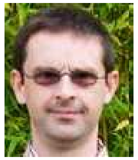
"Electrical and calcium signalling"

E&CS group

E&CS, a group formed on March 2009

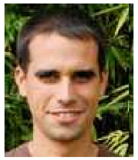
Dr. Claire Corratgé-Faillie (CDD Ing. Recherche)

Dr. Tracey Ann Cuin (Post-doc Marie Curie)

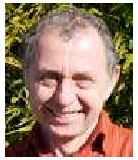


Dr. Erwan Michard (Post-doc Agropolis Fondation)

Elsa Ronzier (PhD student)



Frédéric Sanchez (TR)



Dr. Jean-Baptiste Thibaud (DR)

Dr. Tou Cheu Xiong (CR)

Disclosing the molecular basis of electrical and Ca^{2+} signalling in plants

Propagation of electrical signals in plants

Basipetal, then acropetal propagation of an electrical signal in Mimosa leaves

Examples of recent papers

Plant, Cell and Environment (2009) 32, 194–207 doi: 10.1111/j.1365-3040.2008.0

Electrical signalling and cytokinins mediate effects of lig and root cutting on ion uptake in intact plants

SERGEY SHABALA[1], JIAYIN PANG[1,2], MEIXUE ZHOU[2], LANA SHABALA[1,2], TRACEY A. CUIN[1], PETER NICK[3] & LARS H. WEGNER[3,4]

[1]School of Agricultural Science, University of Tasmania, Private Bag 54, Hobart, Tas 7001, Australia, [2]Tasmanian Instit Agricultural Research, University of Tasmania, Kings Meadows, Tas 7249, Australia, [3]Institute of Botany I, Kaiserstrasse ..., D-76131 Karlsruhe, Germany and [4]Plant Bioelectrics Group, Karlsruhe Institute of Technology, Department of Pulsed Pow ...

Physiologia Plantarum 131: 263–272. 2007

Voltage-dependent action potentials in *Arabidopsis thaliana*

Patrick Favre[a] and Robert Degli Agosti[a,b,c,*]

[a]Laboratory of Plant Physiology and Biochemistry, Plant Physiomatics, University of Geneva, 3 Place de l'Université, CH-1211 Geneva 4, Switzerland
[b]Department of Plant Biology, University of Geneva, 30 Quai Ernest-Ansermet, CH-1211 Geneva 4, Switzerland
[c]Laboratory of Plant Physiomatics, EIL/EIG, University of Applied Sciences of Western Switzerland, 150 rte de Presinge, CH-1254 Jussy, Switzerland

Plant, Cell and Environment (2007) 30, 249–257 doi: 10.1111/j.1365-3040.2006.

Electrical signals and their physiological significance in plants

JÖRG FROMM & SILKE LAUTNER

Fachgebiet Holzbiologie, TU München, Winzererstrasse 45, 80797 München, Germany

Planta (2007) 226:203–214
DOI 10.1007/s00425-006-0458-y

ORIGINAL ARTICLE

Systemic signalling in barley through action potentials

Hubert H. Felle · Matthias R. Zimmermann

Planta (2009) 229:539–547
DOI 10.1007/s00425-008-0850-x

ORIGINAL ARTICLE

Dissection of heat-induced systemic signals: superiority of ion fluxes to voltage changes in substomatal cavities

Mathias R. Zimmermann · Hubert H. Felle

Journal of Plant Physiology 168 (2011) 653–660

Contents lists available at ScienceDirect

Journal of Plant Physiology

journal homepage: www.elsevier.de/jplph

ELSEVIER

Plant, Cell and Environment (2009) 32, 319–326 doi: 10.1111/j.1365-3040.2008.01922

Heat-induced electrical signals affect cytoplasmic and apoplastic pH as well as photosynthesis during propagation through the maize leaf

THORSTEN E. E. GRAMS[1], SILKE LAUTNER[2], HUBERT H. FELLE[3], RAINER MATYSSEK[1] & JÖRG FROMM[2]

