Noninvasive measurements of plant roots using spectral induced polarization

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האוניברסיטה העברית בירושלים
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1. Motivation

The properties and processes of plant roots and their rhizosphere control critical factors as water and nutrient transport, soil carbon and nutrient dynamics, and soil microorganisms. Monitoring of these factors is therefore of great importance.

Spectral induced polarization (SIP) holds great promise to monitor root and rhizosphere in a non-invasive fashion. To use this method, knowledge on the relationship between the root properties (e.g. root mass) and the electrical properties is required.

2. Research objective

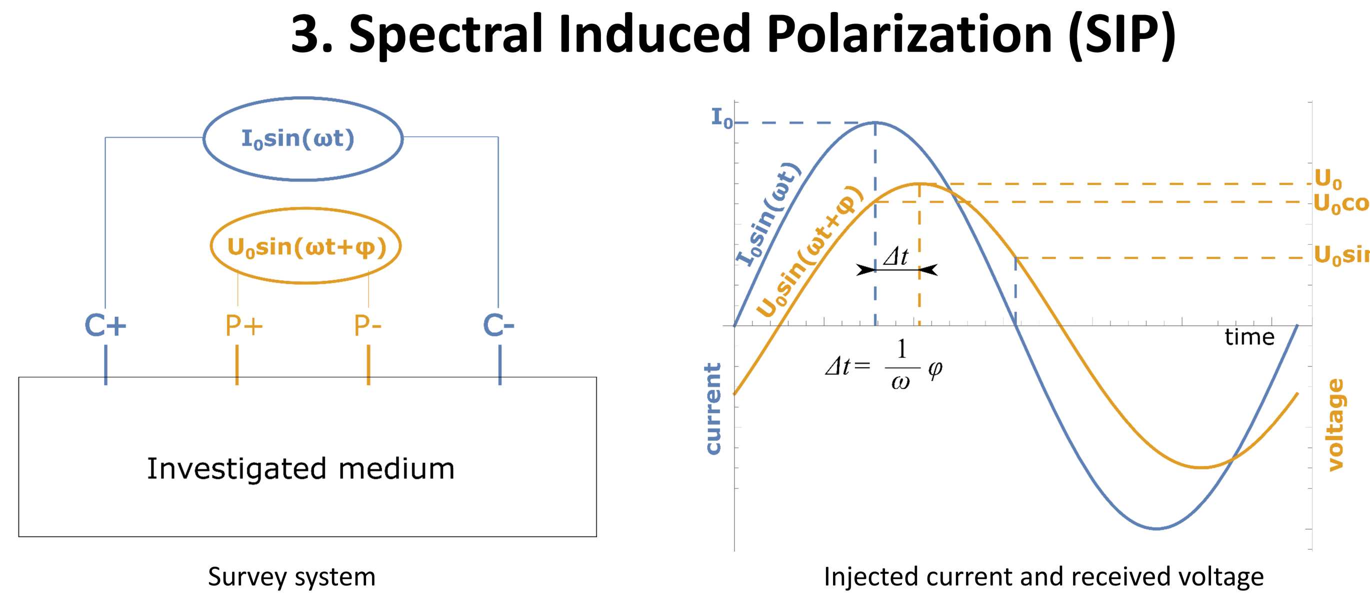
To find relations between the SIP signal and the root parameters.

Root parameters
- Root volume
- Root architecture

⟺

SIP signal
- Magnitude
- Spectrum shape

3. Spectral Induced Polarization (SIP)



The complex conductivity:

