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3D SOURCE LOCATION IN OPTICAL MAPPING

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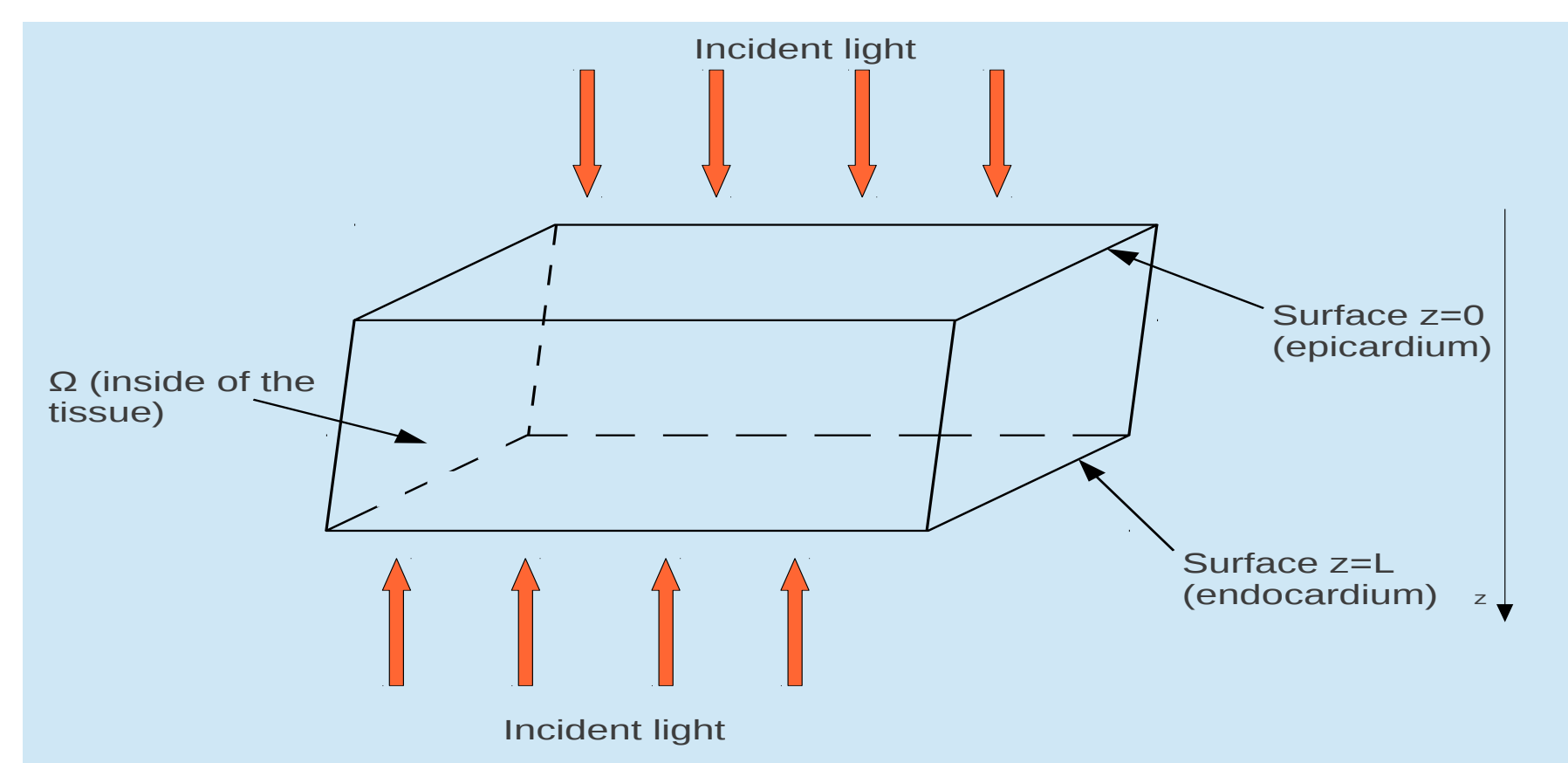
This work is sponsored by the grant number ANR-10-IAHU-04 from the french government.

PROBLEM STATEMENT AND OBJECTIVES

- Optical mapping enables to display optical potentials on the boundary of a slab of tissue.
- At a given time, we have 4 images: 2 from epi-illumination and 2 from endo-illumination.
- Exploit these images to reconstruct an optimal 3D depolarization wave front.