[1]Ecophysiology of Plants, Department of Ecology and Ecosystem Sciences, Technische Universität München, Am Hochanger 13, Freising, Germany, [2]Department of Wood Biology, University of Hamburg, Leuschnerstrasse 91, Hamburg, Germany and [3]Botanisches Institut I, Justus-Liebig-Universität Gießen, Senckenbergstrasse 17, Gießen, Germany

Accession-dependent action potentials in *Arabidopsis*

Patrick Favre[a], Hubert Greppin[b], Robert Degli Agosti[c,d,*]

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[b] Plant Biology Department, University of Geneva, Switzerland
[c] Plant Physiomatics, Plant Biology Department and Faculty of Sciences, University of Geneva, Switzerland
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Role of electrical signalling in plants

WHAT DO PLANTS NEED ACTION POTENTIALS FOR?

Elżbieta Król, Halina Dziubińska, and Kazimierz Trębacz
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Akademicka 19, 20–033 Lublin, Poland

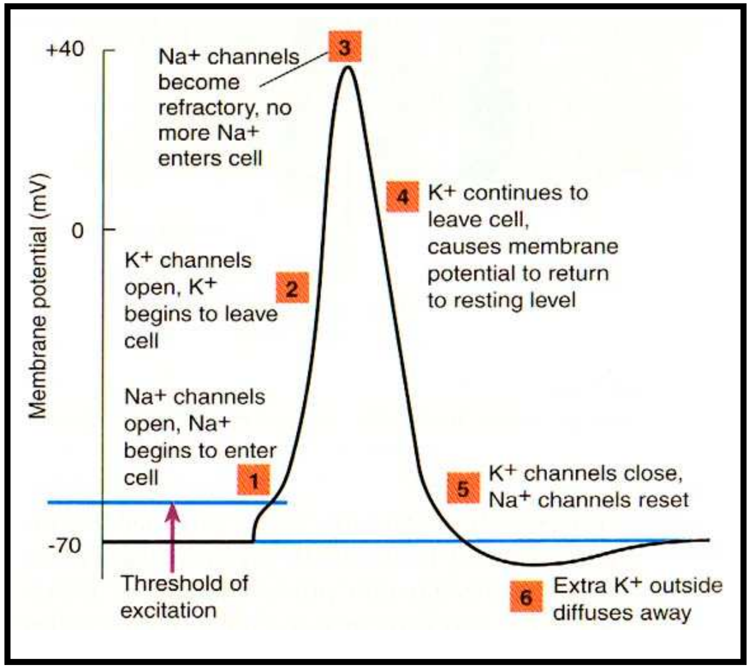
- trap closure and enzyme secretion (*eg*, Droseraceae): up to 250 mm/s !!
- fertilisation (pollen landing on the stigma): 10-30 mm/s
- defence (*eg*, *Mimosa pudica*): 4-40 mm/s
- defence/stress in non specialised plants/tissues
  (cold, light/dark, heat/burning, etc.): 1-10 mm/s

including Arabidopsis!

What is an action potential?

- **Self-propagating, transient electrical signal**
- **Rapid depolarisation then repolarisation of membrane potential**
- **Travels from cell to cell with constant speed**

In animal cells..



In plants...

- everything is much slower than in animals

- no Na^{+} involved in plant APs

- ion fluxes in plants during AP:

- **Ca^{2+} influx into the cell**
- **then Cl^{-} & K^{+} efflux**

- but we don't know which channels are involved

Need for mathematical modelling

ion transport

ATP-fueled ion pumps
voltage-gated ion channels

non linear diff. equ.

