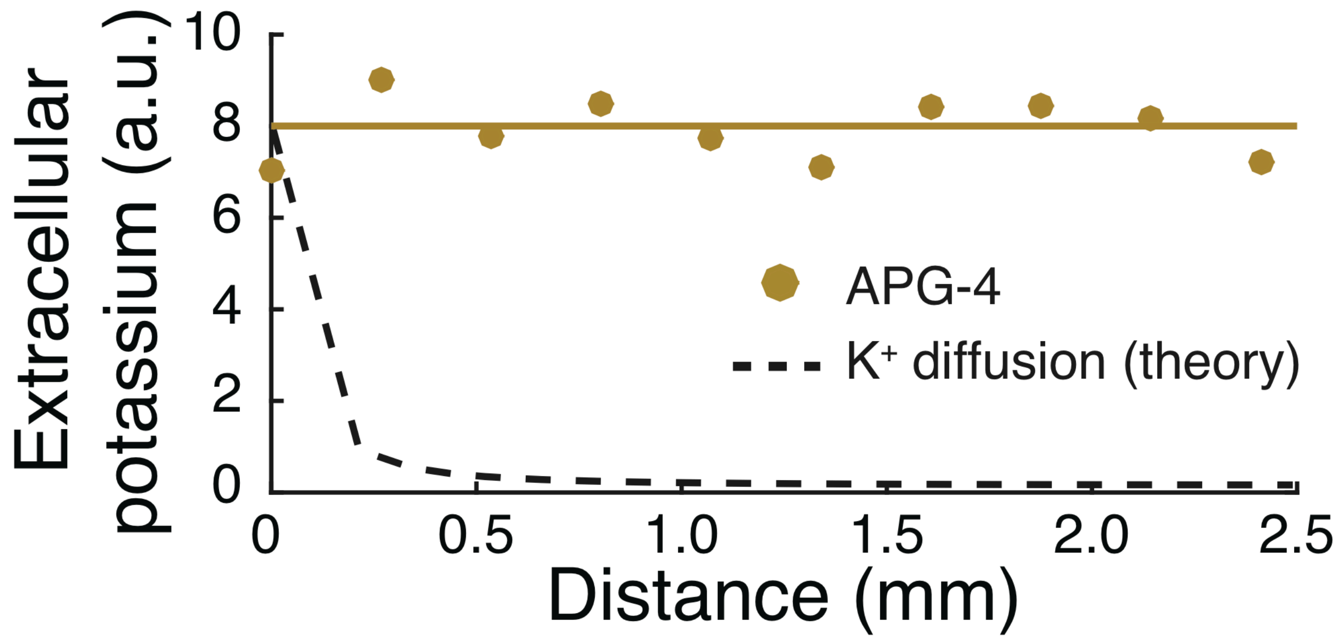
Prindle et al, Nature **527**, 59 (2015)

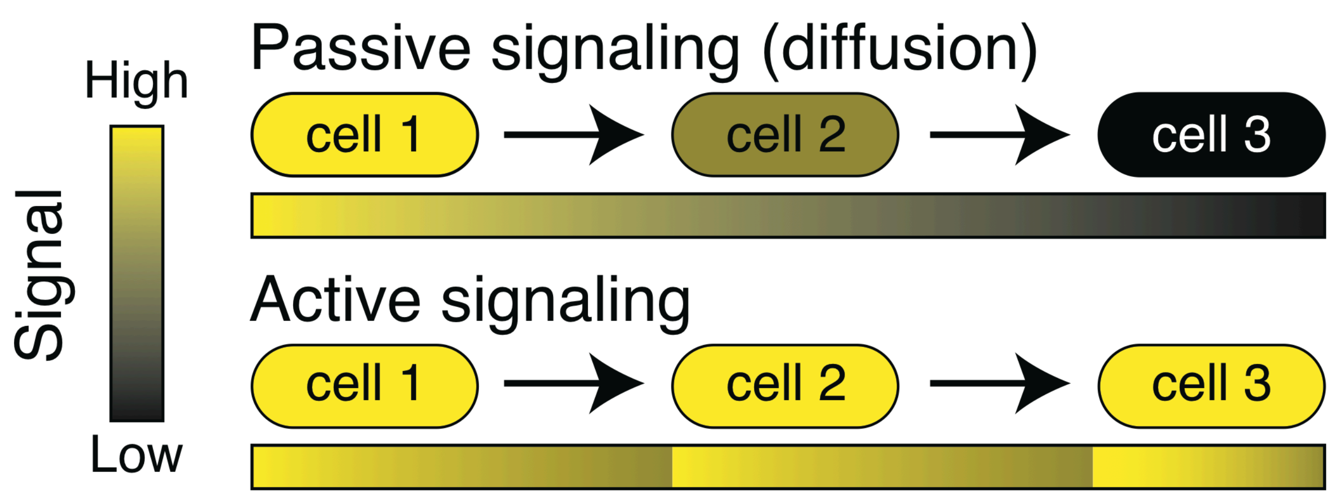
Propagating dynamics of the extracellular potassium