EQUATIONS

Domain:



finite elements discretization

Incident light:

$$\begin{cases} D_e \Delta \phi_e - \mu_e \phi_e = 0 & \text{in } \Omega \\ \phi_e = \frac{I_e \delta_e}{D_e} & \text{on illuminated surface} \\ \phi_e = d_e \frac{\partial \phi_e}{\partial \nu} & \text{elsewhere} \end{cases} \quad (1)$$

- λ : wavelength
- $I_e(\lambda)$: light intensity
- $D_e(\lambda), \delta_e(\lambda), \dots$: material properties

Fluorescence:

source: $w = \beta(V_m - V_0)\phi_e$

$$\begin{cases} D \Delta \phi - \mu \phi + w = 0 & \text{in } \Omega \\ \phi = d \frac{\partial \phi}{\partial \nu} & \text{on } \partial \Omega \end{cases} \quad (2)$$

- V_m : transmembrane potential
- V_0 : rest potential

MATRIX RELATIONS

- discretization of (2) gives:

$$A\Phi = MW$$

$$L\Phi = \Phi_S$$

Φ_S : projection on surface, observations

- reformulation: $B = A^{-1}M$

$$W(V_m) \xrightarrow{B} \Phi \xrightarrow{L} \Phi_S$$

- under-determined problem because 19954 points in the whole domain including 1871 on the epicardium.

WAVE FRONT : RESTRICTION

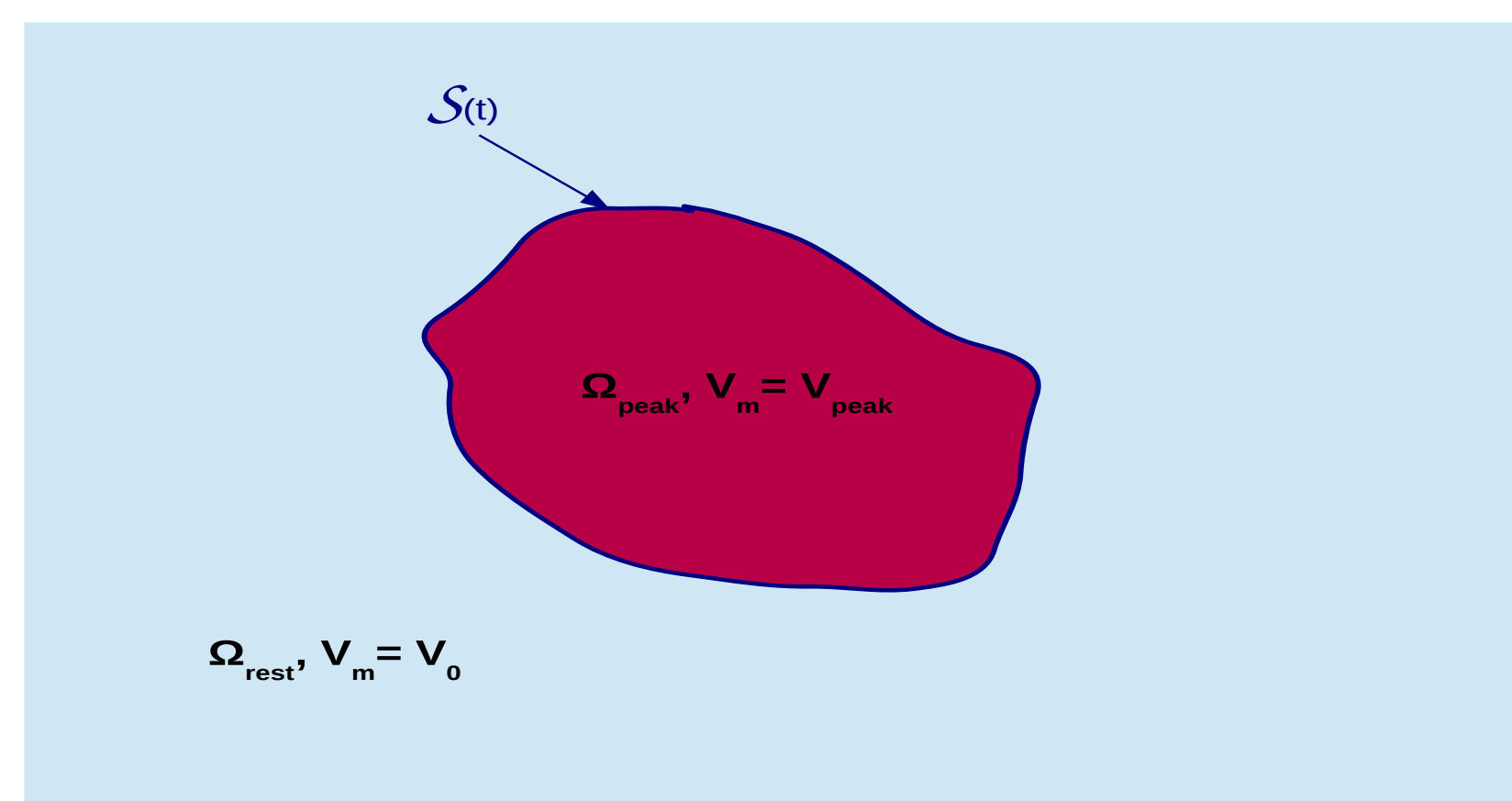
$$\mathcal{S}(t) \longrightarrow V_m \longrightarrow W \xrightarrow{B} \Phi \xrightarrow{L} \Phi_S$$

