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► To cite this version:

Jérôme Fehrenbach, Lisl Weynans. Activation Sites Estimation using a Fast Algorithm Based on an Eikonal Equation. Computing in Cardiology 2022, Sep 2022, Tampere, Finland. hal-03913733

HAL Id: hal-03913733

<https://inria.hal.science/hal-03913733>

Submitted on 27 Dec 2022

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Activation Sites Estimation using a Fast Algorithm Based on an Eikonal Equation

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Context and objectives

- ▶ Classical algorithms for ECGI solve at each time instant a static and extremely ill-posed inverse problem, requiring an adequate regularization strategy (or instance Tikhonov)
- ▶ An alternative way of regularizing the inverse problem is to **consider information from other time steps, taking into account that electric potentials in the heart are obtained by the propagation of an electric wave.**
- ▶ Our objectives: design a fast algorithm based on a simple activation front model to retrieve significant features of the ECGI inverse problem

Propagation model

- ▶ We consider in the present work only the surface of the heart
- ▶ **Anisotropic eikonal equation:** simplified model of electrical activation front in asymptotic regime:

$$\begin{cases} \|\nabla T\|_{D(x)}^2 = 1, \\ T(x_i^0) = \tau_i, i = 1 \dots s, \end{cases}$$
- with
 - ▶ T depolarization time of heart surface,
 - ▶ $D(x)$ tensor quantity describing the anisotropic conduction
 - ▶ τ_i activation times at sources x_i^0 (earliest activation sites)
 - ⇒ parameters relevant in the context of ECGI
- ▶ $T(x)$ is also the length of the shortest path joining the sources to x

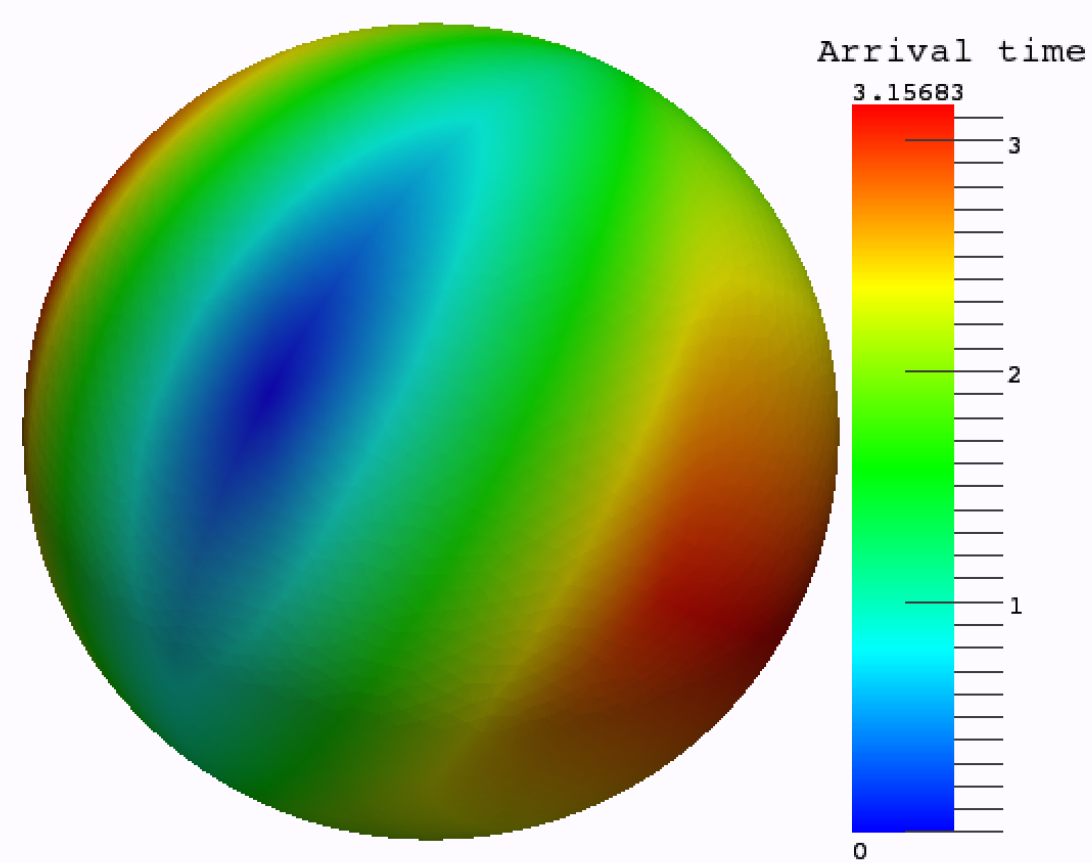


Figure: Example of solution of eikonal equation with anisotropic conduction

Methods

- ▶ Iterative algorithm to minimize misfit between observations and predictions of the model
- ▶ **Cost function**