Propagation of potassium is active

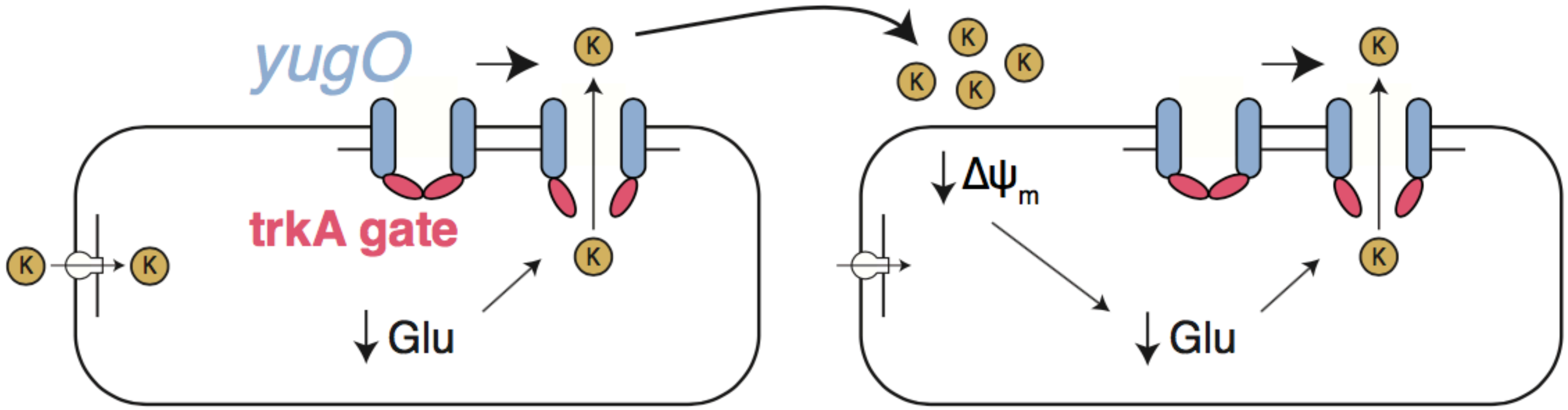


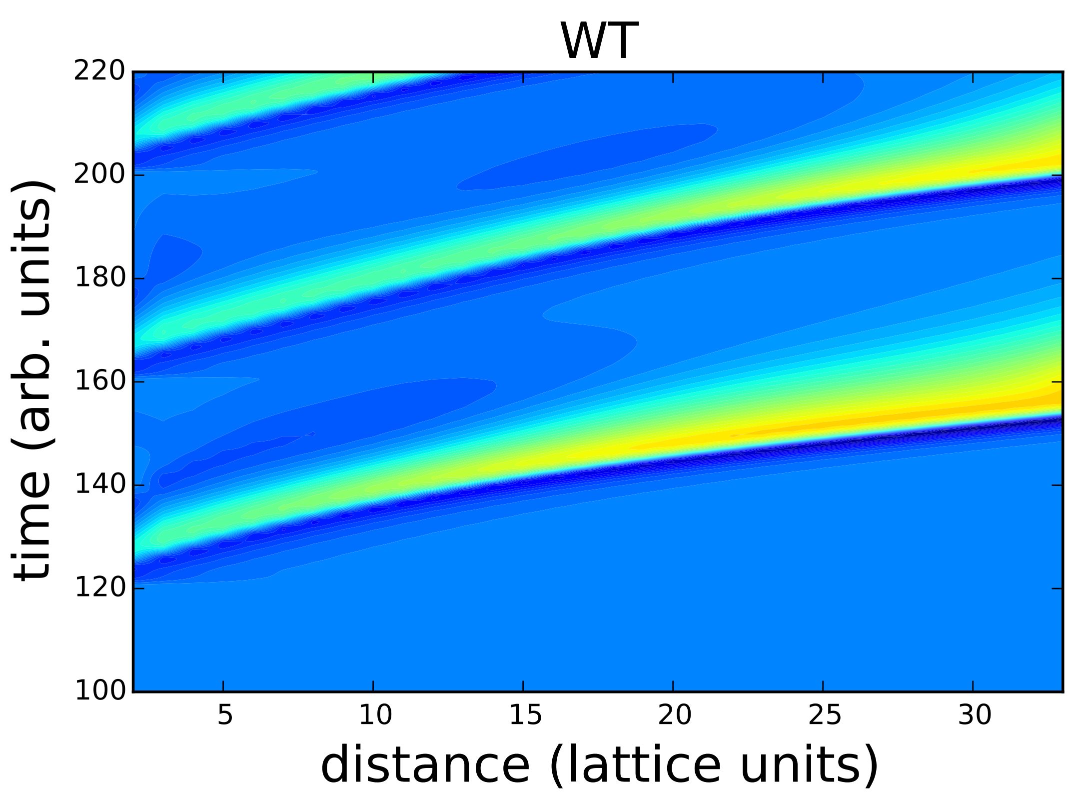




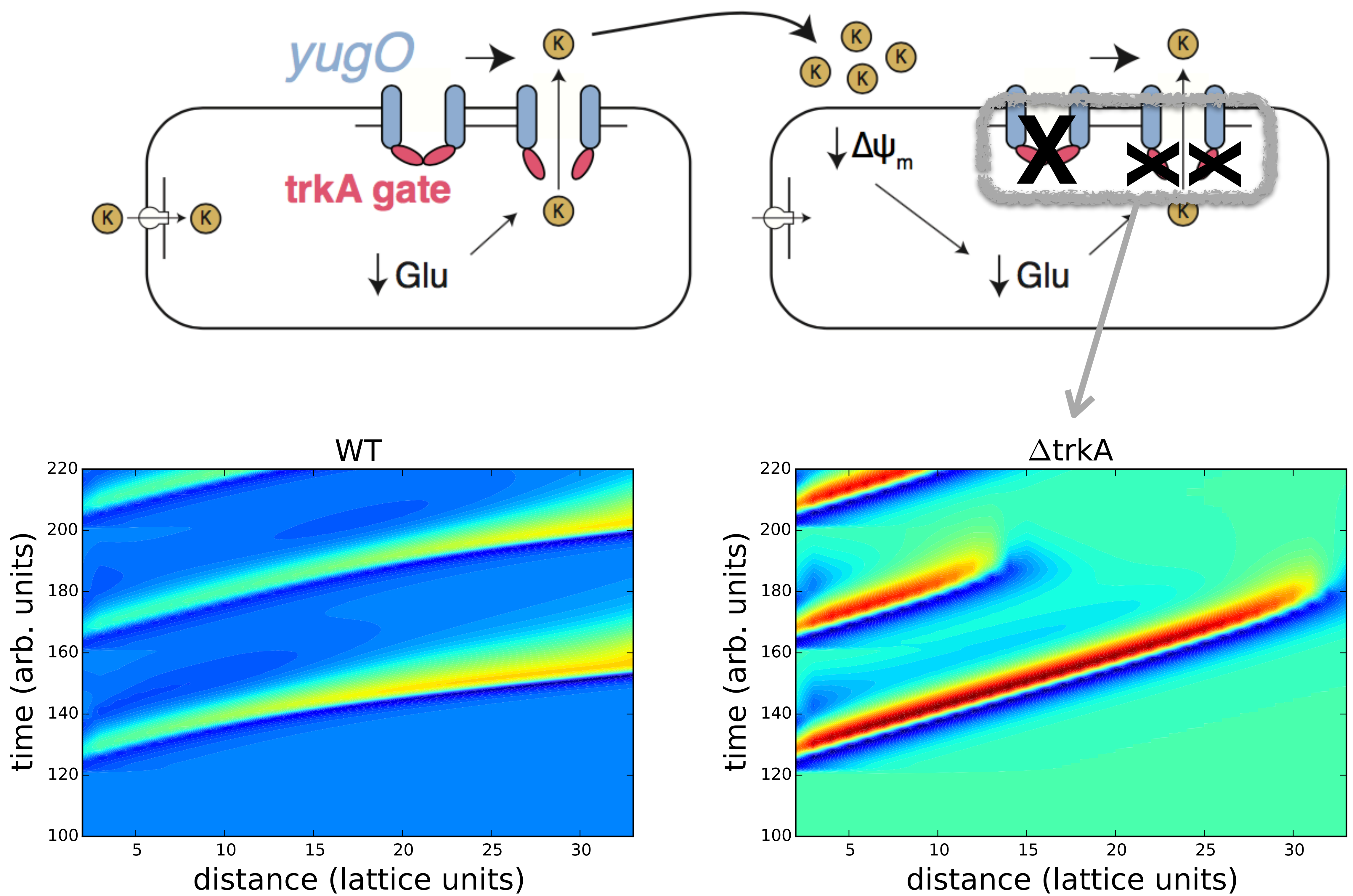
Prindle et al, Nature **527**, 59 (2015)