$$\text{We look for } V_m = \begin{cases} V_0 & \text{in } \Omega_{rest} \\ V_{peak} & \text{in } \Omega_{peak} \end{cases}$$

where $\overline{\Omega_{rest}} \cap \overline{\Omega_{peak}} = \mathcal{S}(t)$

WAVE FRONT : RESTRICTION

2D representation:



choice: $\mathcal{S}(t) = \{|X - X_0| - c(t - t_0) = 0\}$,
expanding sphere
parameters to identify: X_0, t_0 and sometimes c .

INVERSE PROBLEM

Minimize

$$e(X_0, t_0, \dots) = \|\Phi_S - \Phi^*\|_{L^2(S)}^2$$

Φ^* : observation

Method:

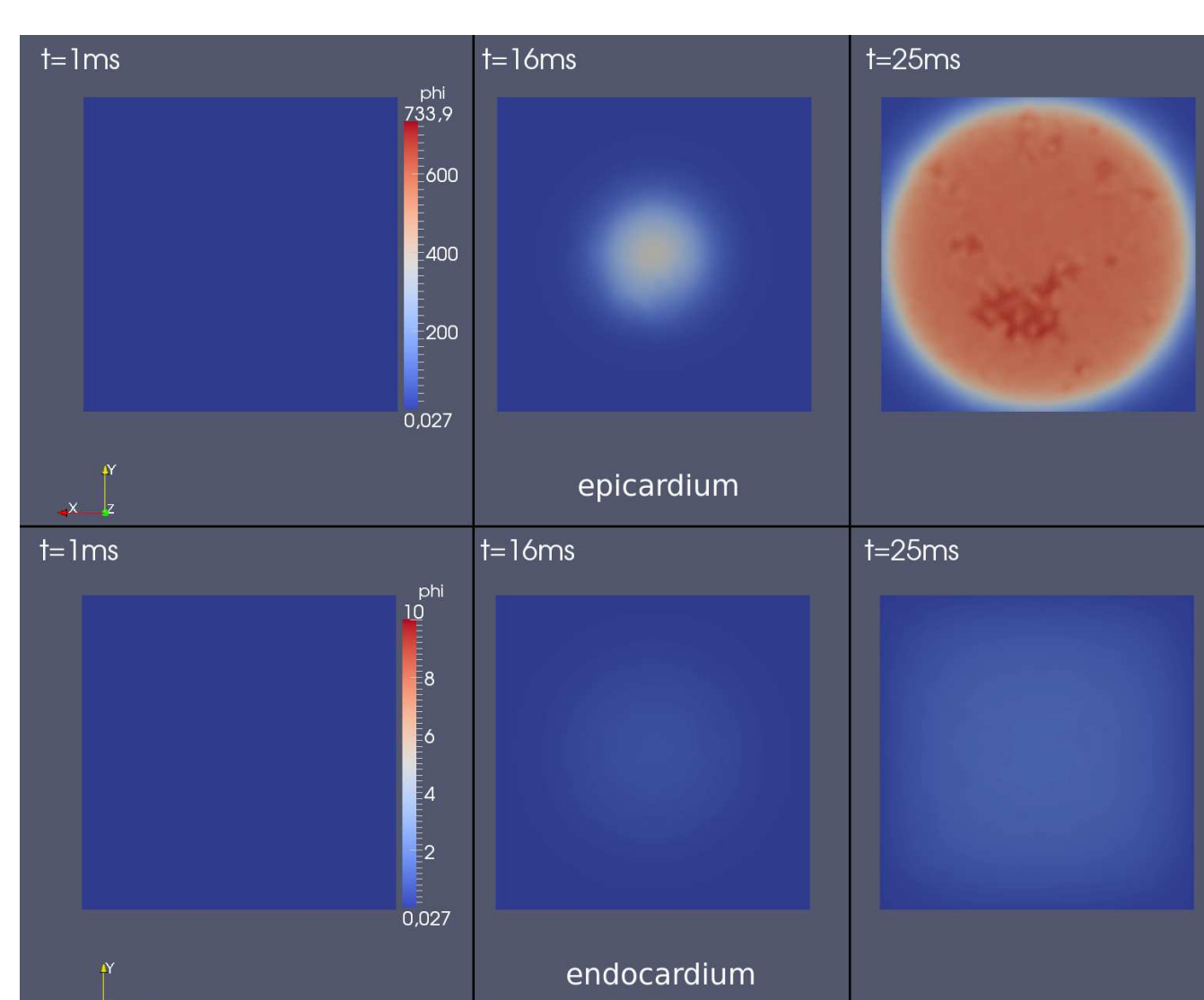
- BFGS method
- 1st case functional:
 $e(X_0, t_0, \dots) = \|\Phi_S(t_k) - \Phi_k^*\|_{L^2(S)}^2$
 Φ_k^* : observation at time t_k
- 2nd case functional:
 $e(X_0, t_0, \dots) = \left(\sum_k \|\Phi_S(t_k) - \Phi_k^*\|_{L^2(S)}^2 \right)^{1/2}$