$$J(x, \tau) = \frac{1}{2} \|G(\tau + \phi_x) - g^{\text{OBS}}\|_Y^2.$$
- with G observation operator (on heart or torso surface), x sources location, g^{OBS} observations with noise
- ▶ Least square minimization with Gauss Newton algorithm
- ▶ Sensitivity of cost function with respect to source locations and activation times depends on **Logarithmic map**:
 - if γ is a unique shortest geodesic path from point x to point y then

$$\text{Log}_x(y) = \gamma'(0) = \text{initial direction of } \gamma$$
- ▶ **Vector Heat Method:** efficient computational method to compute Logarithmic map, avoiding to compute all geodesics

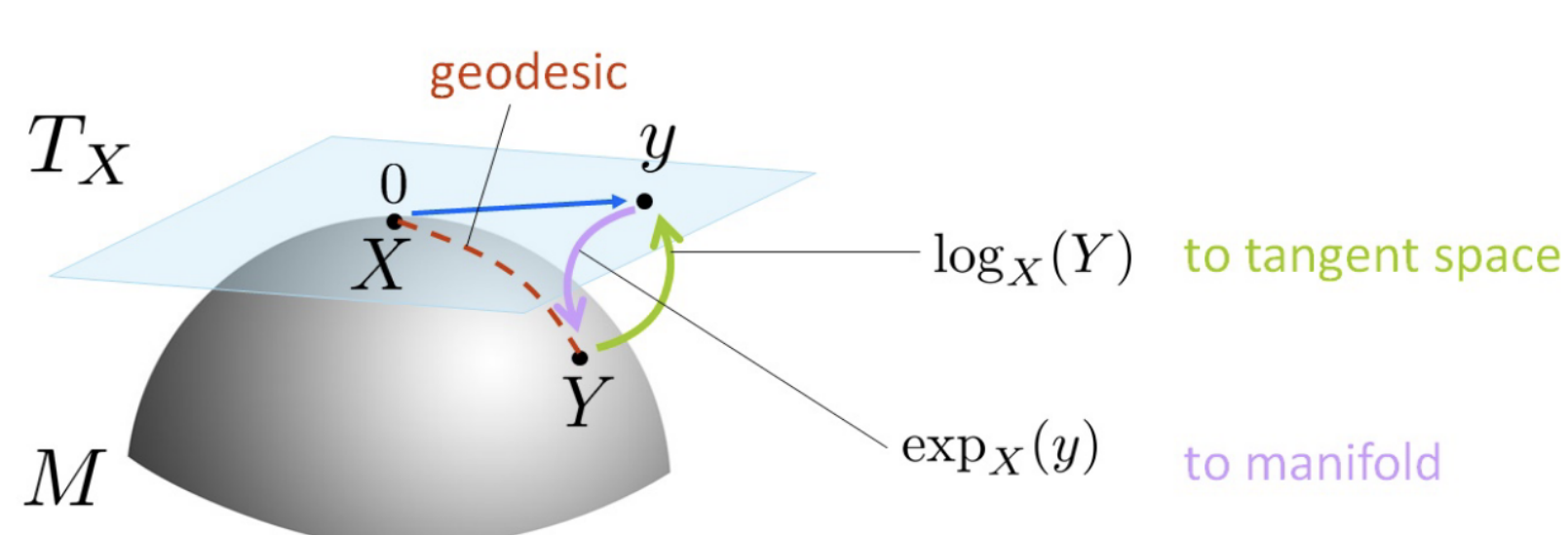


Figure: Illustration of Log map from et al

Test case: Localization of 2 sources and metric estimation

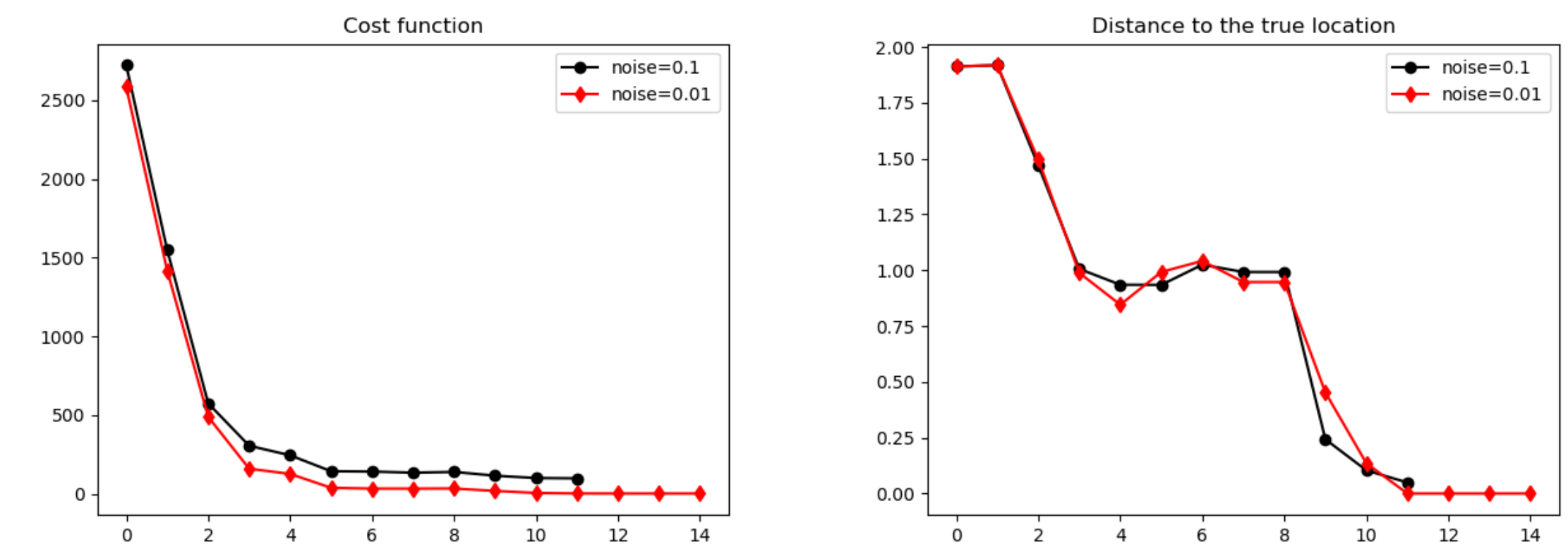


Figure: Left: evolution of the cost function J . Right: evolution of the distance to the solution $\|x^k - x^*\|$.