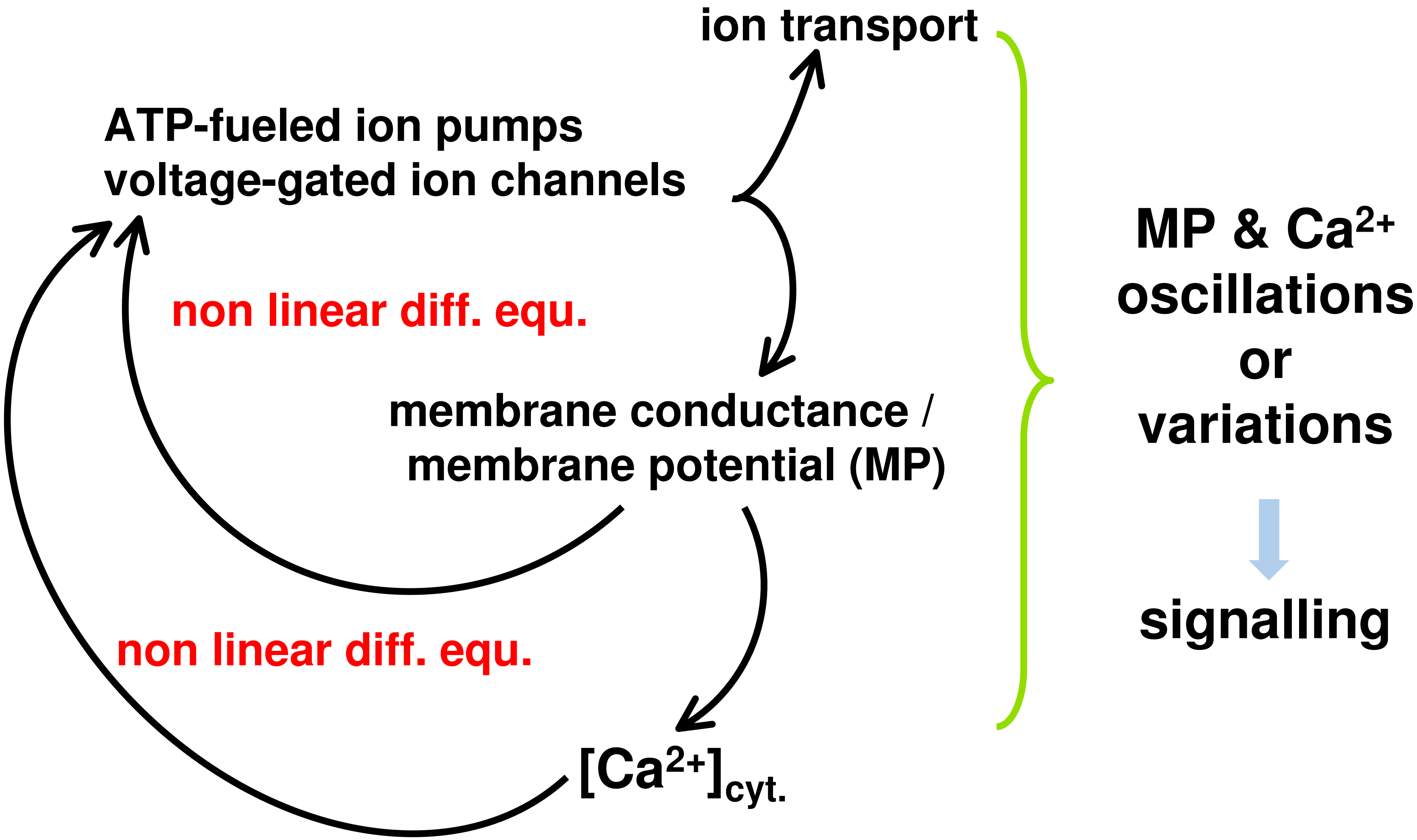
membrane conductance /
membrane potential (MP)

MP
oscillations
or
variations

↓

signalling

Need for mathematical modelling



We focus on voltage (and Ca^{2+}) waves

ion transport

ATP-fueled ion pumps
voltage-gated ion channels

non linear diff. equ.

membrane conductance /
membrane potential (MP)

non linear diff. equ.

$[Ca^{2+}]_{cyt.}$

MP & Ca^{2+}
oscillations
or
variations

signalling

Our research aims

ATP-fueled ion pumps
voltage-gated ion channels

non linear diff. equ.

membrane conductance /
membrane potential (MP)

non linear diff. equ.