A bucket brigade of potassium

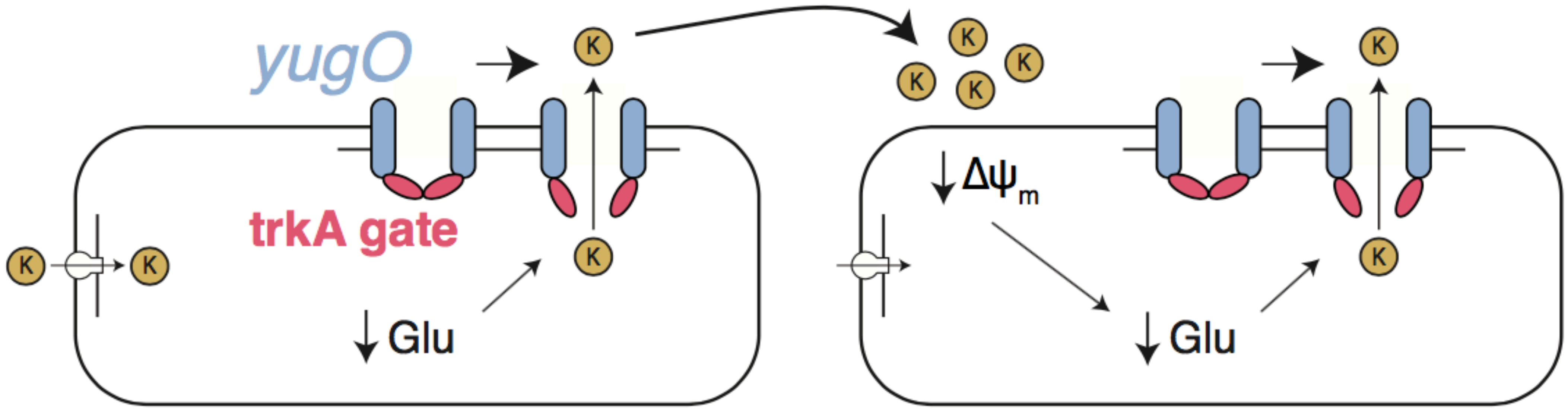


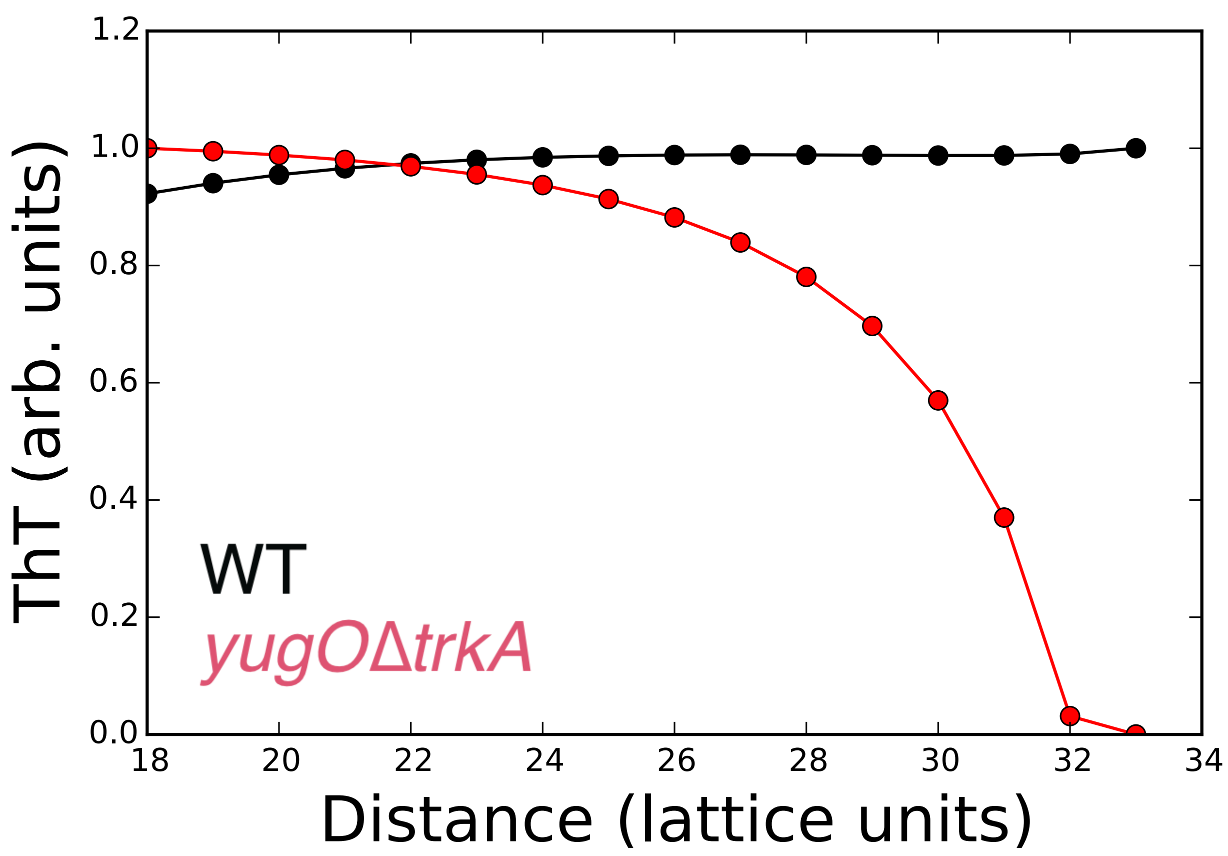


Model prediction: impairing the gate affects propagation

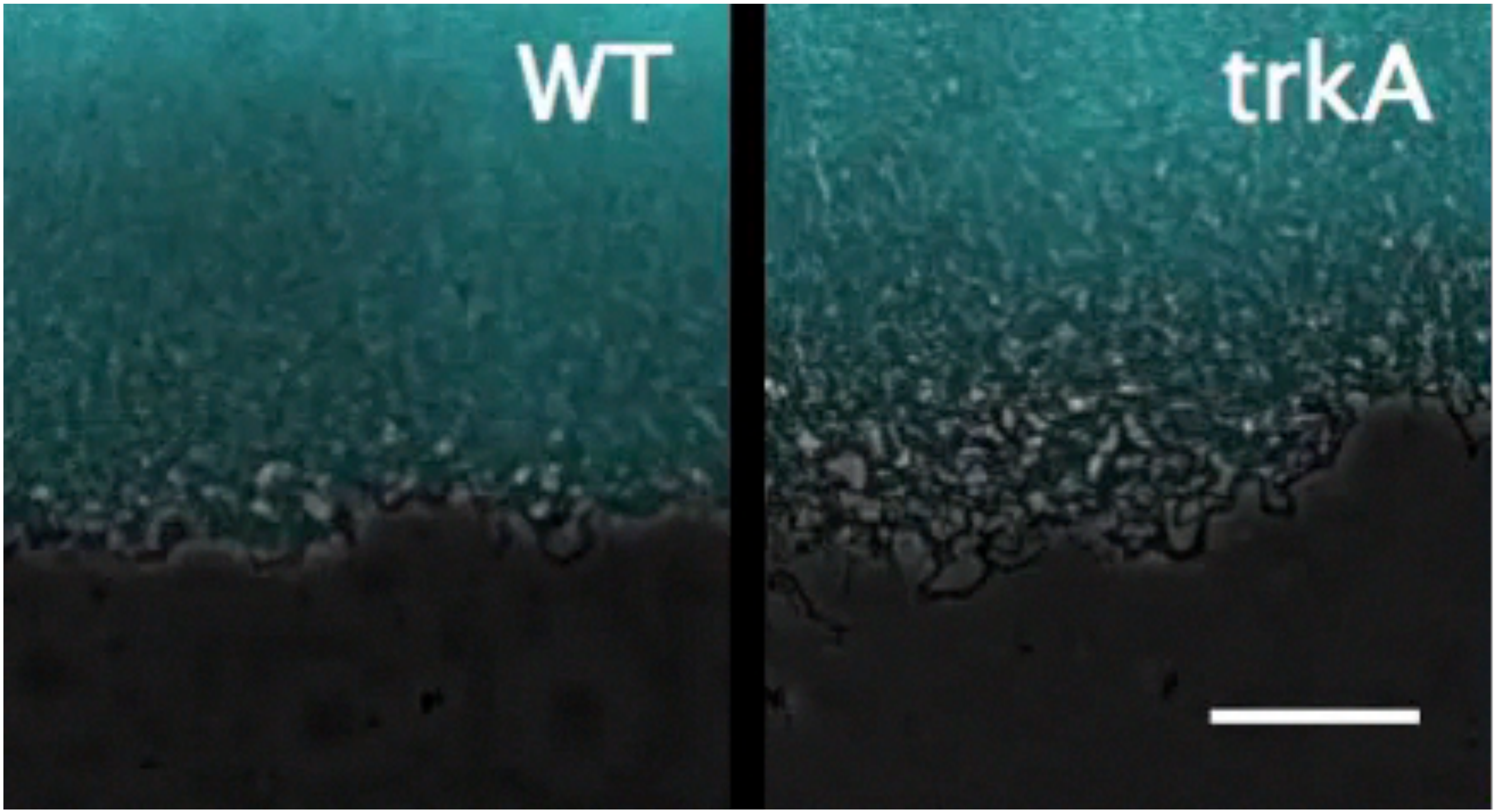


Model prediction: impairing the gate affects propagation



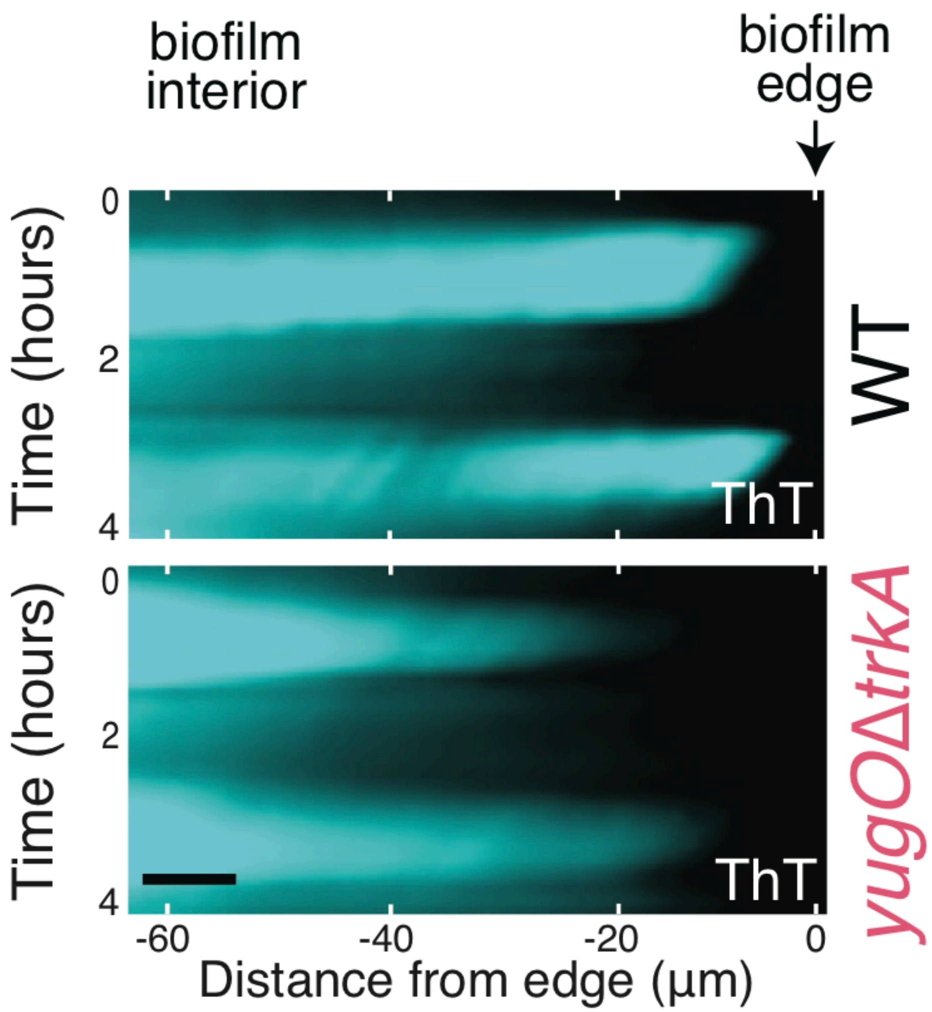


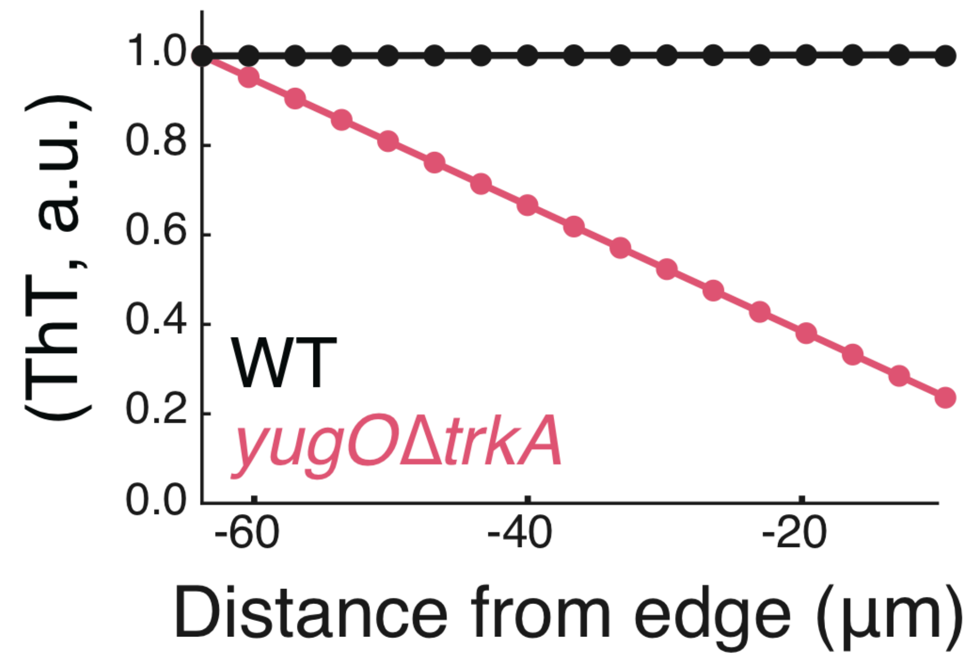
Impairing the gate affects propagation



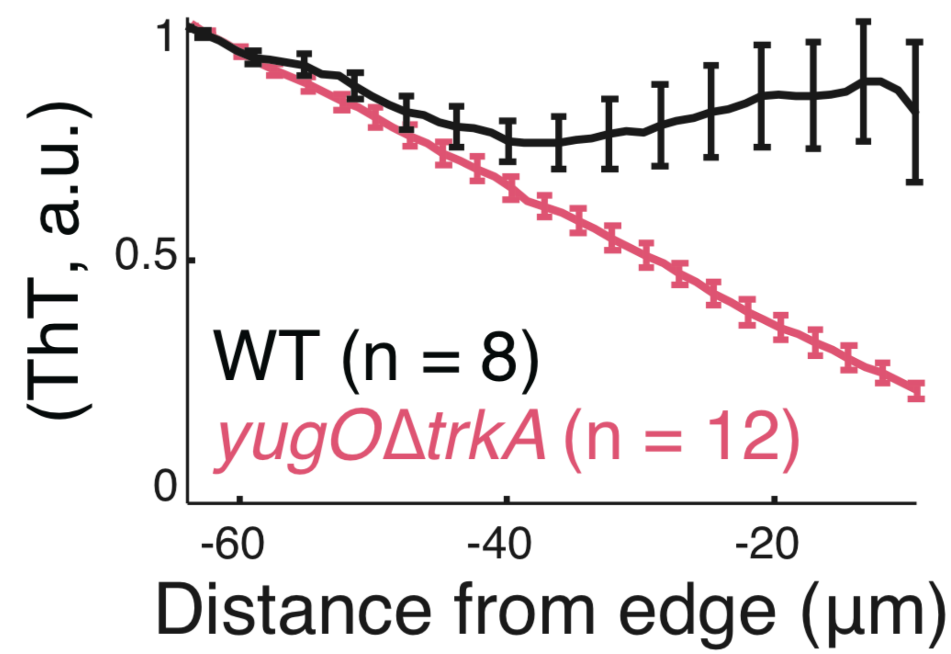
Prindle et al, Nature **527**, 59 (2015)

Impairing the gate affects propagation





model

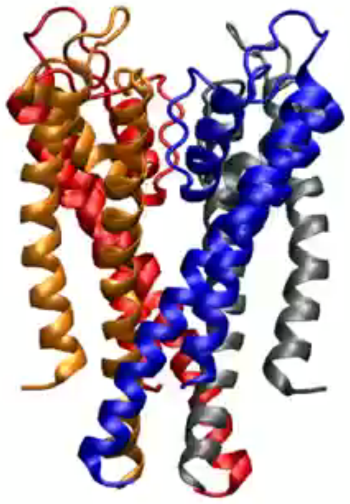


experiment

Prindle et al, Nature **527**, 59 (2015)

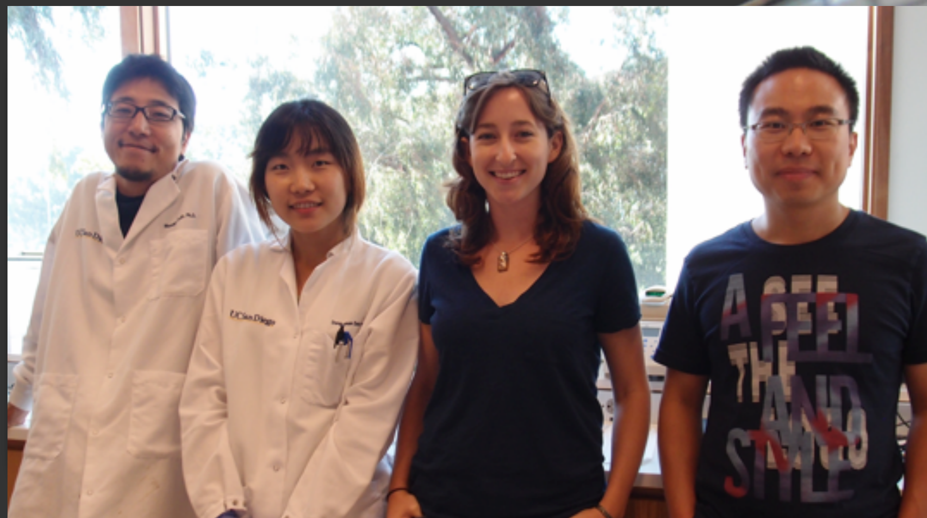
Conclusions

- Metabolic co-dependence leads to global oscillations in a biofilm
- The oscillations resolve a conflict between protection and nutrient availability among interior and peripheral cells
- The metabolic state is transmitted within a biofilm via electrical communication involving potassium
- A Hodgkin-Huxley-like model reproduces the observations
- A biological role for ion channels in bacteria



Bacteria as ancestral neurons

M. Berkmen and M. Penil, "Neurons"
Composite of Nesterenkonia, Deinococcus and Sphingomonas bacteria
American Society for Microbiology's 1st Agar Art contest



Marçal Gabaldà, Rosa Martínez-Corral (UPF)
Jintao Liu, Arthur Prindle, Jacy Humphries, Gürol Süel (UCSD)
Munehiro Asally (Warwick)