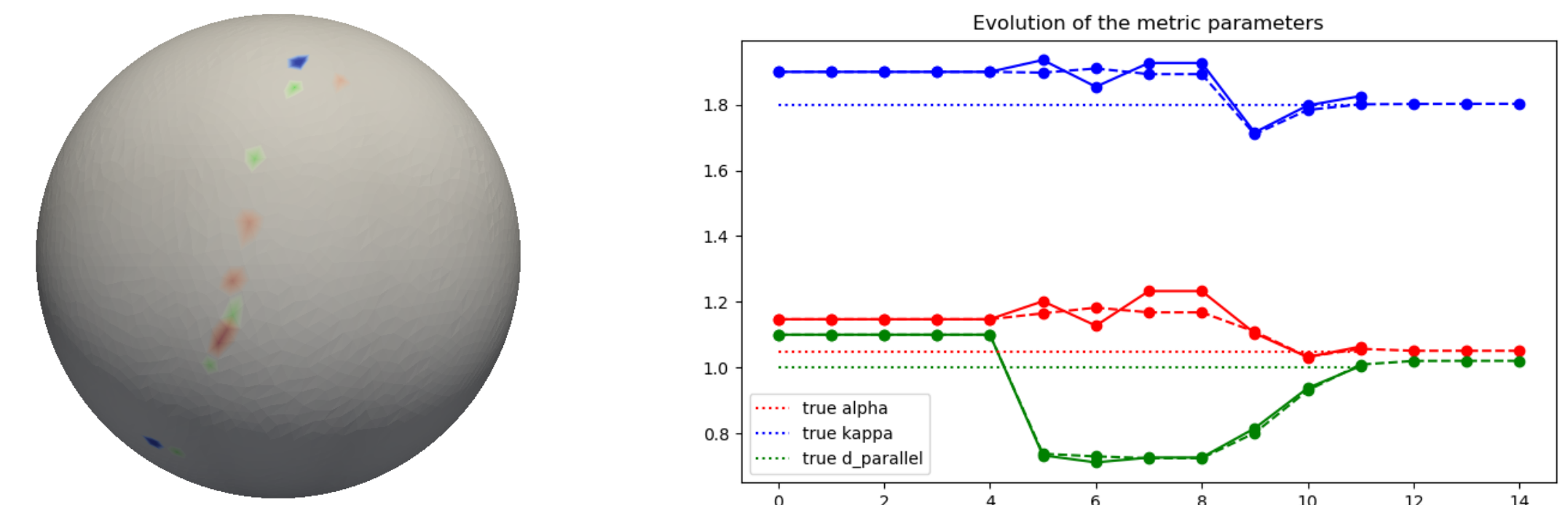


Figure: Left: location of the successive iterates x^k (red) and the true source point x^* (blue). Right: evolution of the parameters of the metric.