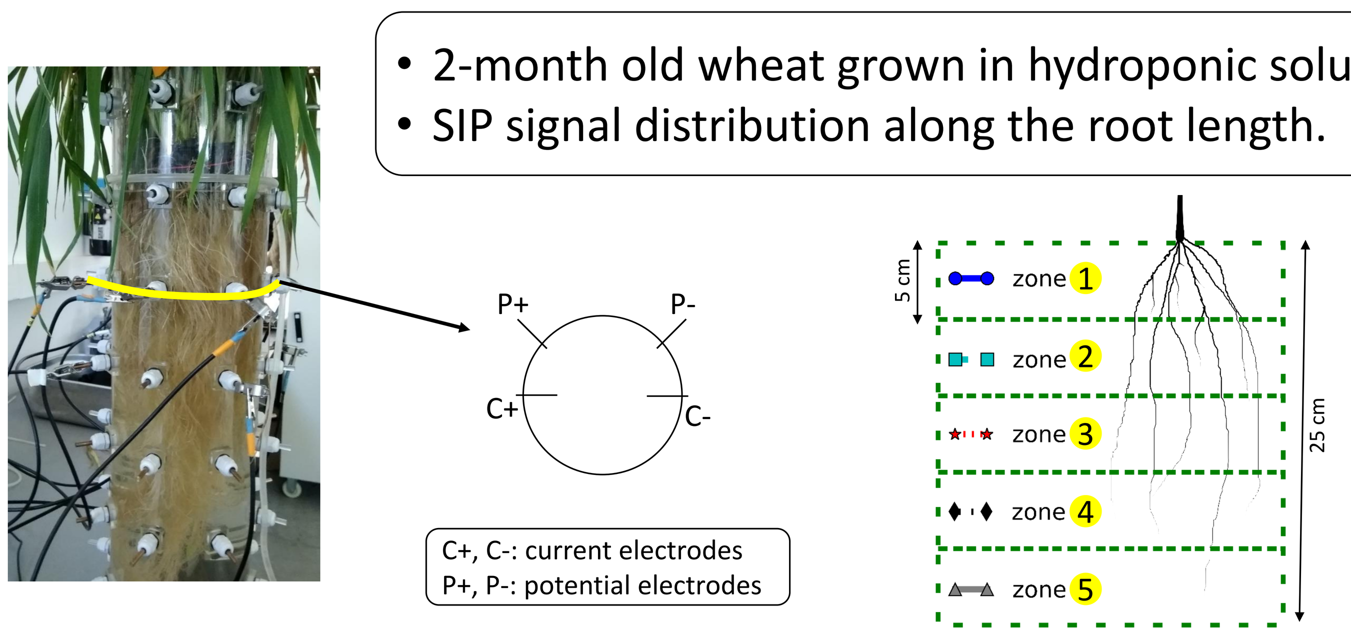
$$\sigma(\omega) = \frac{1}{G}\frac{I(\omega)}{U(\omega)} = \sigma'(\omega) + i\sigma''(\omega)$$

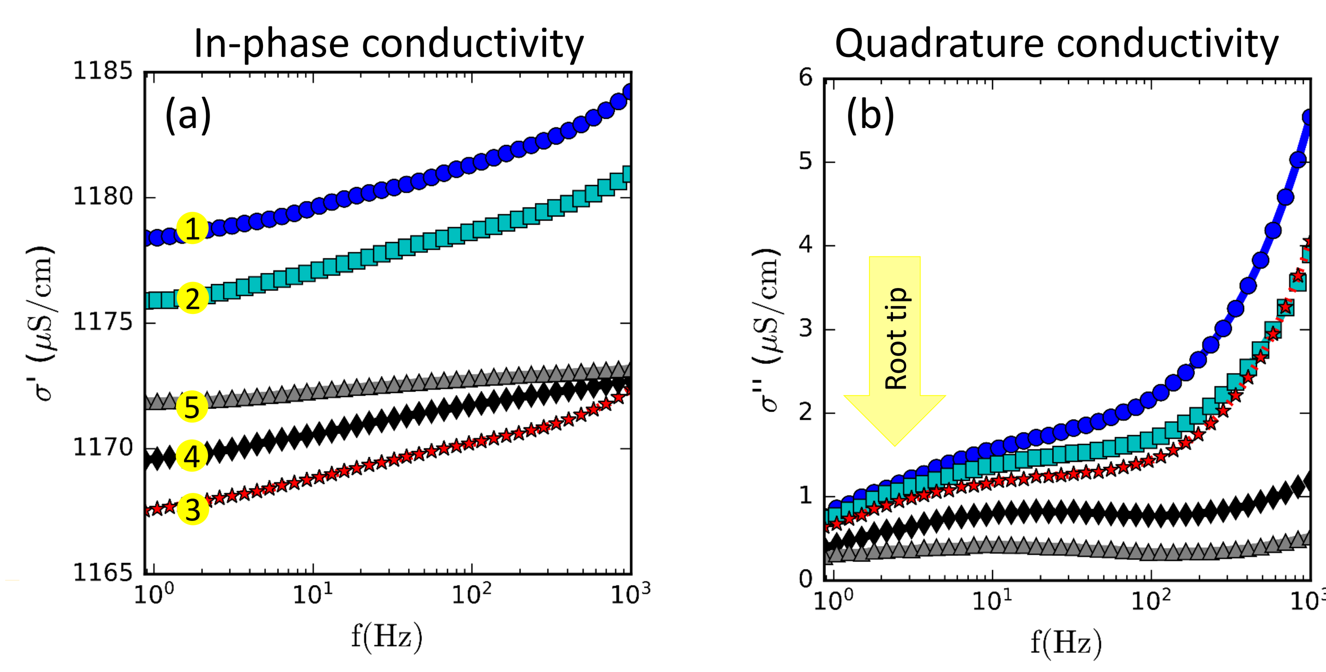
G is geometric factor determined by the electrode arrangement.

