www.crewes.org

Least squares DAS to geophone transform

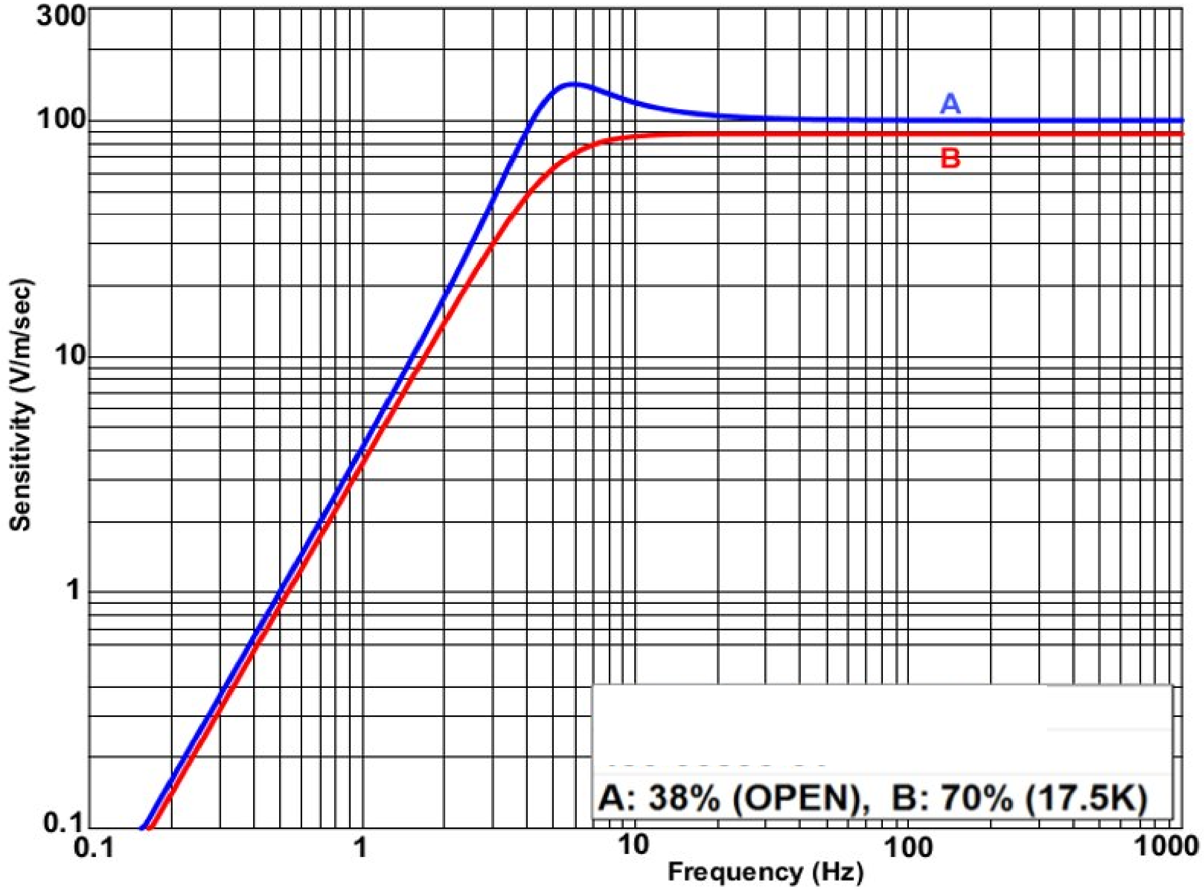
Jorge Monsegny, Kevin Hall, Daniel Trad, Don Lawton