$[Ca^{2+}]_{cyt.}$

Addressed questions

- which ion transporters contribute to APs?
- how do they interplay to make an AP?
- how do APs travel?
- how is Ca^{2+} involved?
- do Ca^{2+} waves occur and travel?

E&CS group: the aims

- to uncover the molecular mechanisms behind electrical signals in plants

- to disclose mechanisms of regulation by Ca^{2+} of K^{+} voltage-gated channels

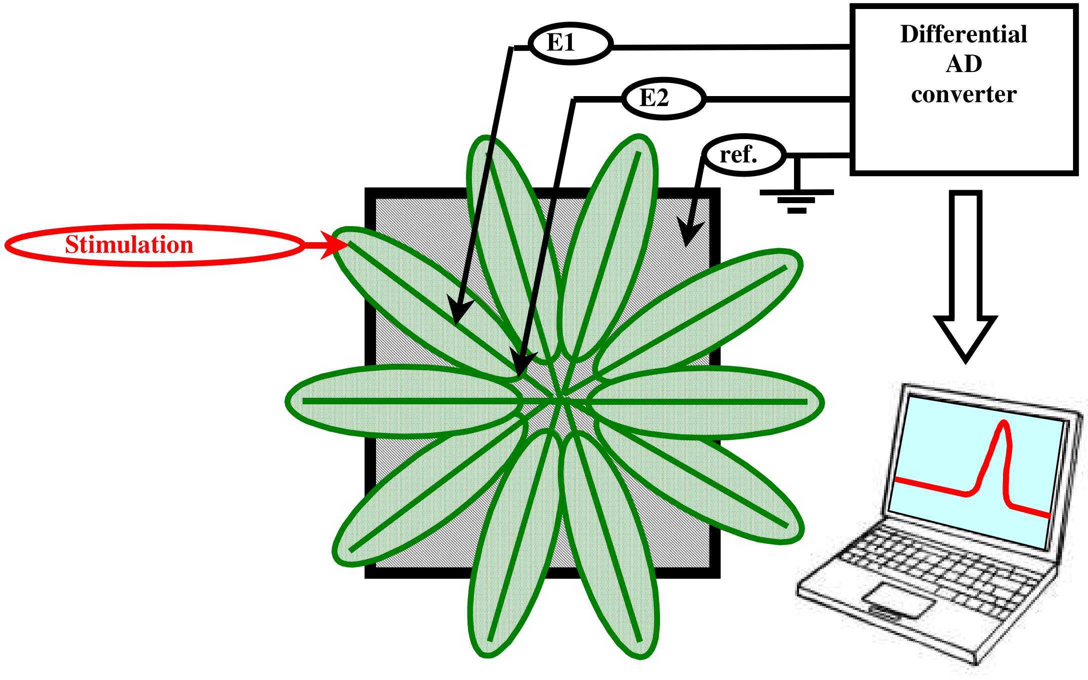
- to establish *in planta* Ca^{2+} imaging at BPMP

- to evidence Ca^{2+} waves travelling through plant tissues

E&CS group: the tasks

- Install AP recording at BPMP
- Compare action potentials in WT and mutant lines
- (*AKT2* and *GORK* genes)
- Computer-assisted modelling:
  a single-cell ("0D" model),
  a file of cells ("1D" model)
  a complex network of cells ("2D/3D" model)
- Regulation of Shaker channels by CPKs
- New tools for Ca^{2+} imaging
- Ca^{2+} waves in relation to APs?