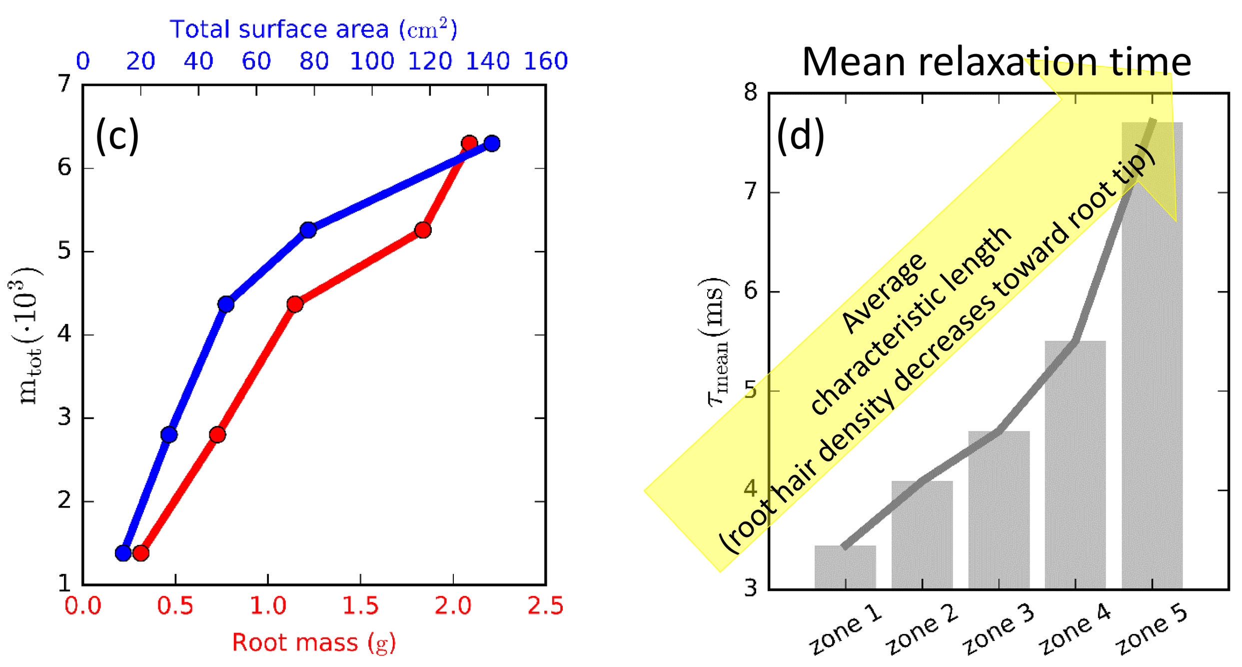
In-phase conductivity $\sigma'(\omega)$	⟺	Dissipation process
Quadrature conductivity $\sigma''(\omega)$	⟺	Polarization process

4. SIP response along the root length

- 2-month old wheat grown in hydroponic solution.
- SIP signal distribution along the root length.