Calgary, Canada

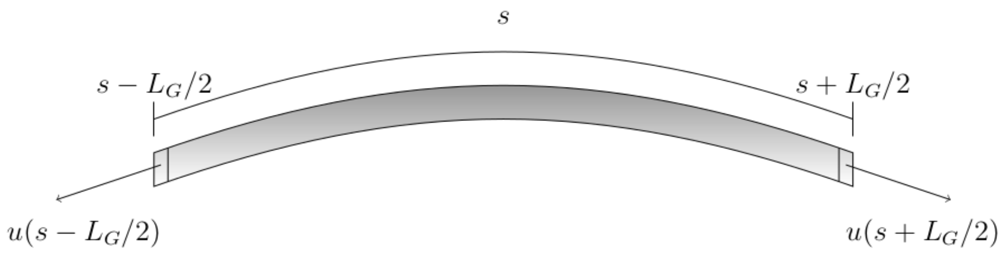
December 3 2020

Motivation

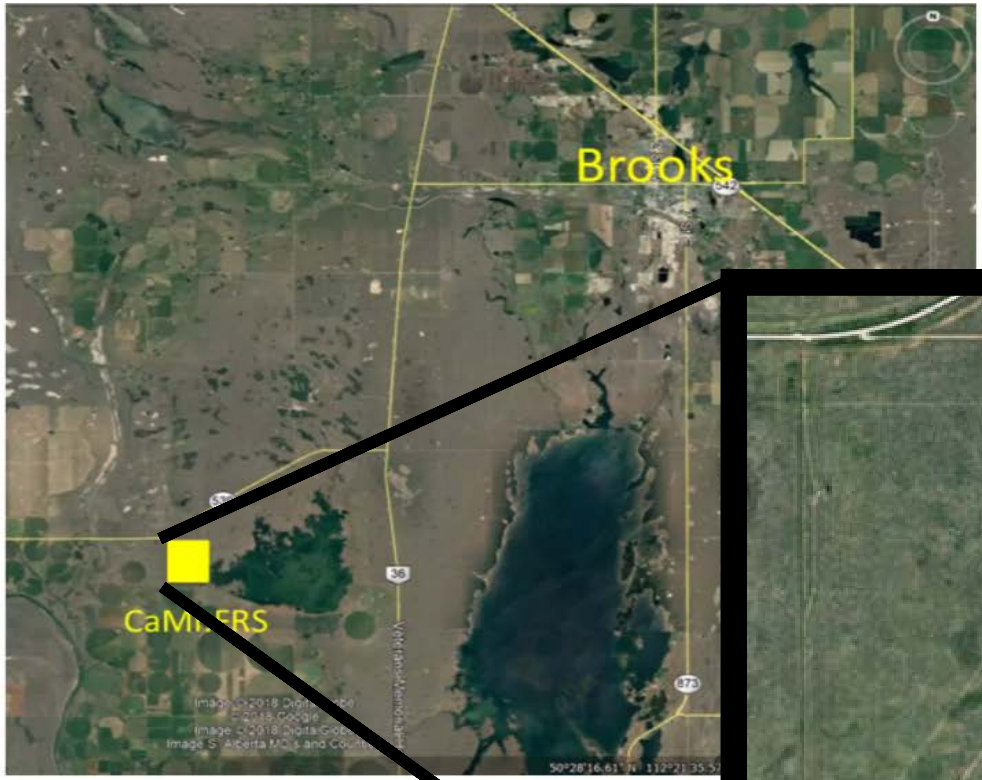
Geophone: particle velocity



DAS: strain (rate)



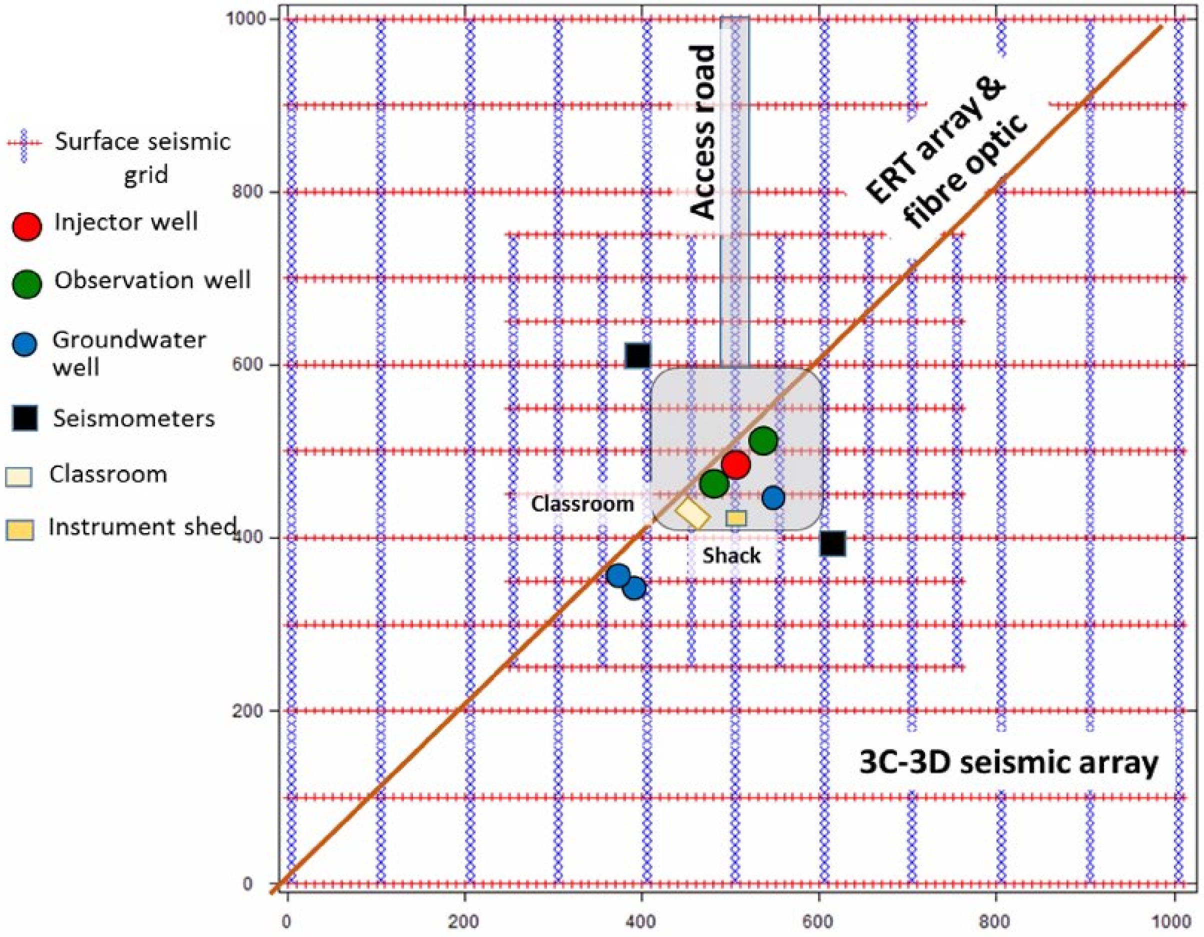
Containment and Monitoring Field Research Station CaMI-FRS