RESULTS

In-silico example:

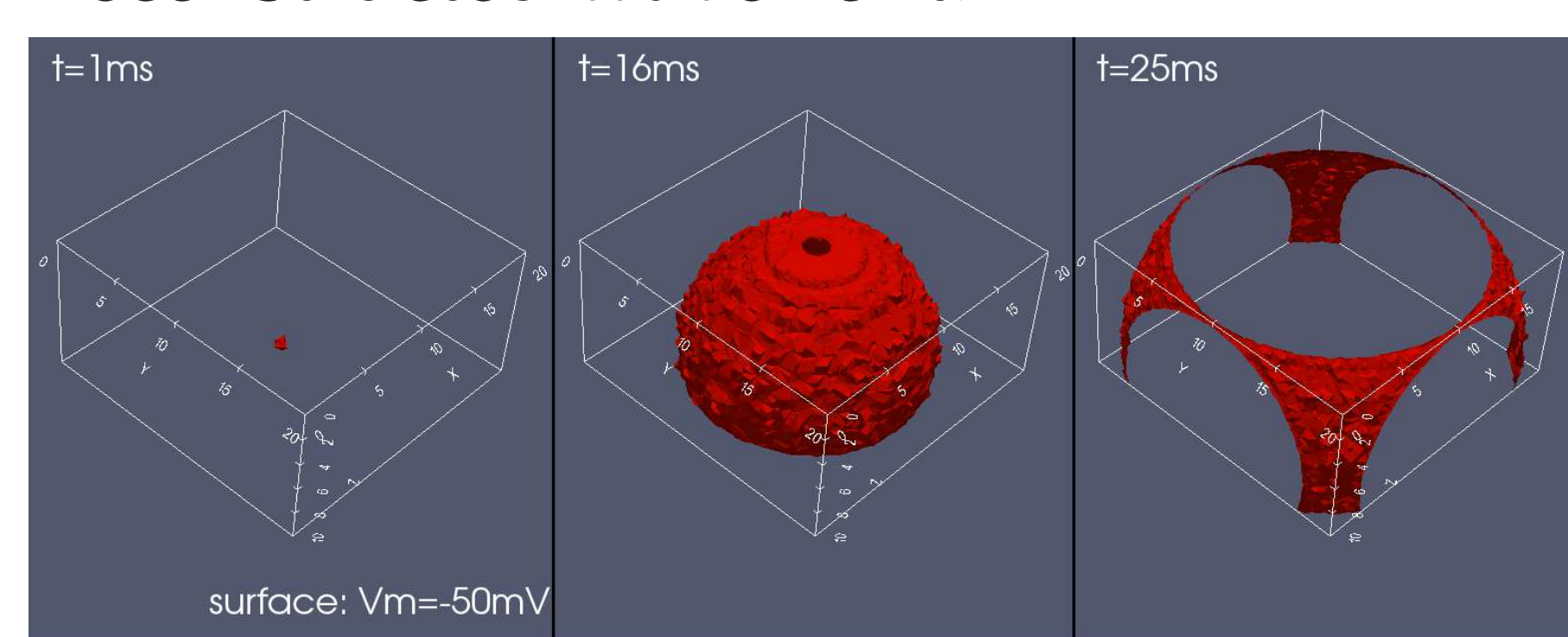
Direct simulation of a single source at $X^* = (10, 10, 8)$ and $t^* = 0$.