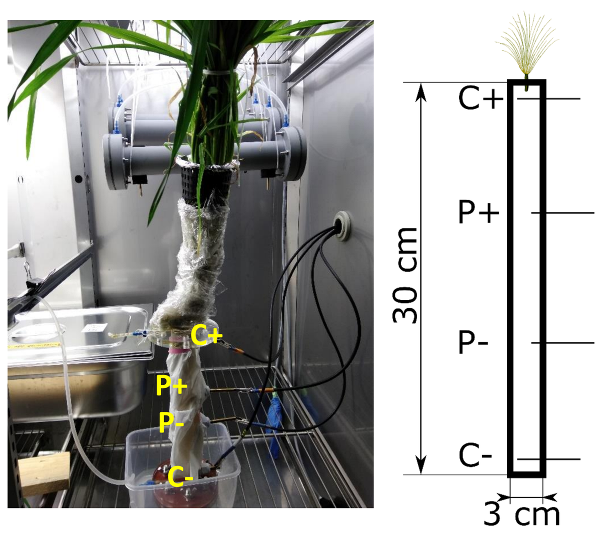






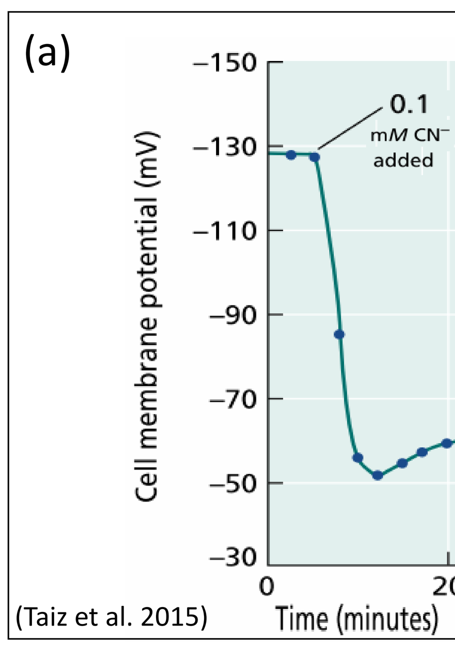
(a) Negligible change of the in-phase conductivity.
(b) Quadrature conductivity decreases toward the root tip.
(c) A decrease in the root mass and the total surface area is followed by a decrease in polarization.
(d) Relaxation time might be related to the root hair distribution.

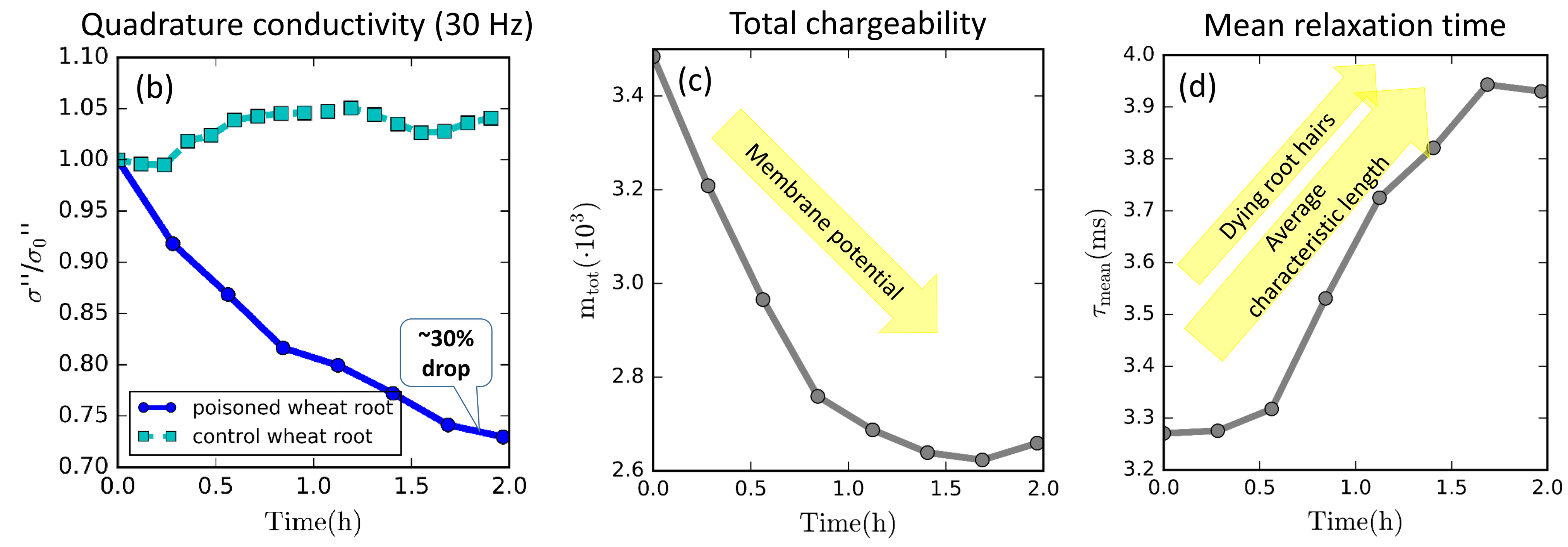
5. SIP monitoring of wheat root poisoned by cyanide



- 1.5 month old wheat in hydroponic solution.
- Solution + cyanide.
- SIP monitoring for 2 hours.