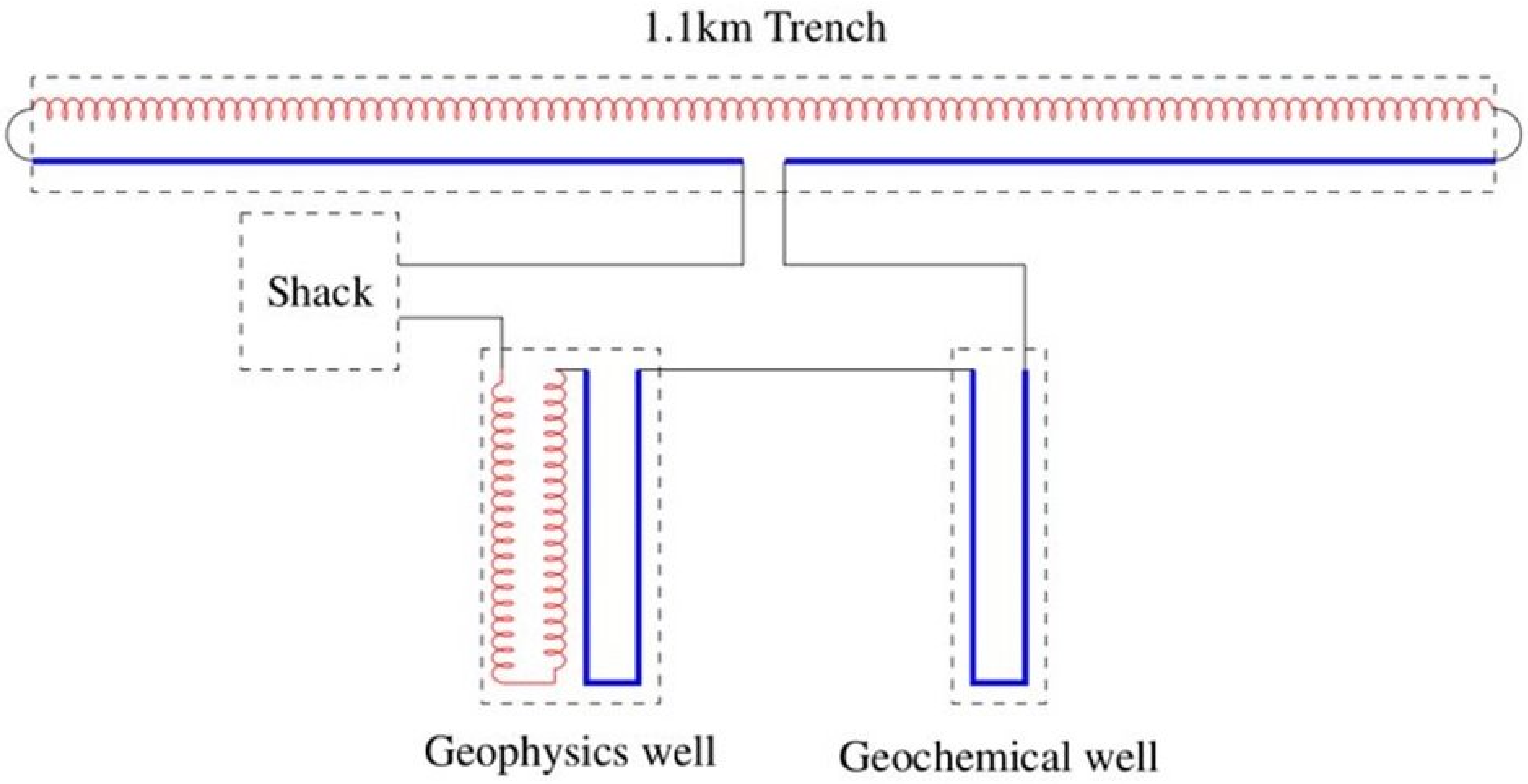
(Lawton et Al., 2019-2020)

Monitoring facilities at CaMI-FRS

(Lawton et Al., 2019-2020)



DAS facilities at CaMI-FRS



Summary

1. The least squares DAS to geophone transformation is based on a linear modelling operator that includes most of the known DAS aspects.