Simulated observations:



Reconstructed X_0 : $X_0 = X^*$

Reconstructed wavefront:



RESULTS

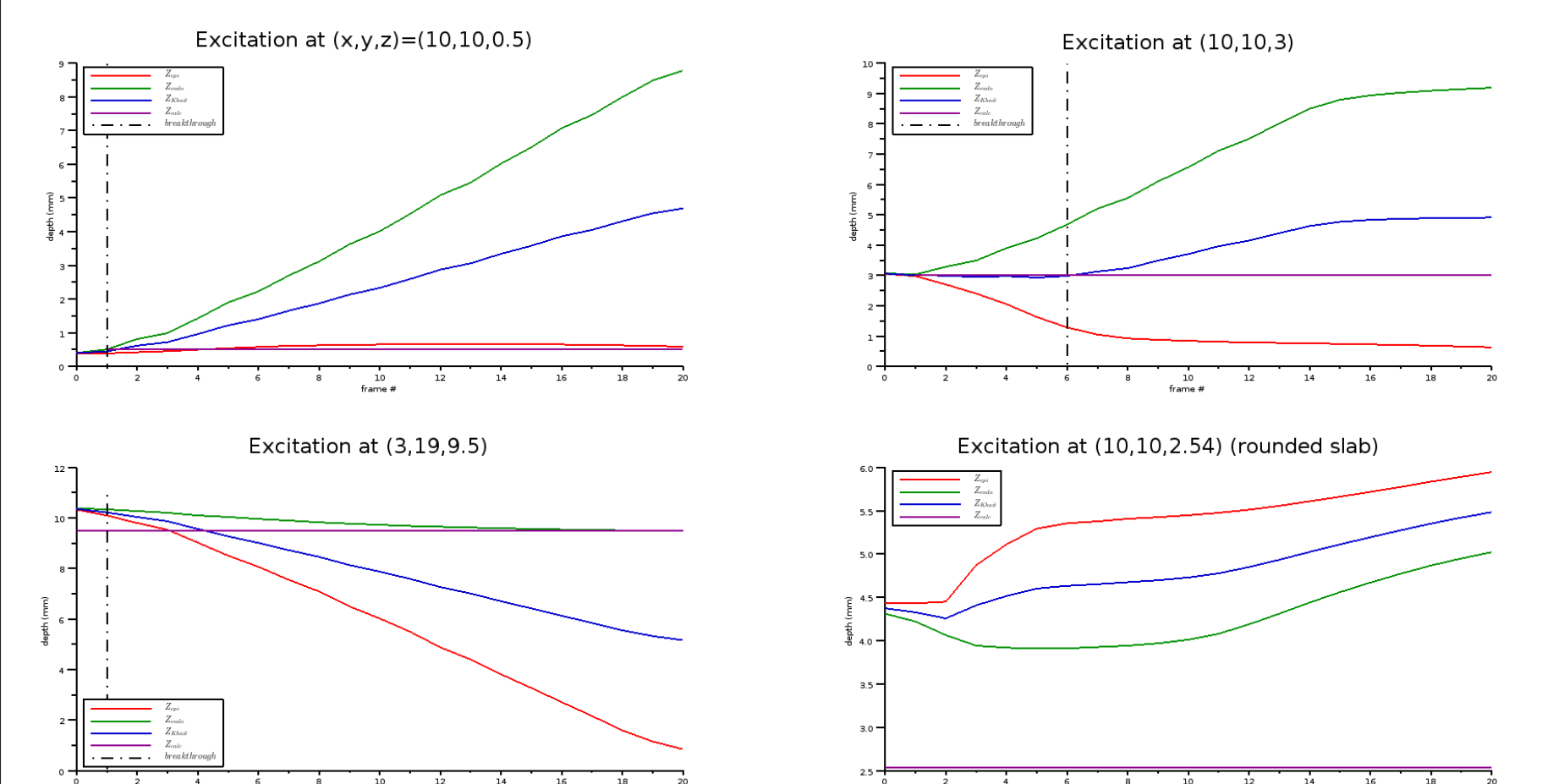
Our approach:

several situations tested:

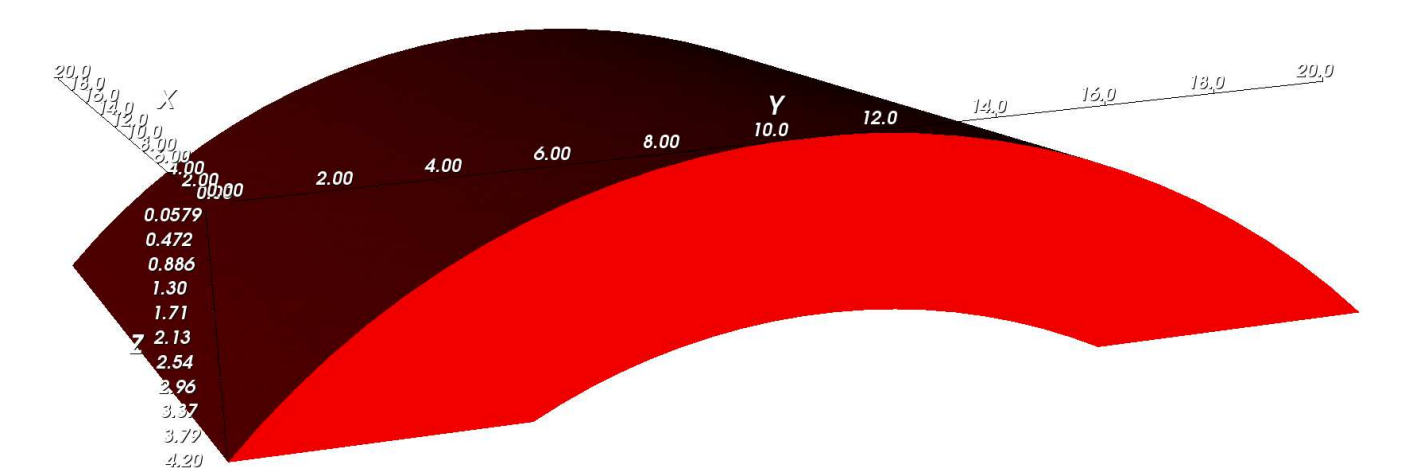
- reflexion in epi-illumination
- reflexion and transillumination in epi-illumination
- reflexion in epi- en endo-illumination
- unknown speed
- unknown excitation time

ANY SOURCE COULD BE
RECONSTRUCTED

Comparison with Khait



In [1], Khait calculates Z_{endo} and Z_{epi} and then defines the depth (Z_{Khait}) as the mean. The last curves were obtained with the following domain:



DISCUSSION - CONCLUSION

Analysis:

- sometimes with not enough depolarised tissue, our method does not converge
- very good accuracy when it converges
- **convergence even after breakthrough**
- **convergence for sources close to boundaries**
- **independence of the domain**

Perspectives:

- validation with optical phantoms: find size and location of spherical fluorescent sources [2]
- generalize the wave front $\mathcal{S}(t)$:
 - Radial Basis functions
 - Eikonal or level sets equations

REFERENCES

- [1] Khait *et al.* "Method for 3-dimensional localization [...]" In: *JBO* (2006).
- [2] Walton *et al.* "Experimental validation of alternating [...]" In: *IEEE* (2011).