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMIA Y COMPETITIVIDAD

*iCrea
INSTITUCIÓ CATALANA DE RECERCA I ESTUDIS AVANÇATS

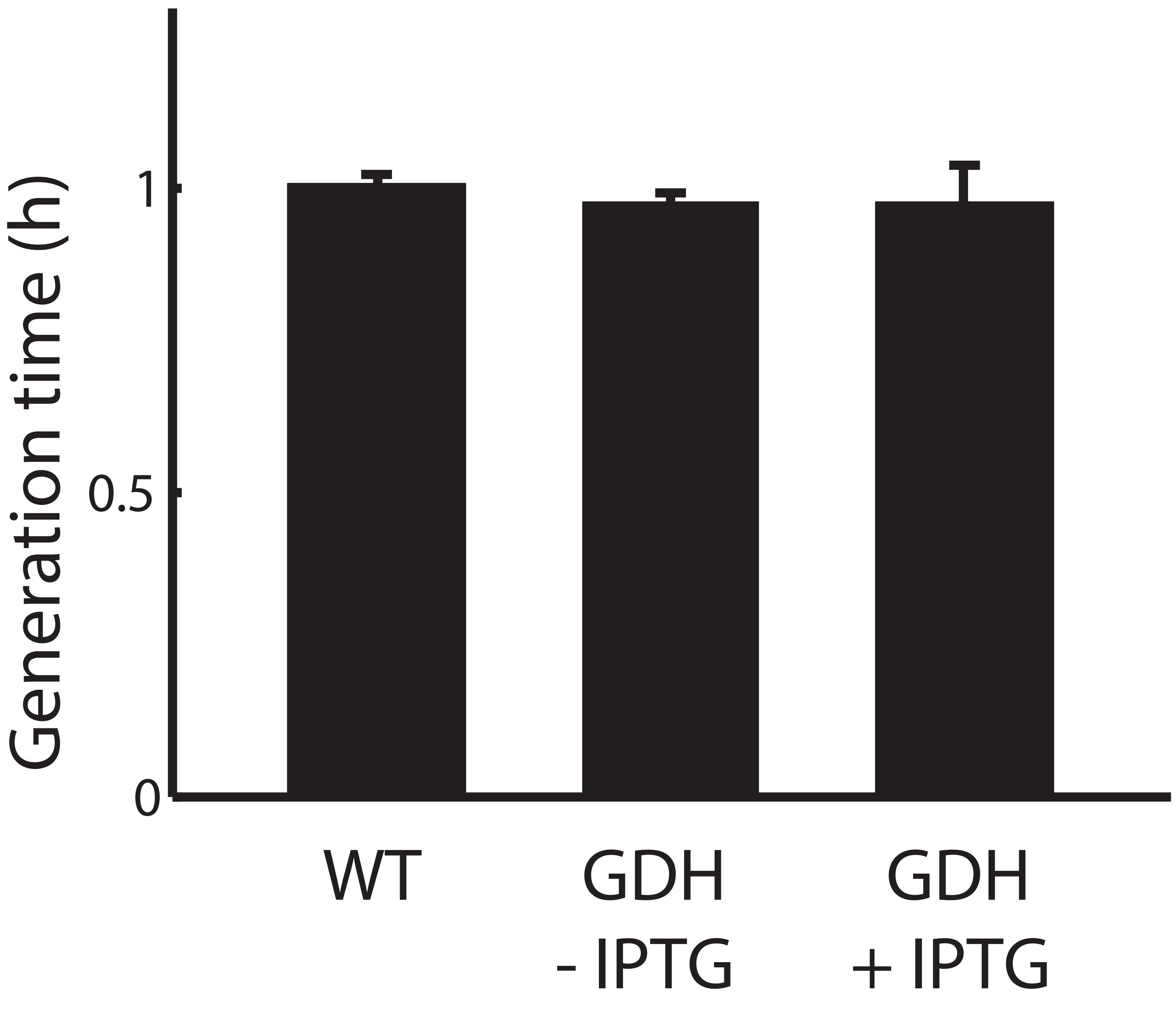
a U|R

MARIE CURIE ACTIONS

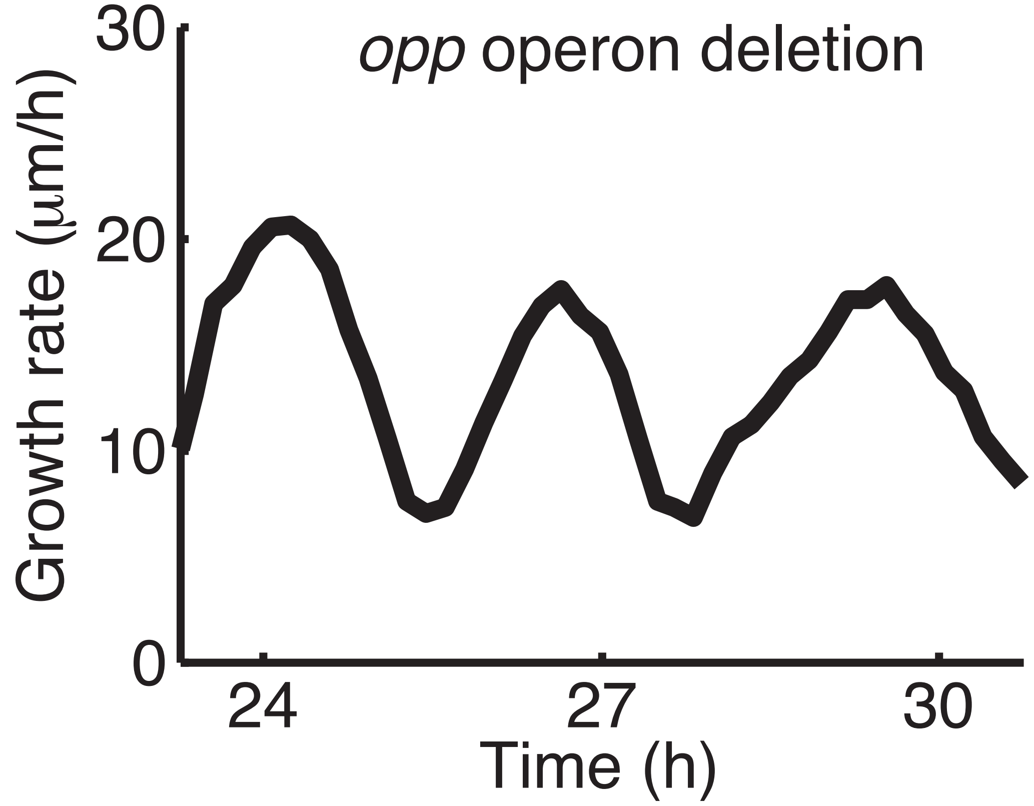
isc
Instituto de Salud Carlos III

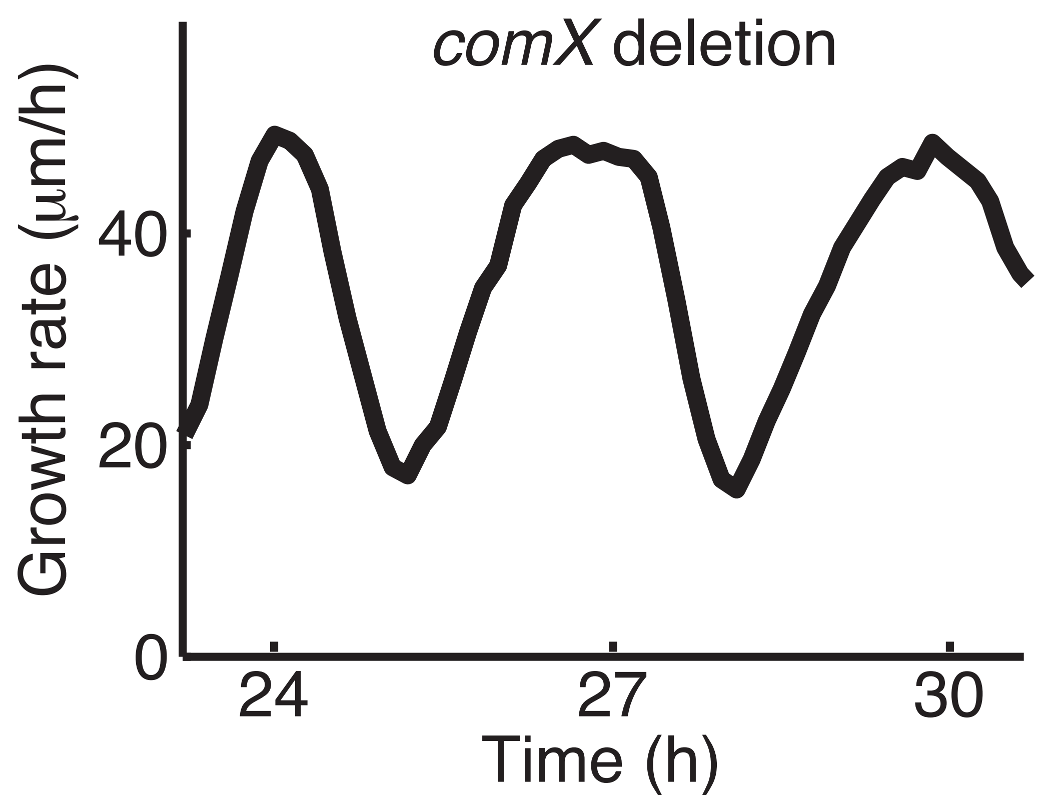

ICSB 2016
International Conference on Systems Biology
BARCELONA
16 - 20 September 2016
INTERNATIONAL CONFERENCE ON SYSTEMS BIOLOGY
upf. Universitat Pompeu Fabra Barcelona
CRG Centre de Regulació Genòmica
Organizers:
James Sharpe, Luis Serrano (CRG)
Jordi Garcia-Ojalvo (UPF)
www.icsb2016barcelona.org