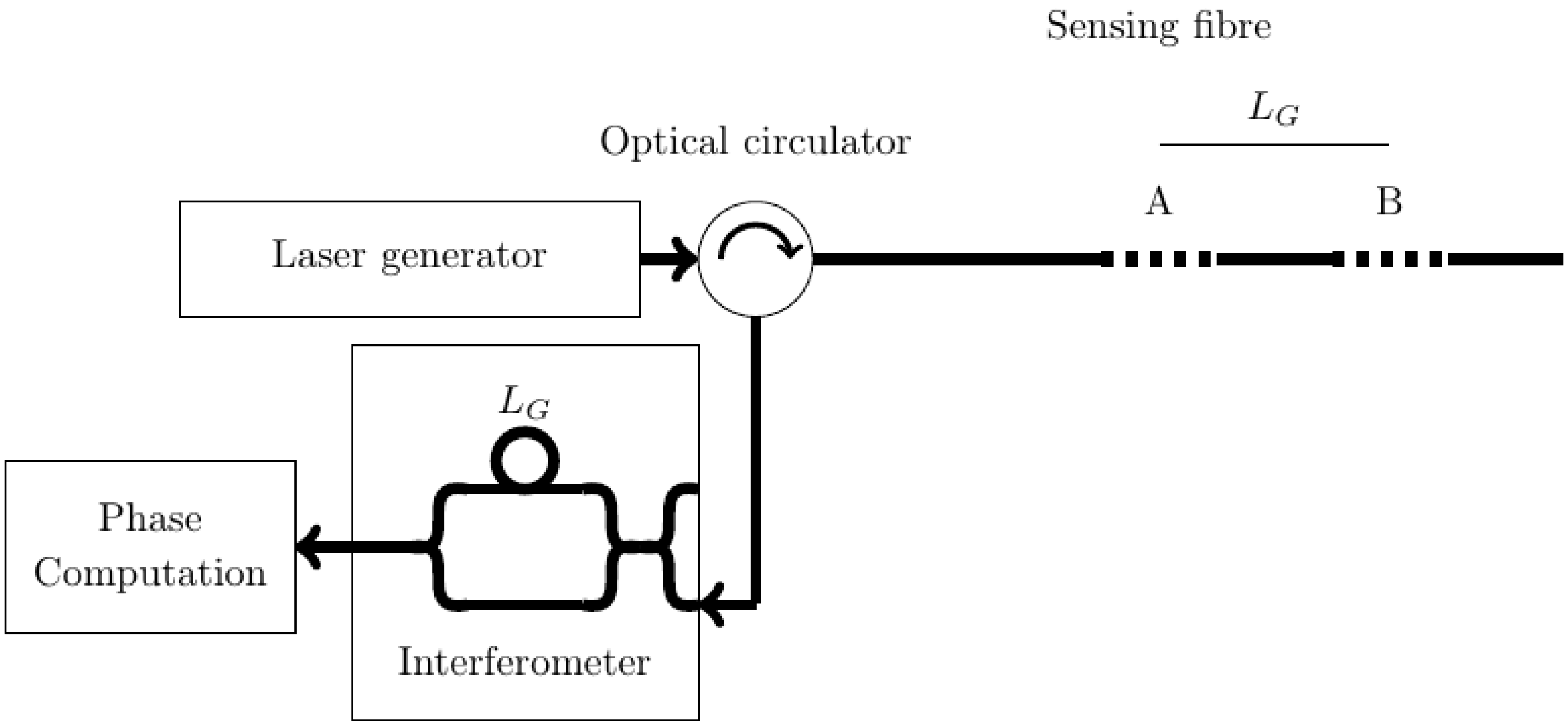
2. The least squares DAS to geophone transformation can invert the early times and the high frequency part of the geophone trace.

3. The regularization is fundamental in this least squares problem.

Plan

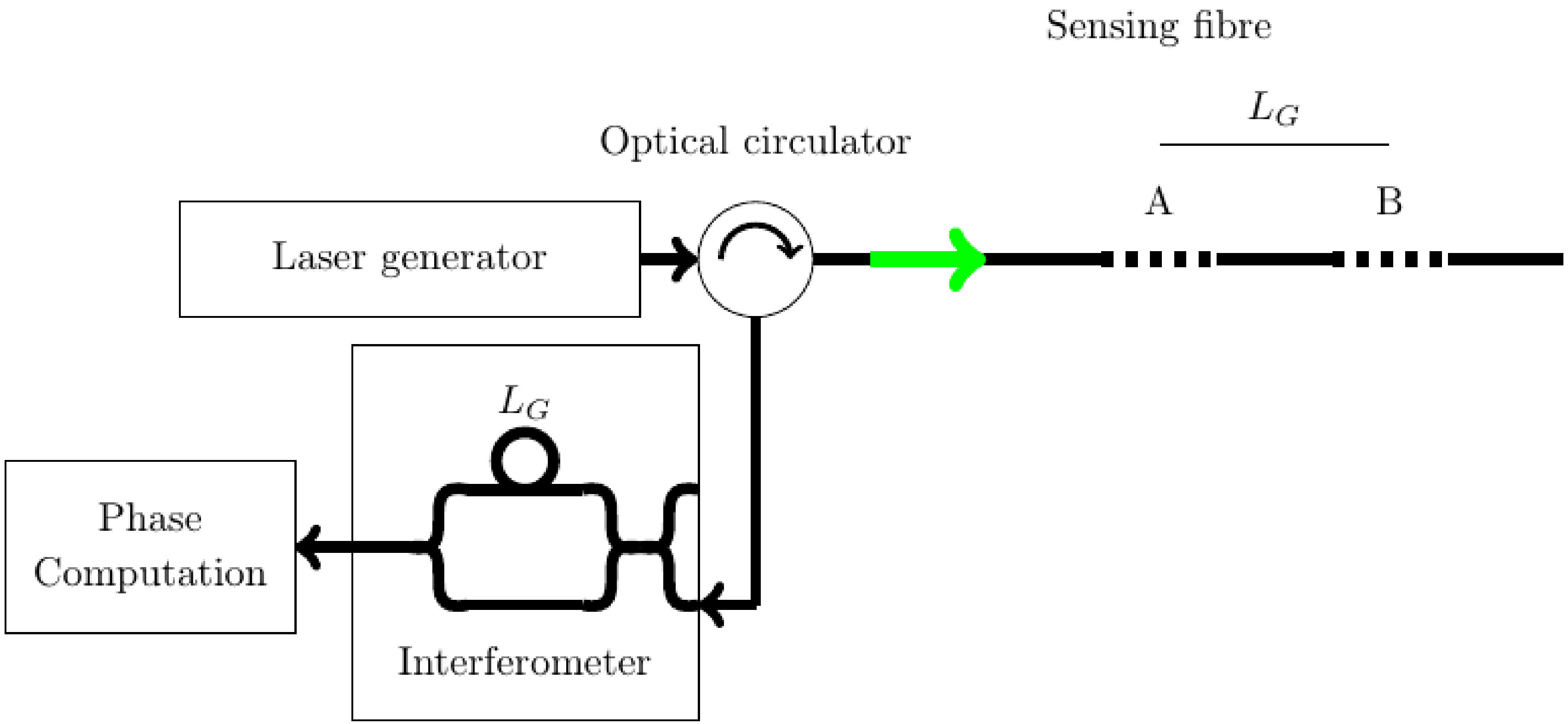
1. DAS principles.
2. Derivation of a particle velocity to strain rate linear operator based on DAS principles.
3. Proposal of a least squares inversion based on the particle velocity to strain rate operator.
4. Inversion test with DAS data from CaMI-FRS.