Recording action potentials



• electrical stimulation

•mechanical stimulation

UNIWERSYTET MARII CURIE SKŁODOWSKIEJ · LUBLIN · 1944 ·

UNIVERSITÉ DE GENÈVE

The AKT2 channel controls "excitability"

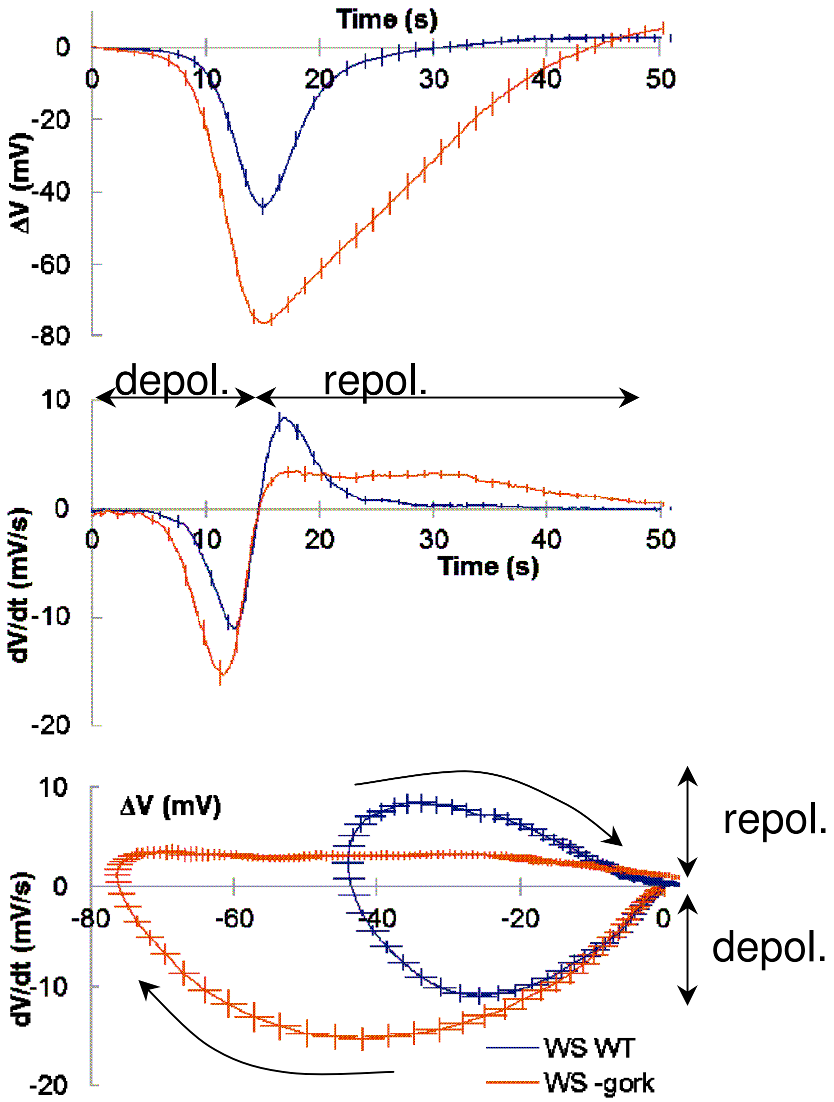
Line	WS ecotype			Col-0 ecotype	
	akt2-1	WT	AKT2-NN	*akt2-2*	WT
Excitability (%)	41%	51%	59%	63%	88%
Amplitude (mV)	38.1 ± 10.6	47.2 ± 11.2	53.0 ± 9.2	52.0 ± 12.3	62.2 ± 5.5
Width (sec)	6.6 ± 2.1	10.9 ± 4.2	6.7 ± 1.6	7.8 ± 2.5	7.8 ± 1.5
Speed (mm s^{-1})	1.2 ± 0.4	1.3 ± 0.3	1.1 ± 0.4	1.0 ± 0.2	1.2 ± 0.4