GDH overexpression is not toxic to single cells

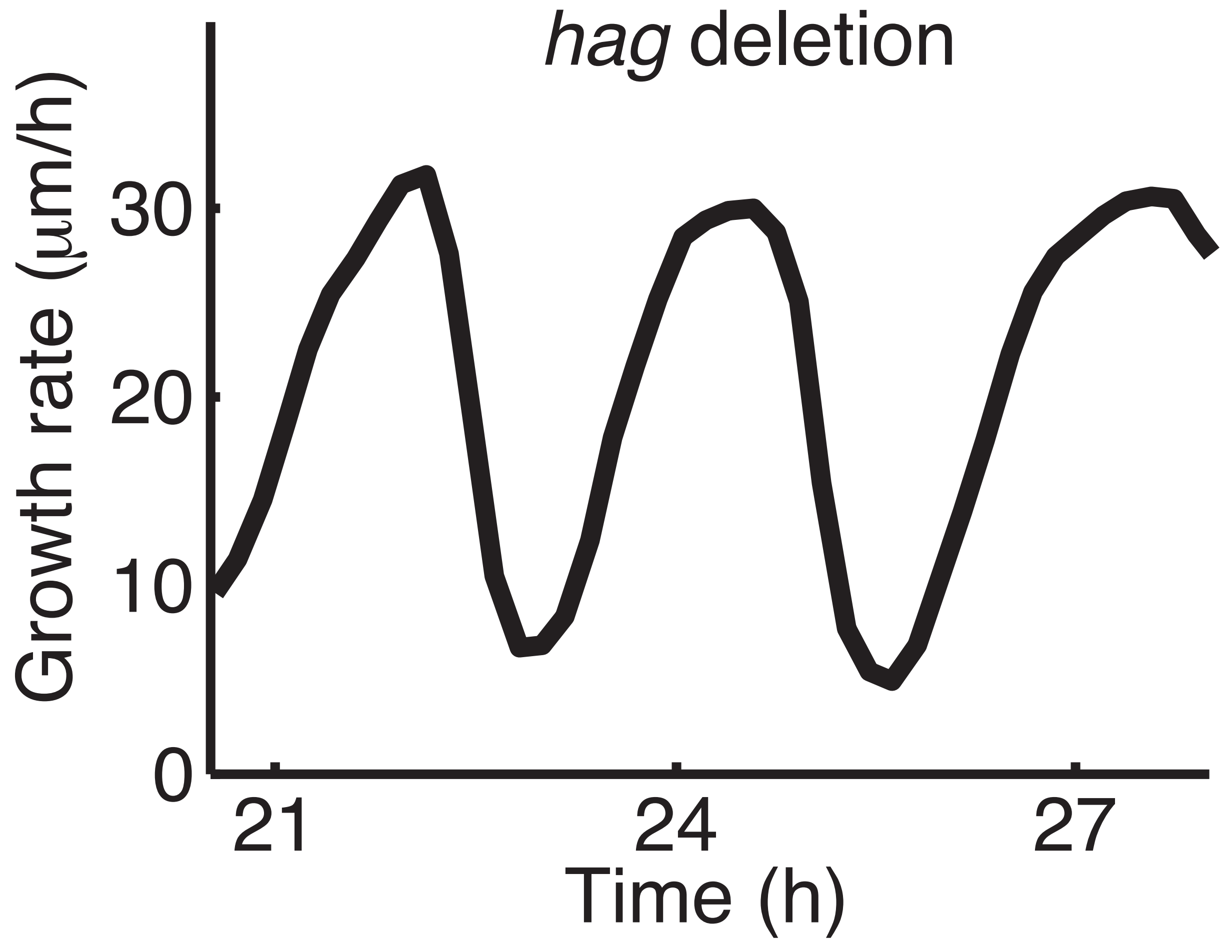


Oscillations do not require quorum sensing

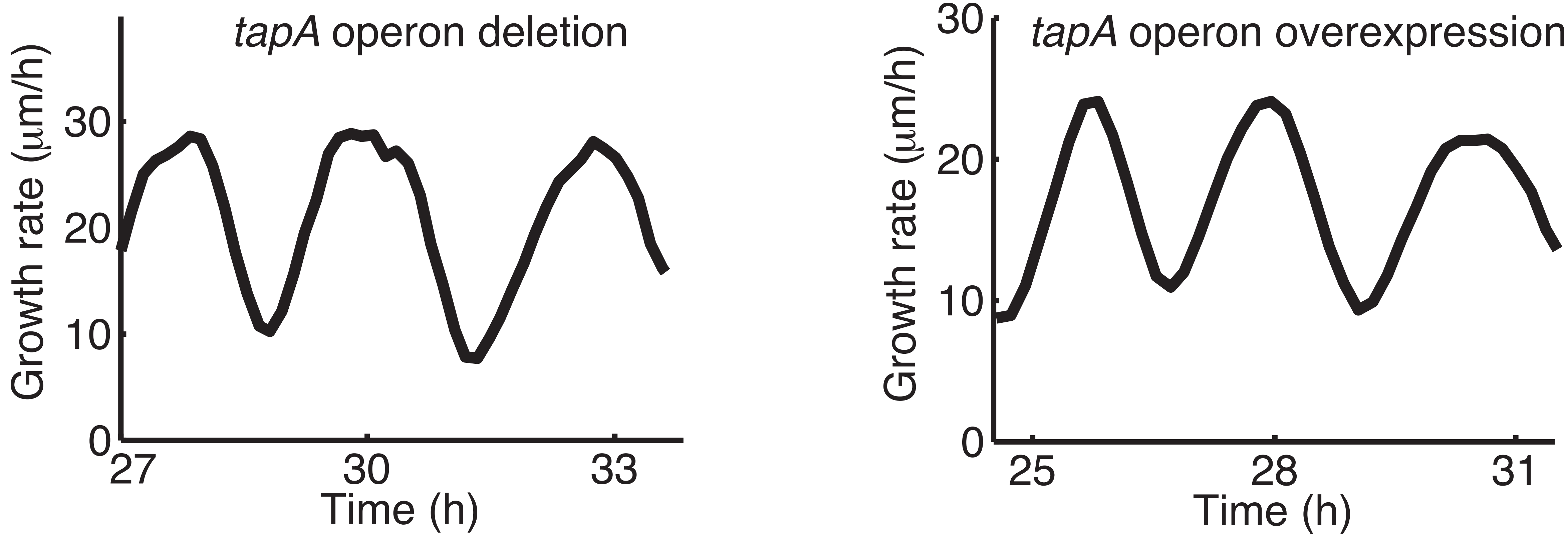




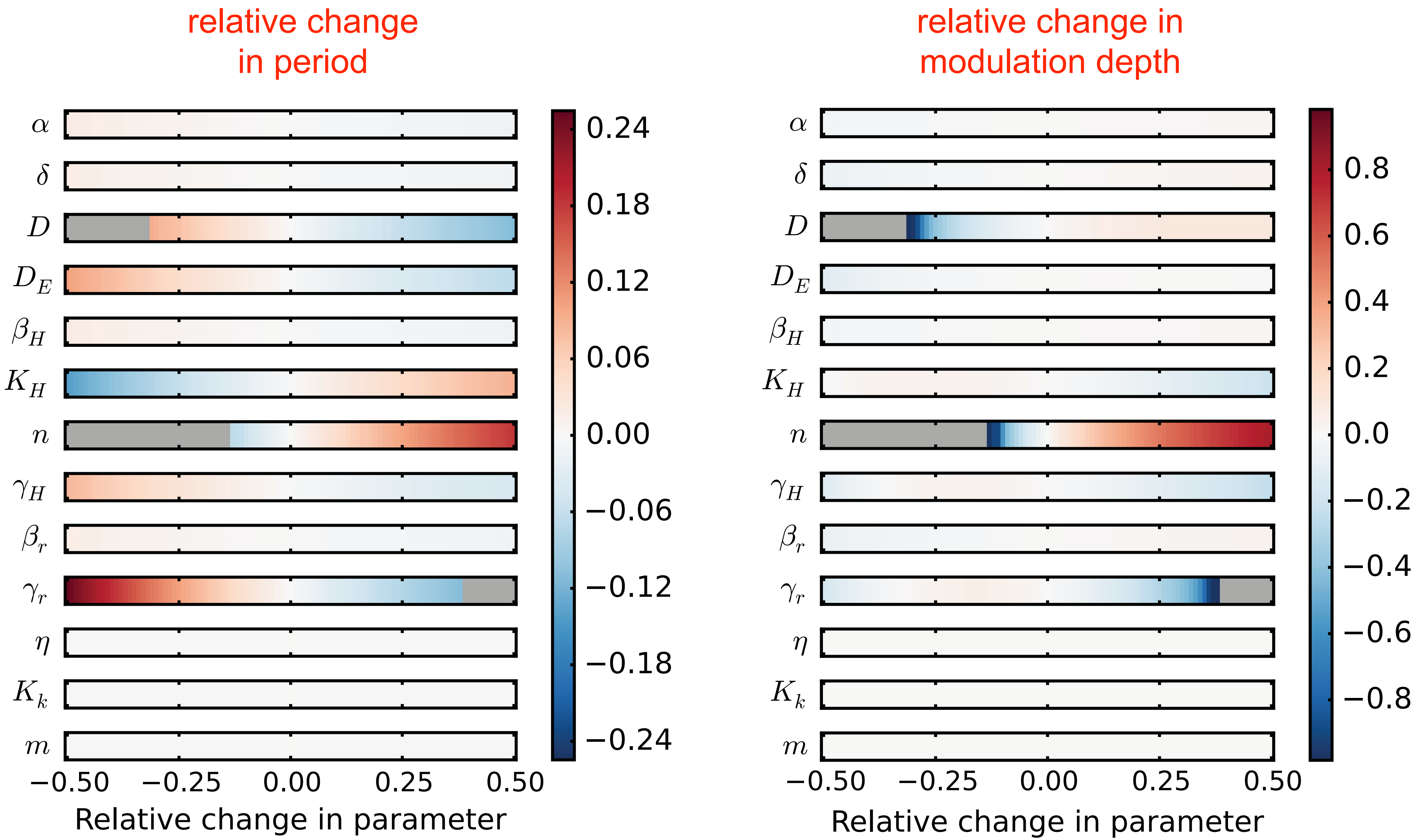
Oscillations do not require swarming



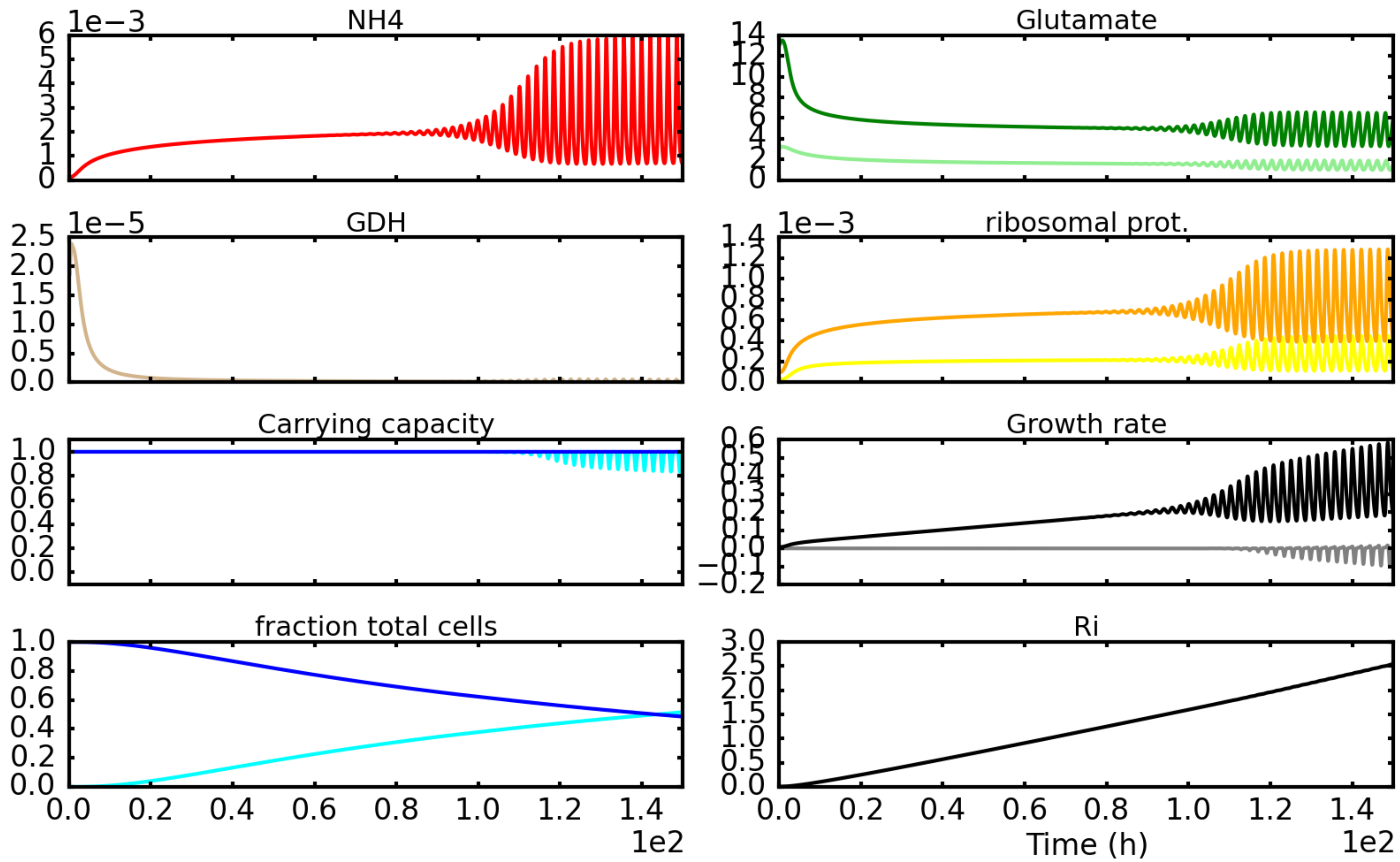
Oscillations are not affected by the extracellular matrix components