DAS principles



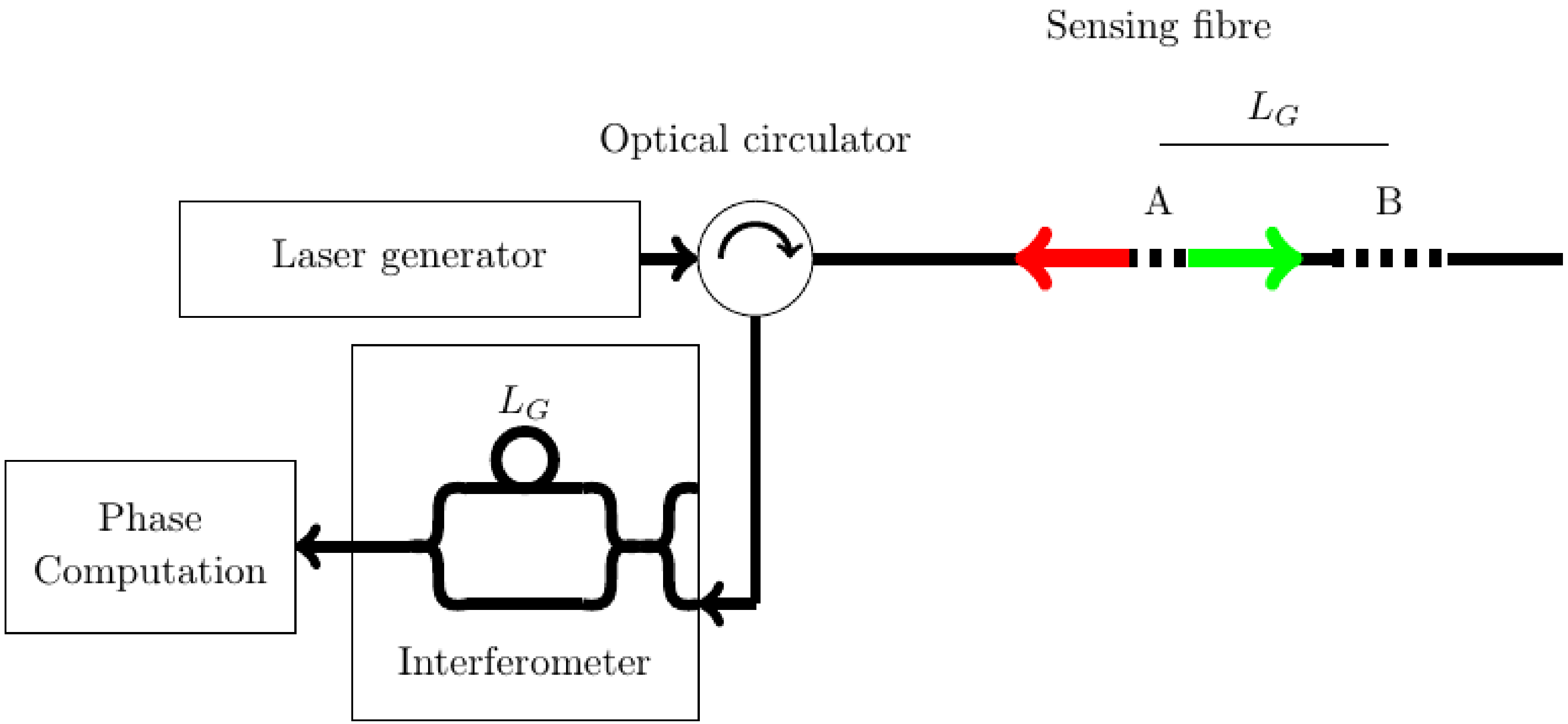
(Modified from Posey et Al., 2000)