WS plants are less excitable than Col-0 plants

knocking-out the *AKT2* gene decreases excitability

AKT2 (phosphorylated) increases excitability

The GORK channel controls the shape of APs



knocking-out GORK lengthens and amplifies the AP

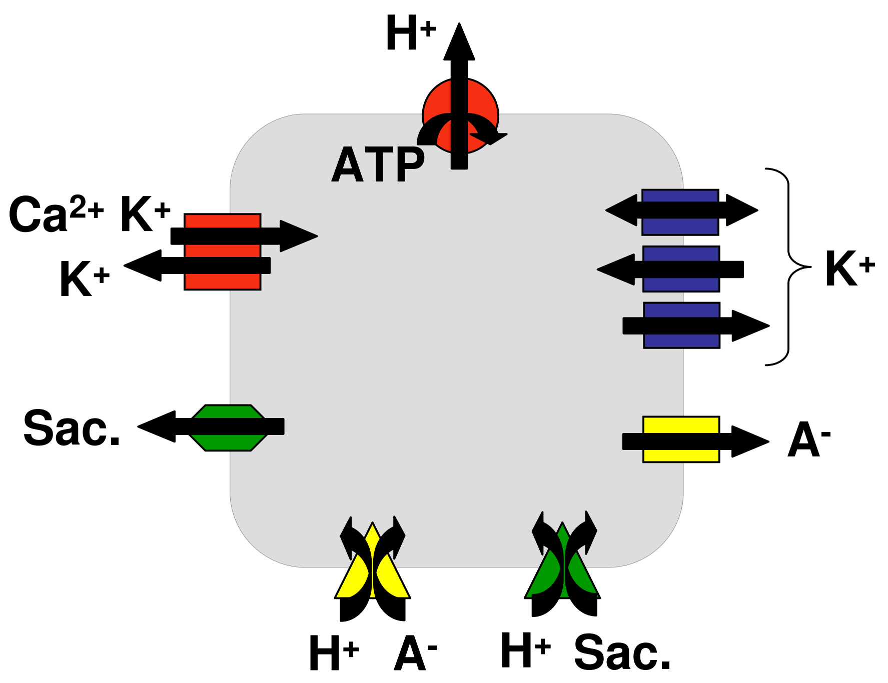
knocking-out GORK has little effect on depolarising currents but flattens time-course of repolarising currents

knocking-out GORK suppresses the voltage-dependence of repolarising currents

GORK is the main V-gated repolarising transporter

What about the model?