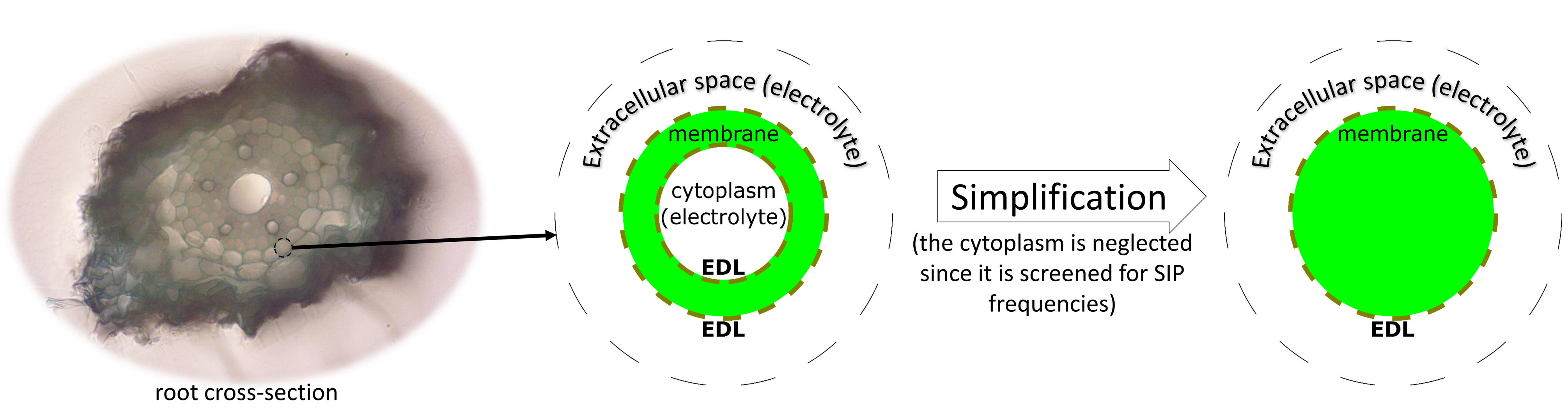
C+, C-: current electrodes
P+, P-: potential electrodes





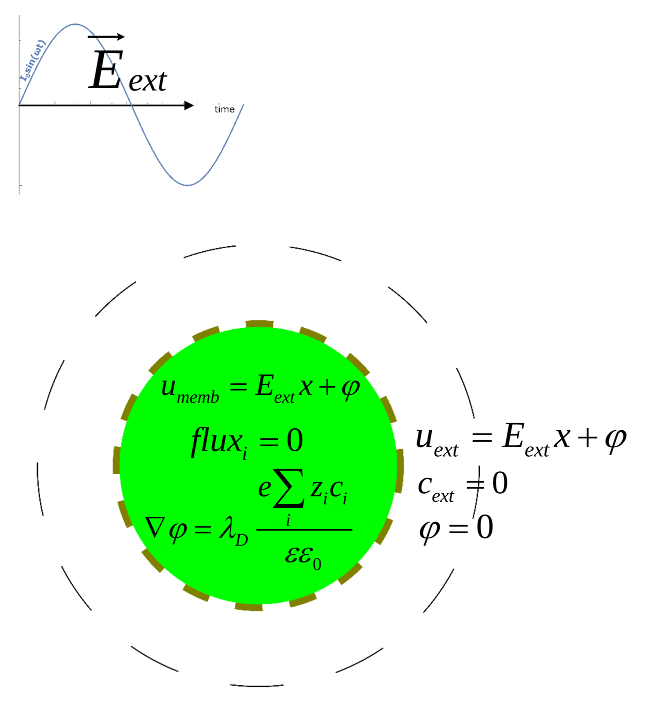
(a) Cell membrane potential drop after the introduction of cyanide.
(b) Quadrature conductivity drop in response to cyanide.
(c) Chargeability decreases after the poisoning, confirming that the cell membrane is the polarization source.
(d) Relaxation time increases suggesting that root hairs are affected before other parts.