DAS principles



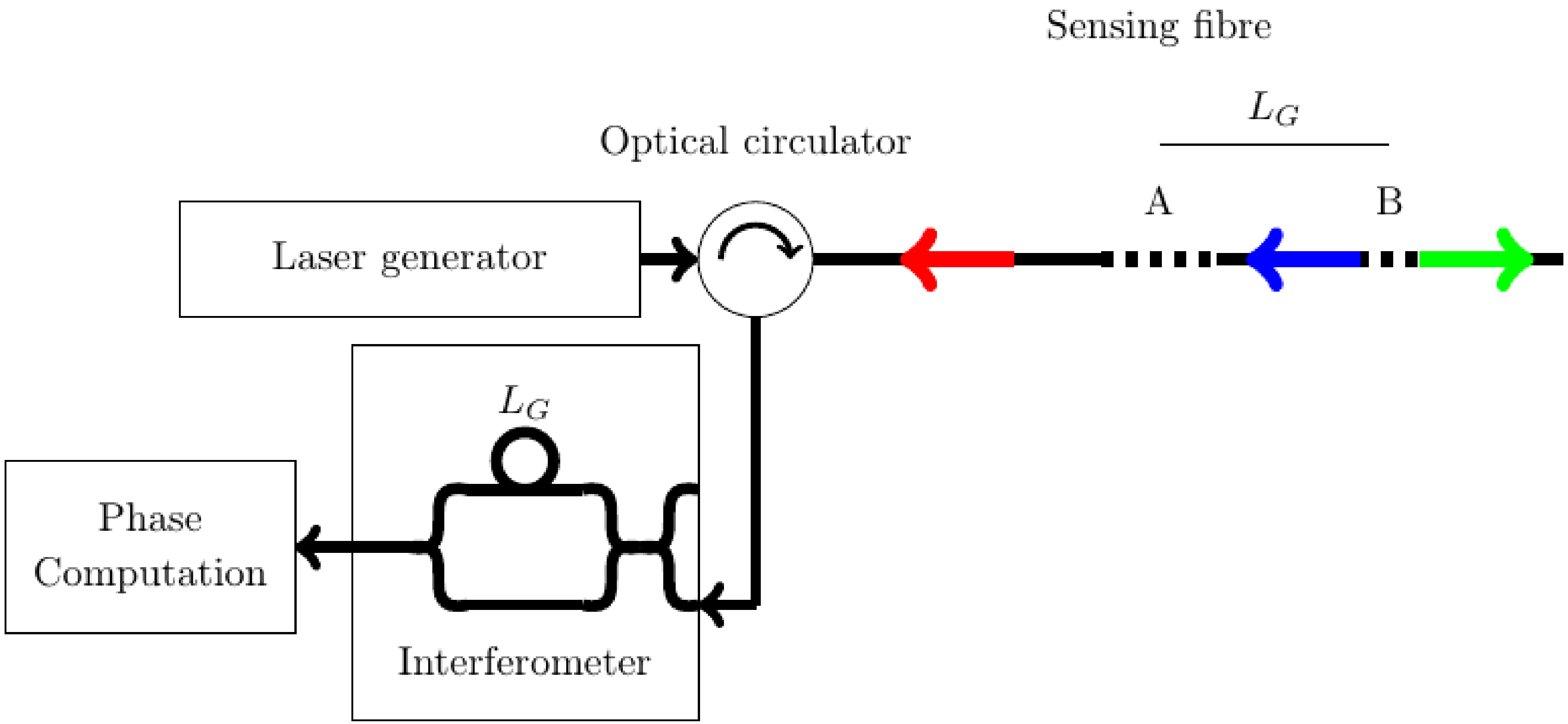
(Modified from Posey et Al., 2000)

DAS principles



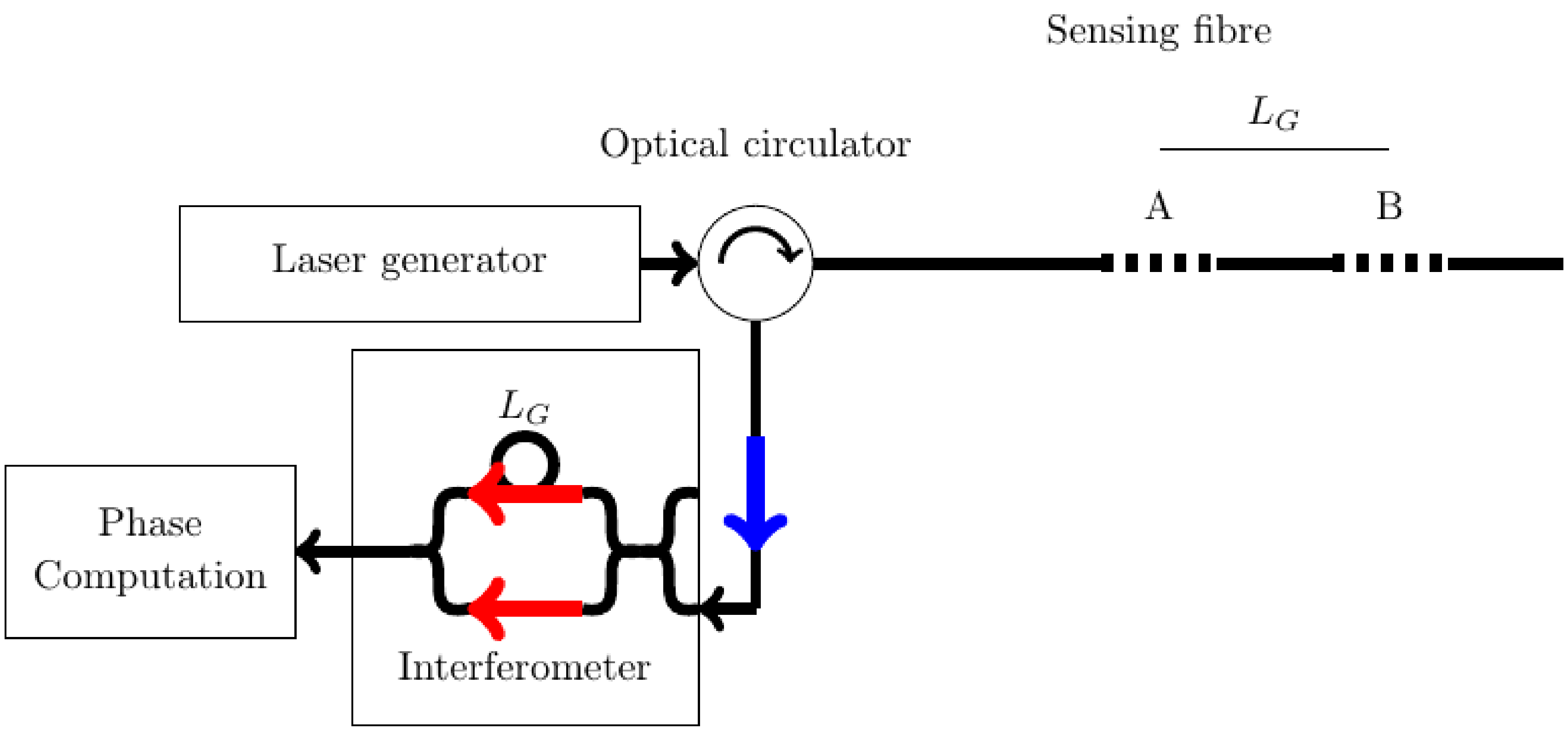
(Modified from Posey et Al., 2000)