functional model of a cell membrane



Transporters

H^+ pump

K^+ channels

anion channels

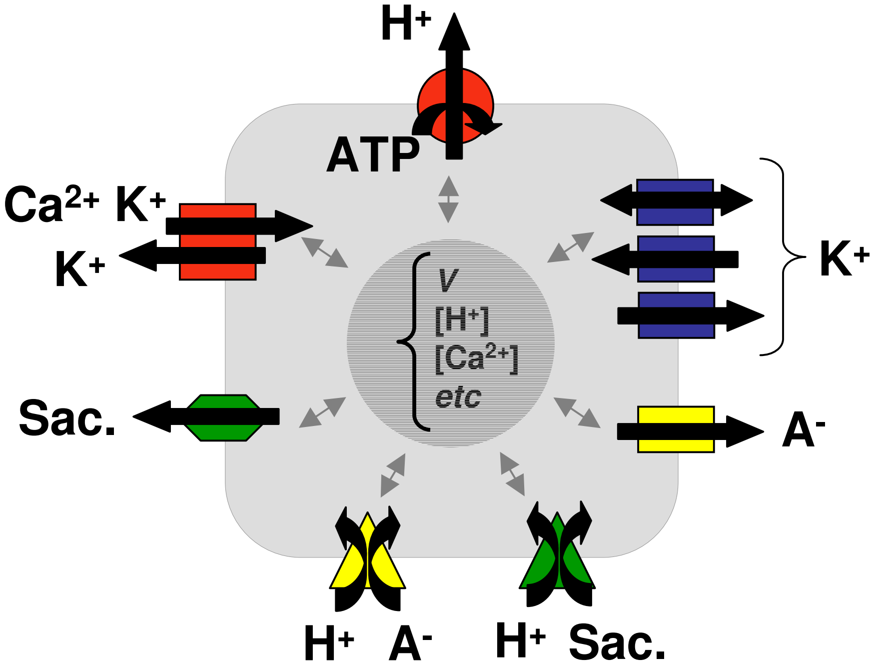
cation (Ca^{2+}) channels

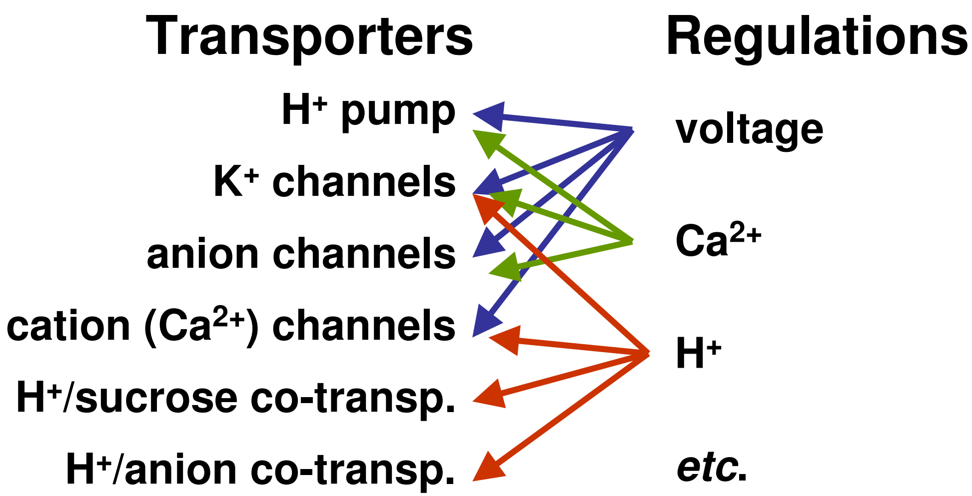
H^+/sucrose co-transp.

H^+/anion co-transp.

What about the model?

functional model of a cell membrane
+ transporter regulations

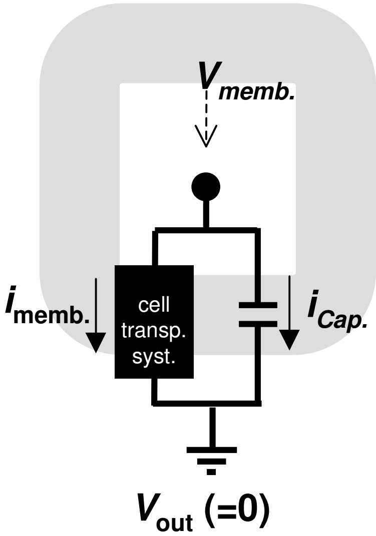




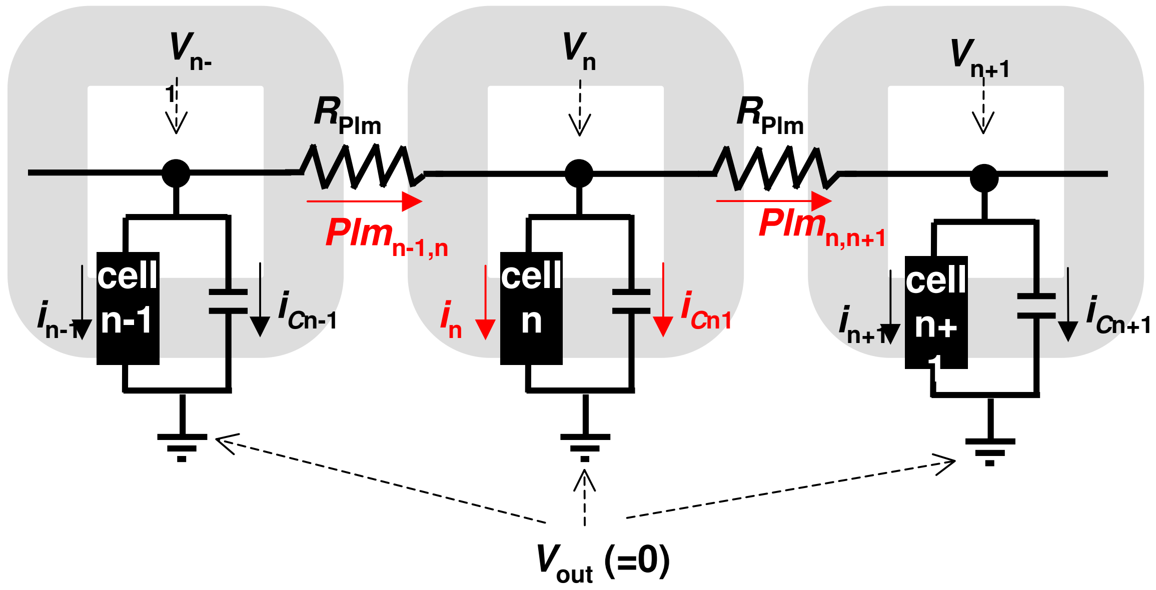
application of laws of biophysics and biochemistry (Nernst, Goldman-Hodgkin-Katz, mass action, Michaelis...)