6. Modeling of SIP response caused by the root cell



Source of the polarization is an **electrical double layer (EDL)** at the root cell membrane.

Root cell model



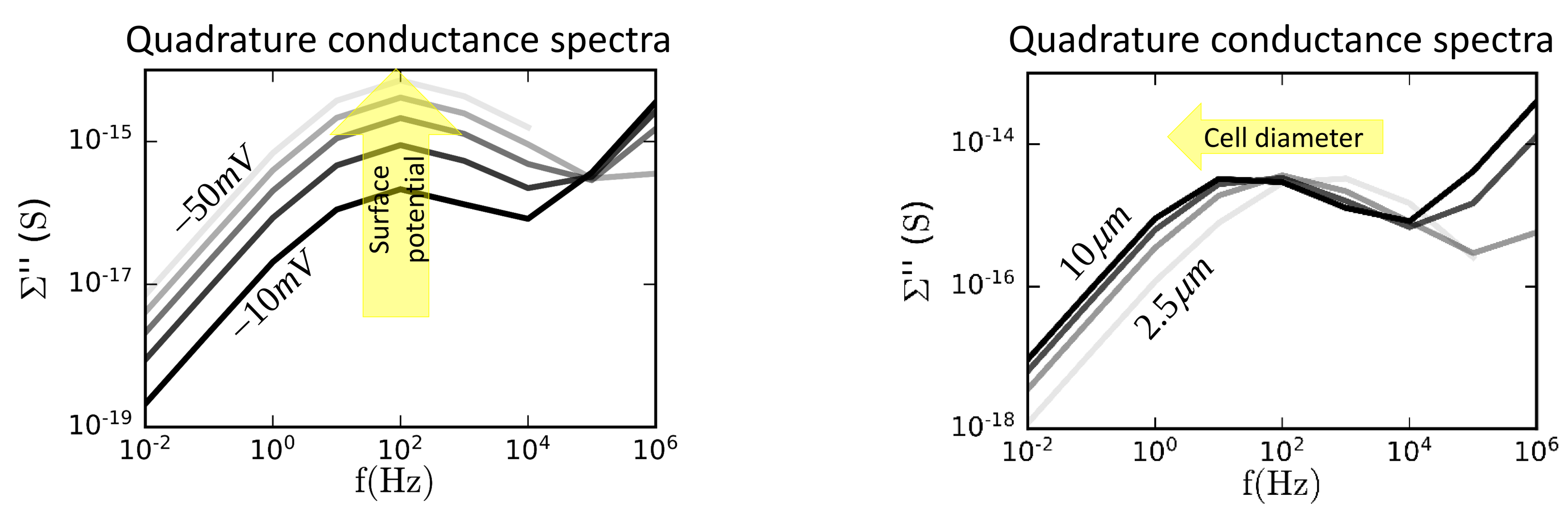
Poisson-Nernst-Planck equation system:

$$\begin{cases} i\omega c_i = \nabla\cdot\left(D_i\nabla c_i + z_i e\frac{D_i}{kT}(c_{i0}\nabla u + c_i\nabla u_0)\right) \\ \nabla\cdot(-\varepsilon\varepsilon_0\nabla u) = \sum_i e z_i c_i \end{cases}$$

Redistribution of the ions at the membrane:

$$\nabla\cdot(-\varepsilon\varepsilon_0\nabla\varphi) = 0$$

c_i	concentration of i_{th} ion
z_i	valence of i_{th} ion
D_i	diffusivity of i_{th} ion
u, φ	electric potential
T	temperature
e	elementary charge
ε	permittivity
ε_0	vacuum permittivity
k	Boltzmann constant
λ_D	Debye screening length
x	coordinate
ω	frequency



7. Conclusion

- The experiment verified that the cell membrane is the source of the root polarization.
- Positive relationship between the chargeability and root surface area is obtained.
- It is hypothesized that the relaxation time is determined by the root hair distribution.
- The in-phase conductivity is not significantly affected by the root.
- The numerical model confirms the interpretation of the SIP experiments.