DAS principles



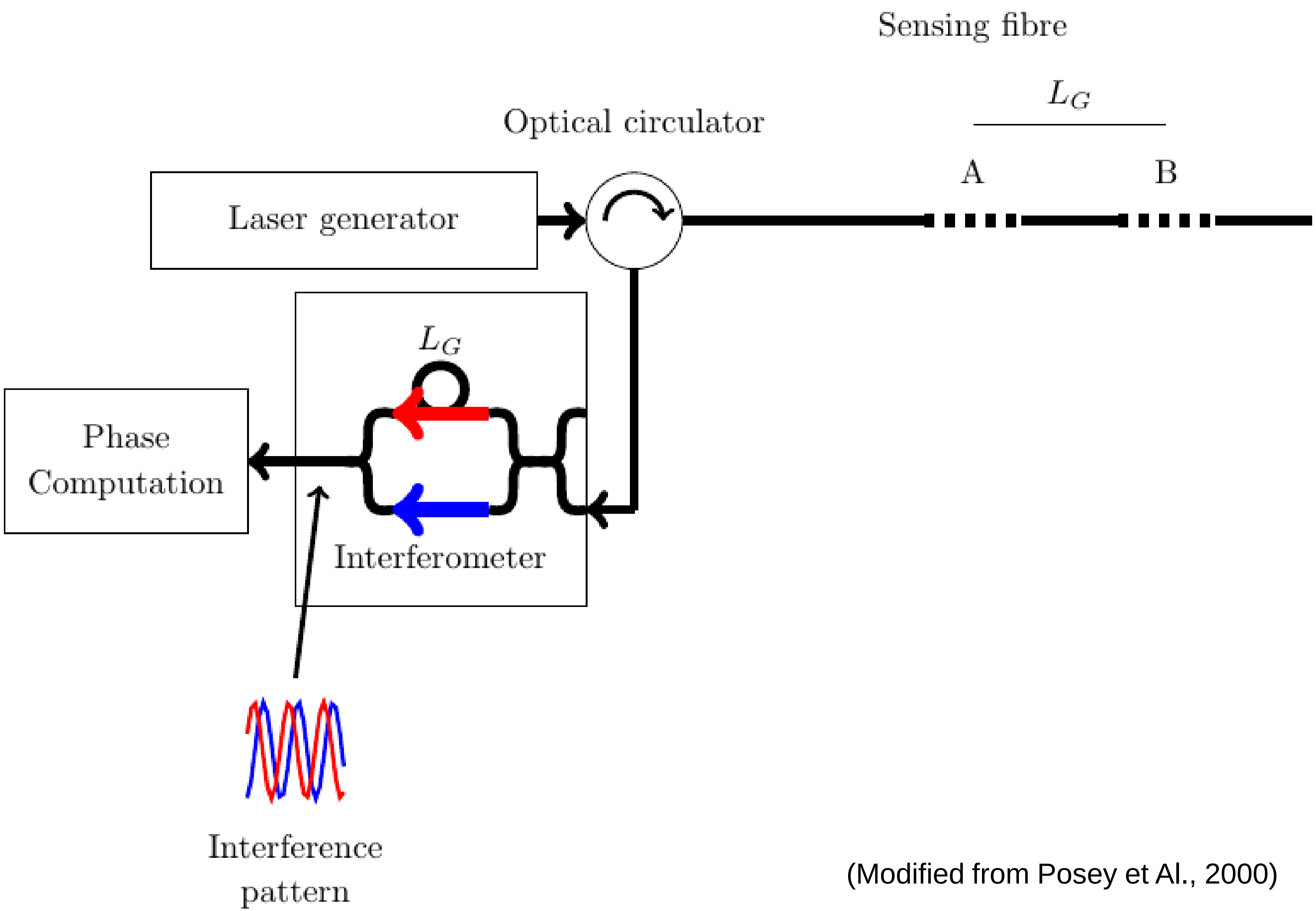
(Modified from Posey et Al., 2000)

DAS principles



(Modified from Posey et Al., 2000)

DAS principles



(Modified from Posey et Al., 2000)

DAS principles

Backscattered pulses electrical fields:

$$\begin{aligned} E_A &= E_{0A} \exp(i(\omega t + \Phi_A)) \\ E_B &= E_{0B} \exp(i(\omega t + \Phi_B)), \end{aligned}$$

B's backscattered pulse electrical field when the fibre changes length:

$$\begin{aligned} E_{Bd} &= E_{0B} \exp(i(\omega t + \Phi_{Bd})) \\ &= E_{0B} \exp(i(\omega t + \Phi_B + \frac{4\pi n \xi \delta l}{\lambda})), \end{aligned}$$

Interference pattern with B's perturbed electrical field:

$$\begin{aligned} I_{AB} &= (E_A + E_{Bd})(E_A + E_{Bd})^* \\ &= E_{0A}^2 + E_{0B}^2 + 2E_{0A}E_{0B} \exp(i(\Phi_A - \Phi_B + \frac{4\pi n \xi \delta l}{\lambda})). \end{aligned}$$