What about the model?

electrical model of a cell membrane...



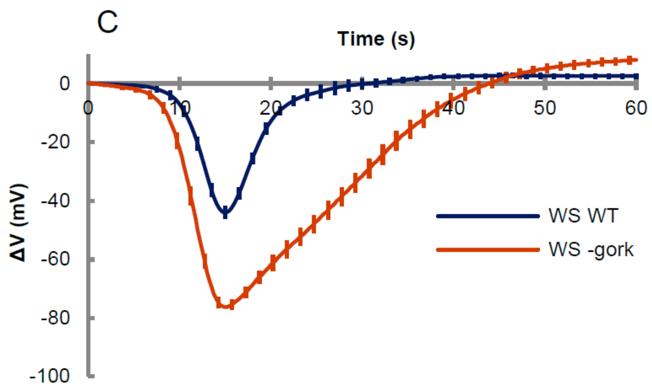
... and of a file of cells



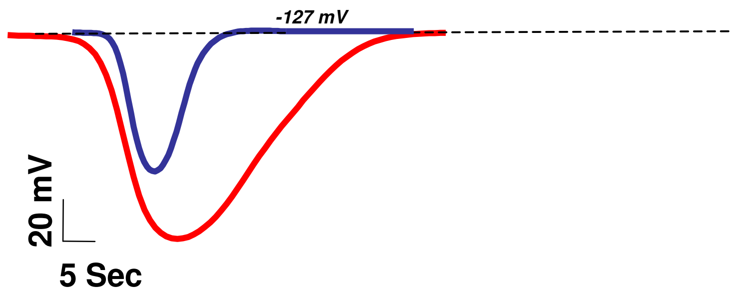
application of laws of electricity (Kirchhoff, Ohm...)

The model confirms experimental results

- exp. WT/*gork-*



- modelled exp. WT/*gork-*



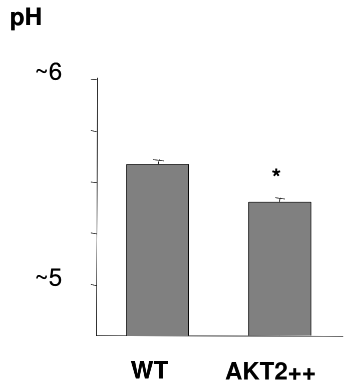
knocking out the *GORK* gene

- **increases the AP amplitude**
- **lengthens de AP (slows the repolarisation phase)**
- **lets the propagation speed unchanged**

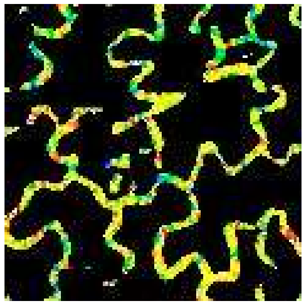
Model predictions

Experimentation

- overexpressing AKT2 should decrease the leaf apoplastic pH



Fluorescein (FITC-DEXTRAN)



- ABA application should trigger APs in leaves
- propagating APs make "Ca^{2+} waves"

soon tested!

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