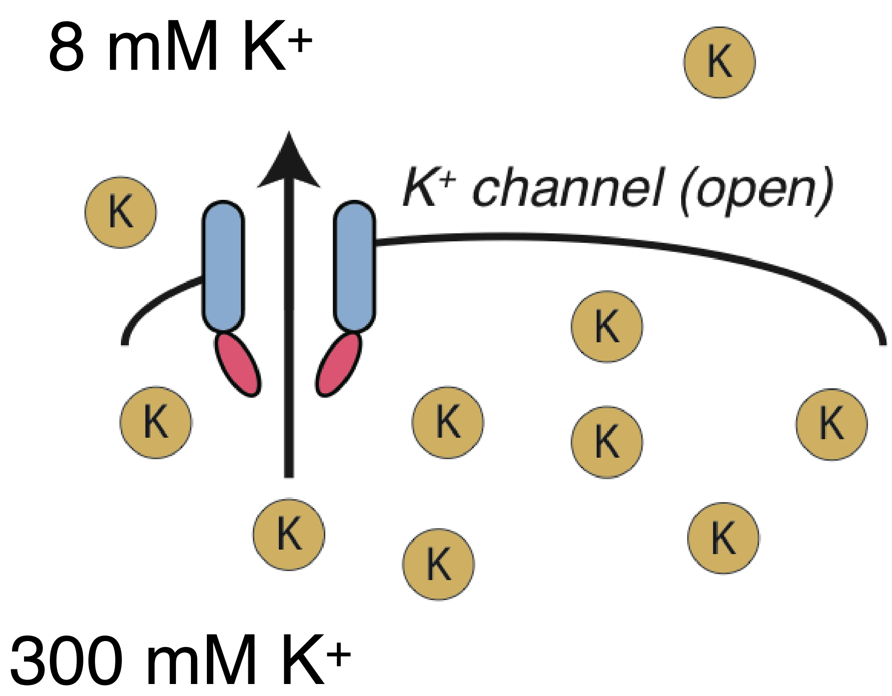
Sensitivity analysis of the model



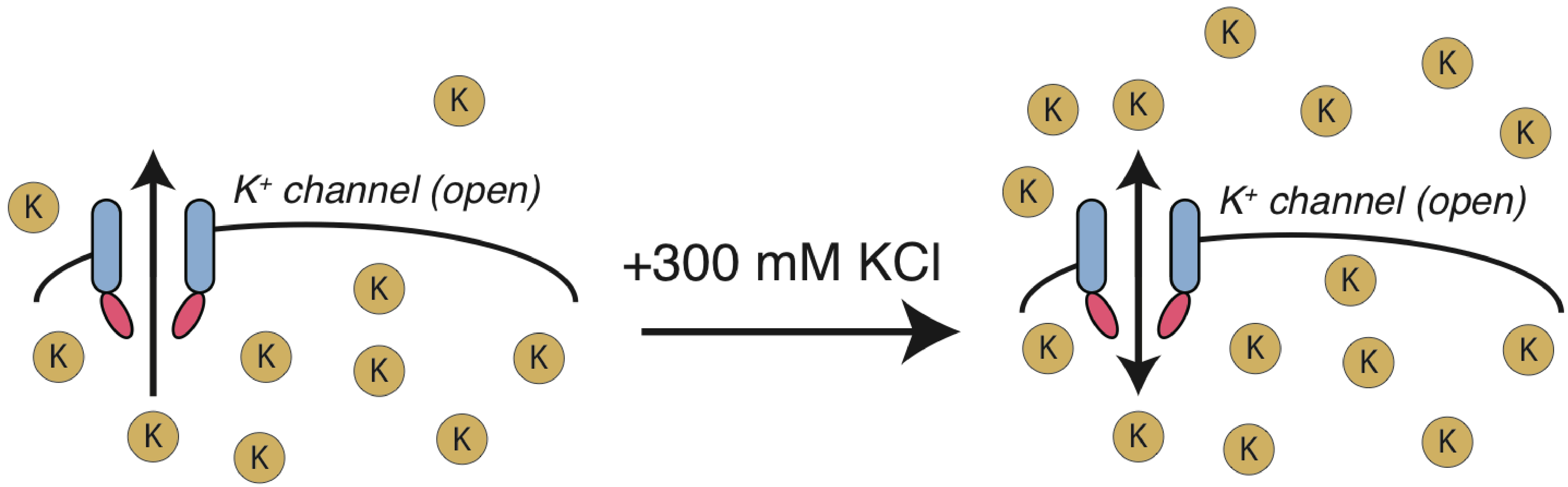
The model reproduces the system size effect