Test case: mimicking an ECG inversion

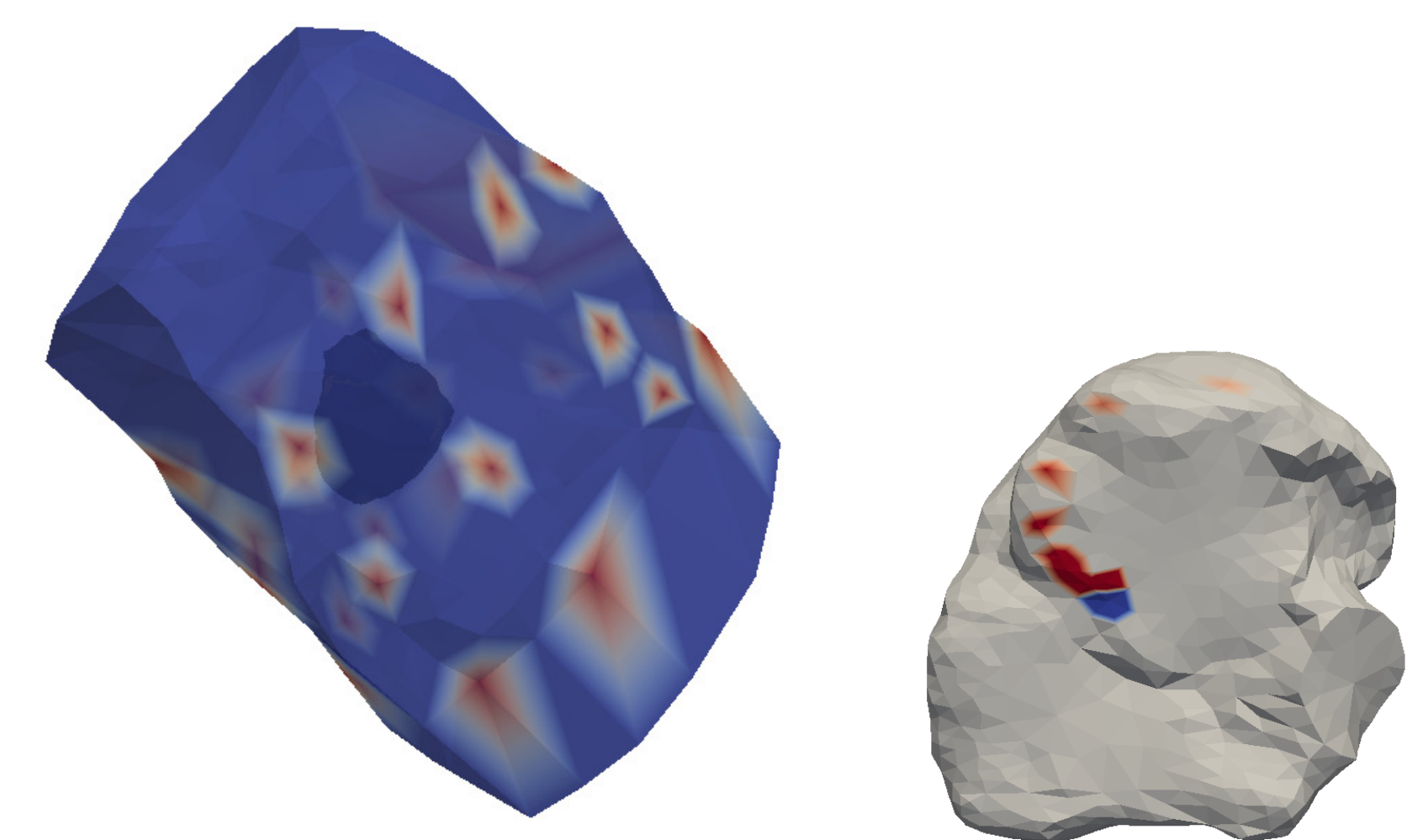


Figure: Left: configuration of the torso (electrodes in red) and the heart surface (visible by transparency). Right: location of the successive iterates x^k (red) and the true source point x^* (blue)

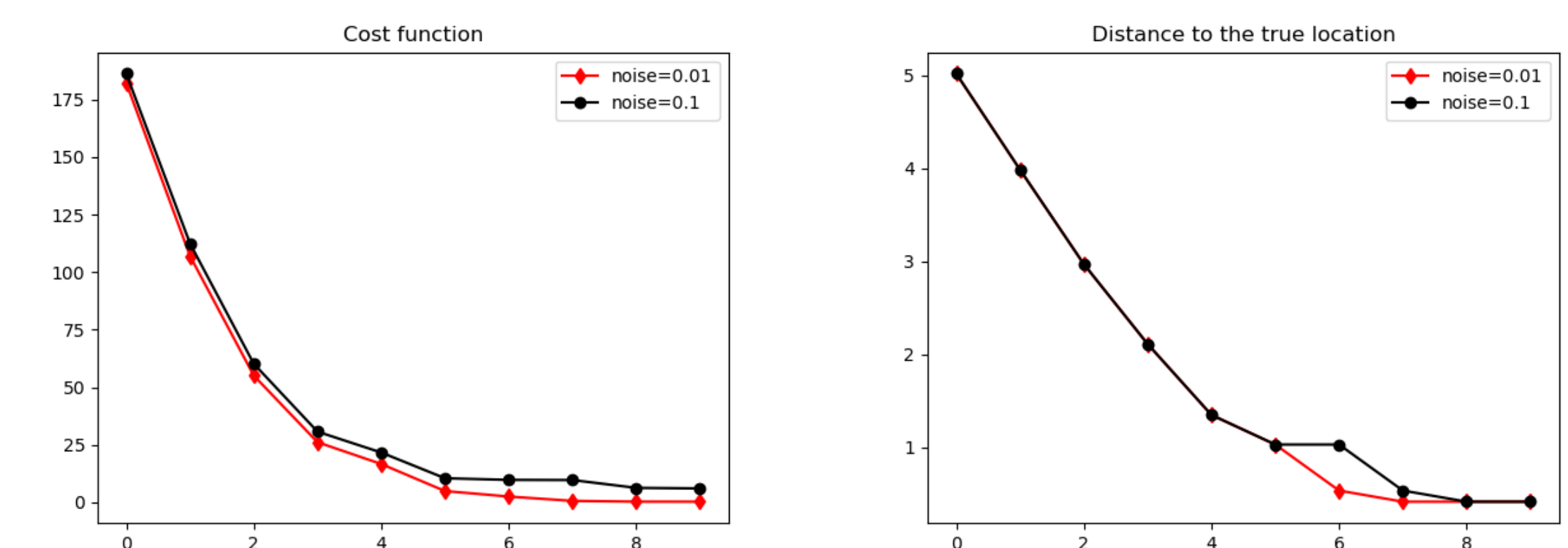


Figure: Left: evolution of the cost function J . Right: evolution of the distance to the solution $\|x^k - x^*\|$.

Conclusion

- ▶ Efficient new method to estimate sources and activation times in the eikonal equation on a surface \Rightarrow applicable to ECGI.
- ▶ In case of complex or pathological propagation patterns, need to extend the method to a cardiac volume.

References

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