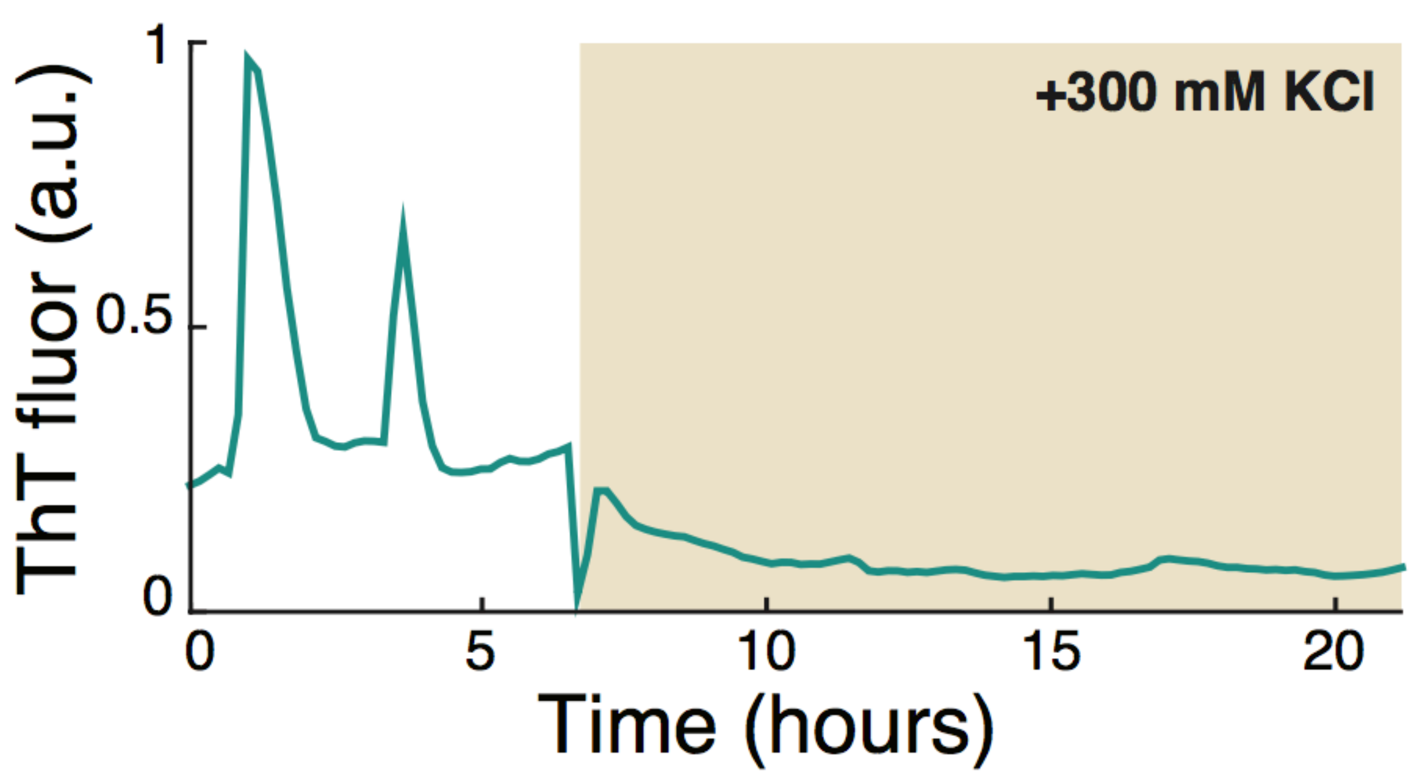


Clamping potassium abolishes oscillations

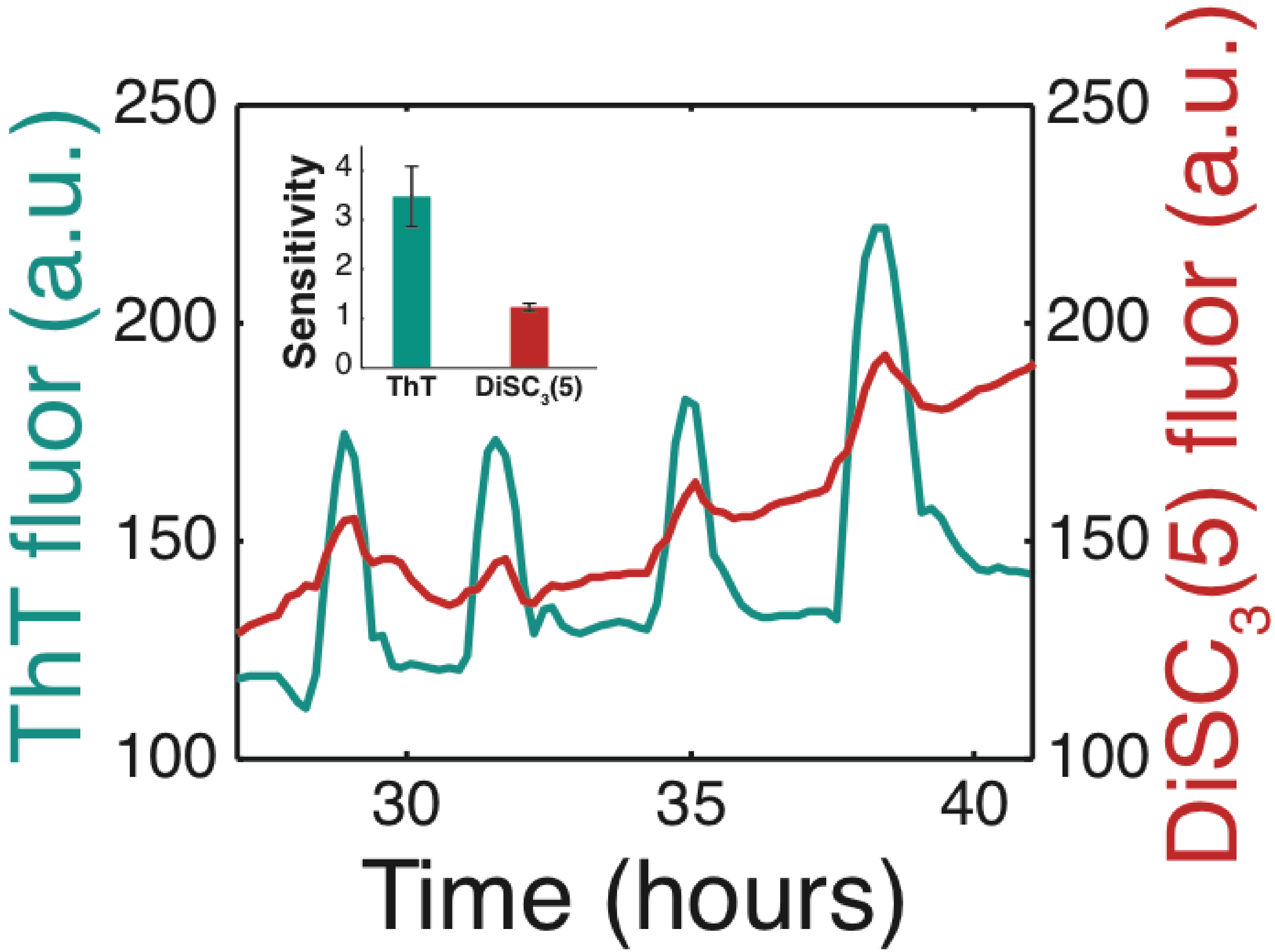


Clamping potassium abolishes oscillations

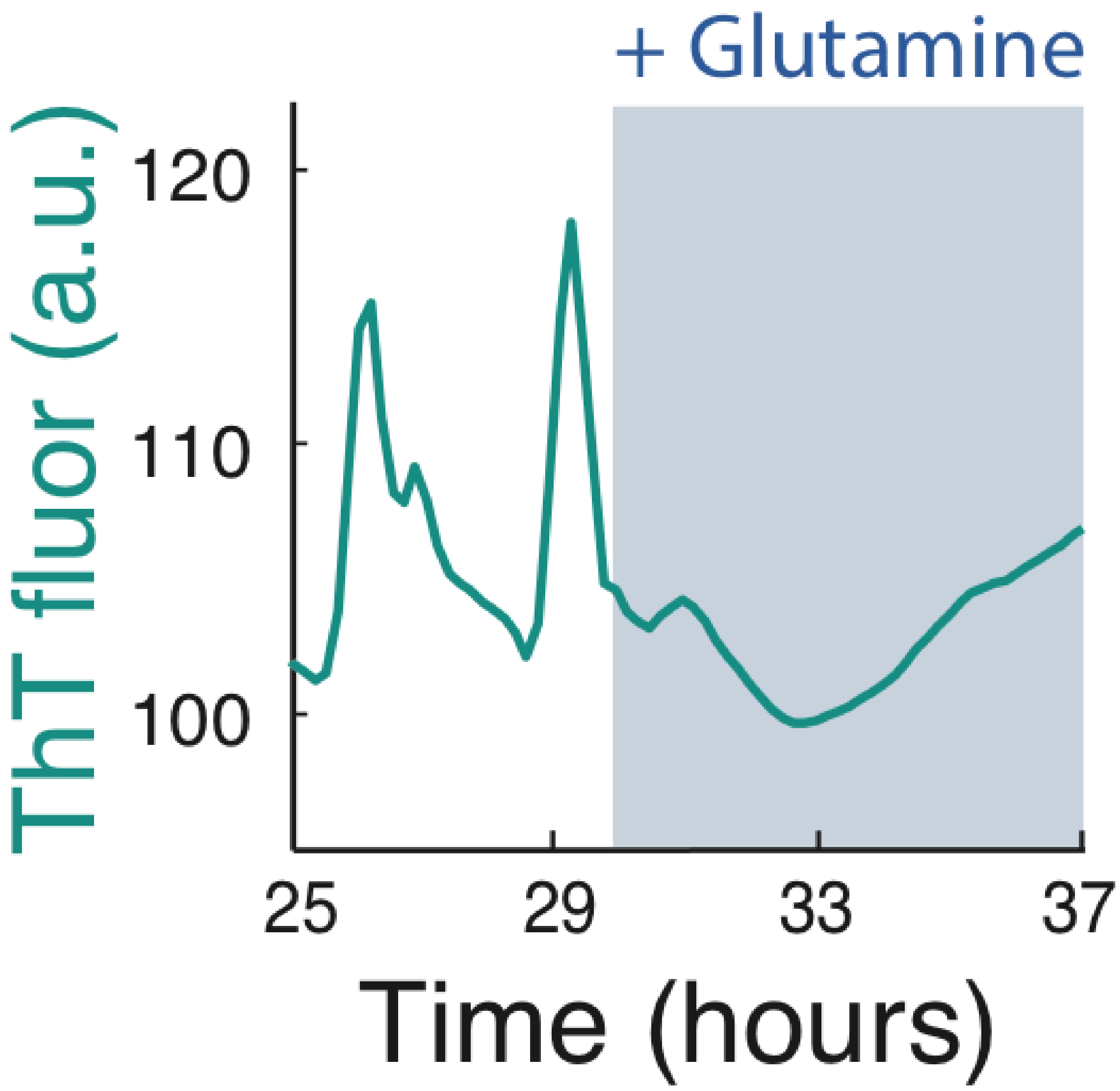




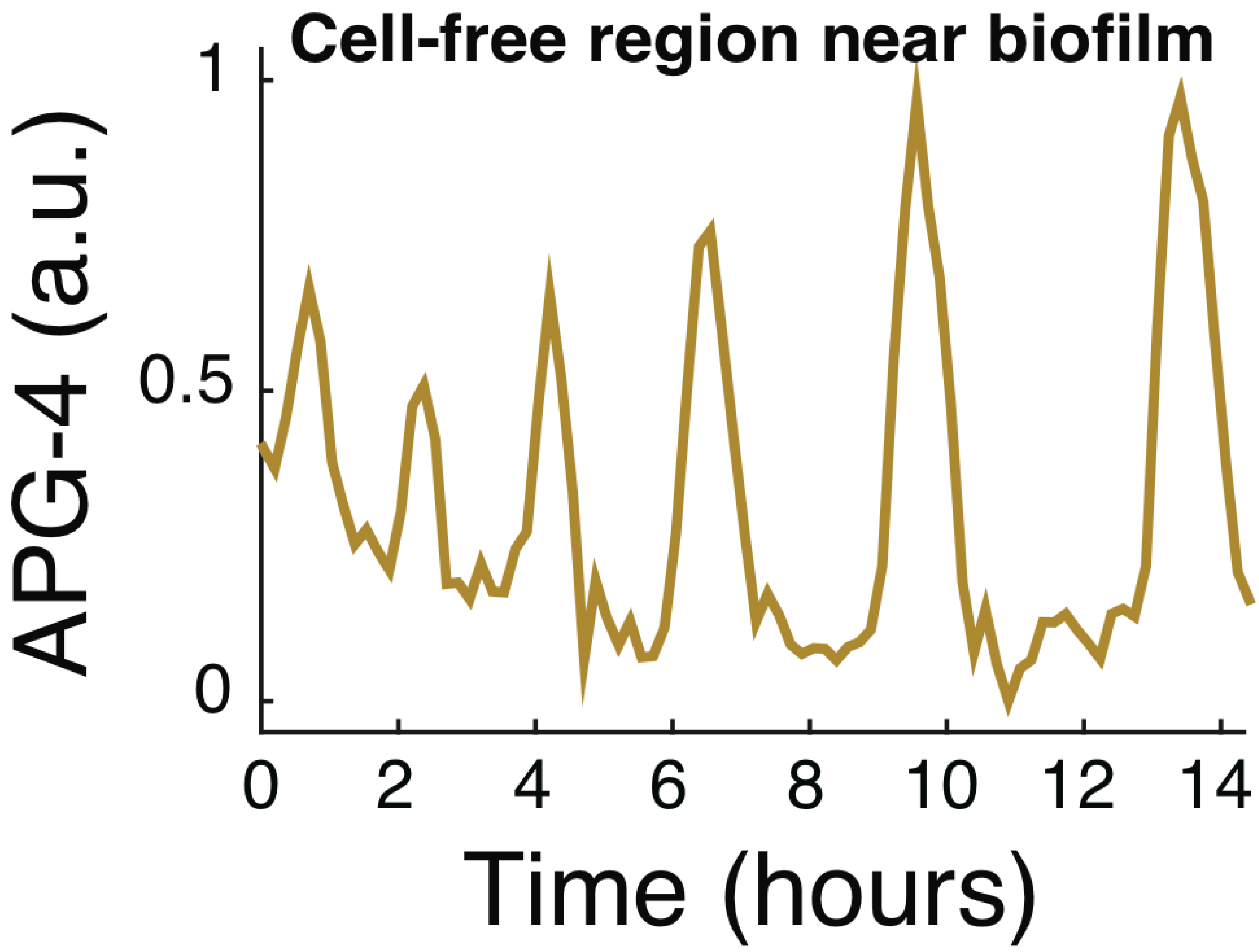
Comparison with a standard voltage-sensing dye



Glutamine quenches ThT oscillations



Potassium oscillations propagate outside biofilm



Sodium clamp does not affect ThT oscillations