Strain from measured fibre length change:

$$\epsilon_f(s) = \frac{\delta l}{L_G}$$

DAS principles

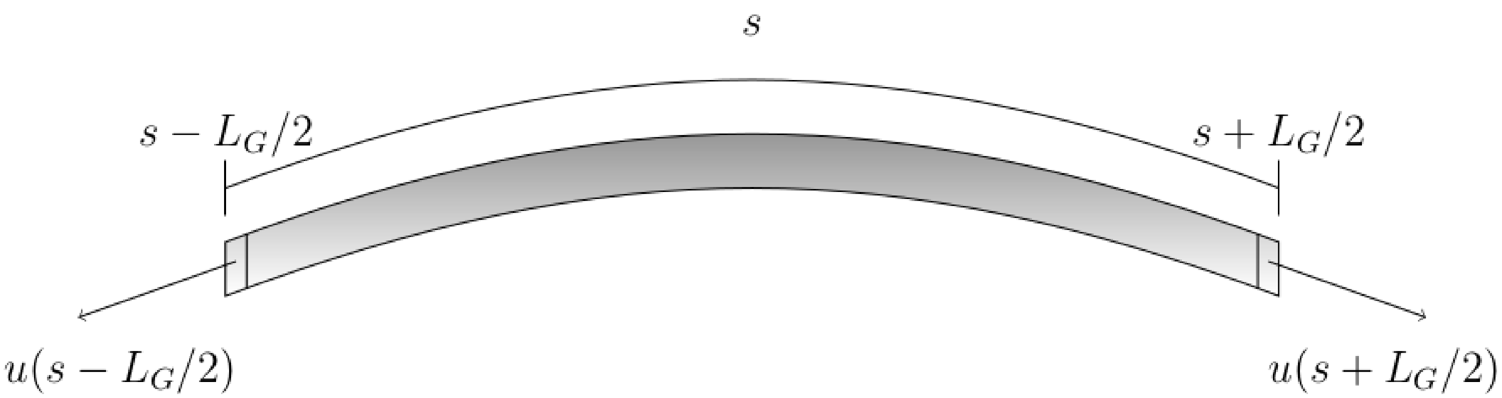
Interference pattern dynamic phase:

$$\Phi_A - \Phi_B + \frac{4\pi n \xi \delta l}{\lambda}$$

Strain from measured fibre length change:

$$\epsilon_f(s) = \frac{\delta l}{L_G}$$

Particle velocity to strain rate linear operator



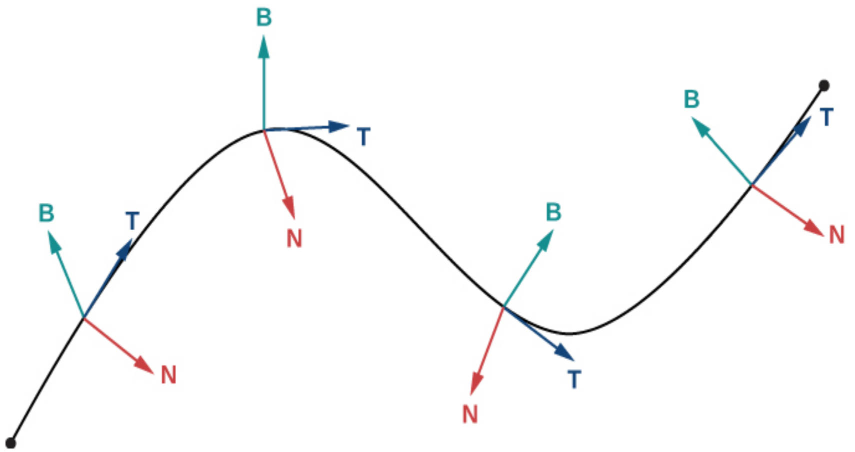
$$\delta l(s) = u(s + L_G/2) - u(s - L_G/2).$$

$$\epsilon_f(s) = \frac{1}{L_G}(u(s + L_G/2) - u(s - L_G/2)).$$

$$\dot{\epsilon}_f(s) = \frac{1}{L_G}(v(s + L_G/2) - v(s - L_G/2)),$$

Particle velocity to strain rate linear operator

$$v(s) = \vec{\boldsymbol{t}}(s) \cdot \vec{\boldsymbol{v}}(s)$$



https://math.libretexts.org/

$$\dot{\epsilon}_f(s) = \frac{1}{L_G}(\vec{\boldsymbol{t}}(s + L_G/2) \cdot \vec{\boldsymbol{v}}(s + L_G/2) - \vec{\boldsymbol{t}}(s - L_G/2) \cdot \vec{\boldsymbol{v}}(s - L_G/2))$$

$$\dot{\epsilon}_f(s) = \frac{1}{L_G}(v_z(s + L_G/2) - v_z(s - L_G/2)),$$

Particle velocity to strain rate linear operator

$$\dot{\epsilon}_f(s_i) = \frac{1}{L_G}(v_z(s_{i+N/2}) - v_z(s_{i-N/2})).$$

$$\begin{bmatrix} \dot{\epsilon}_f(s_1) \\ \vdots \\ \dot{\epsilon}_f(s_i) \\ \vdots \\ \dot{\epsilon}_f(s_M) \end{bmatrix} = \frac{1}{L_G} \begin{bmatrix} -1 & 0 & \cdots & 0 & 1 & 0 & \cdots & 0 \\ 0 & -1 & 0 & \cdots & 0 & 1 & \cdots & 0 \\ \vdots & & & \ddots & & & & \vdots \\ 0 & \cdots & 0 & -1 & 0 & \cdots & 0 & 1 \end{bmatrix} \begin{bmatrix} v_z(s_{1-N/2}) \\ \vdots \\ v_z(s_i) \\ \vdots \\ v_z(s_{M+N/2}) \end{bmatrix}$$

$$\vec{d} = G\vec{m},$$

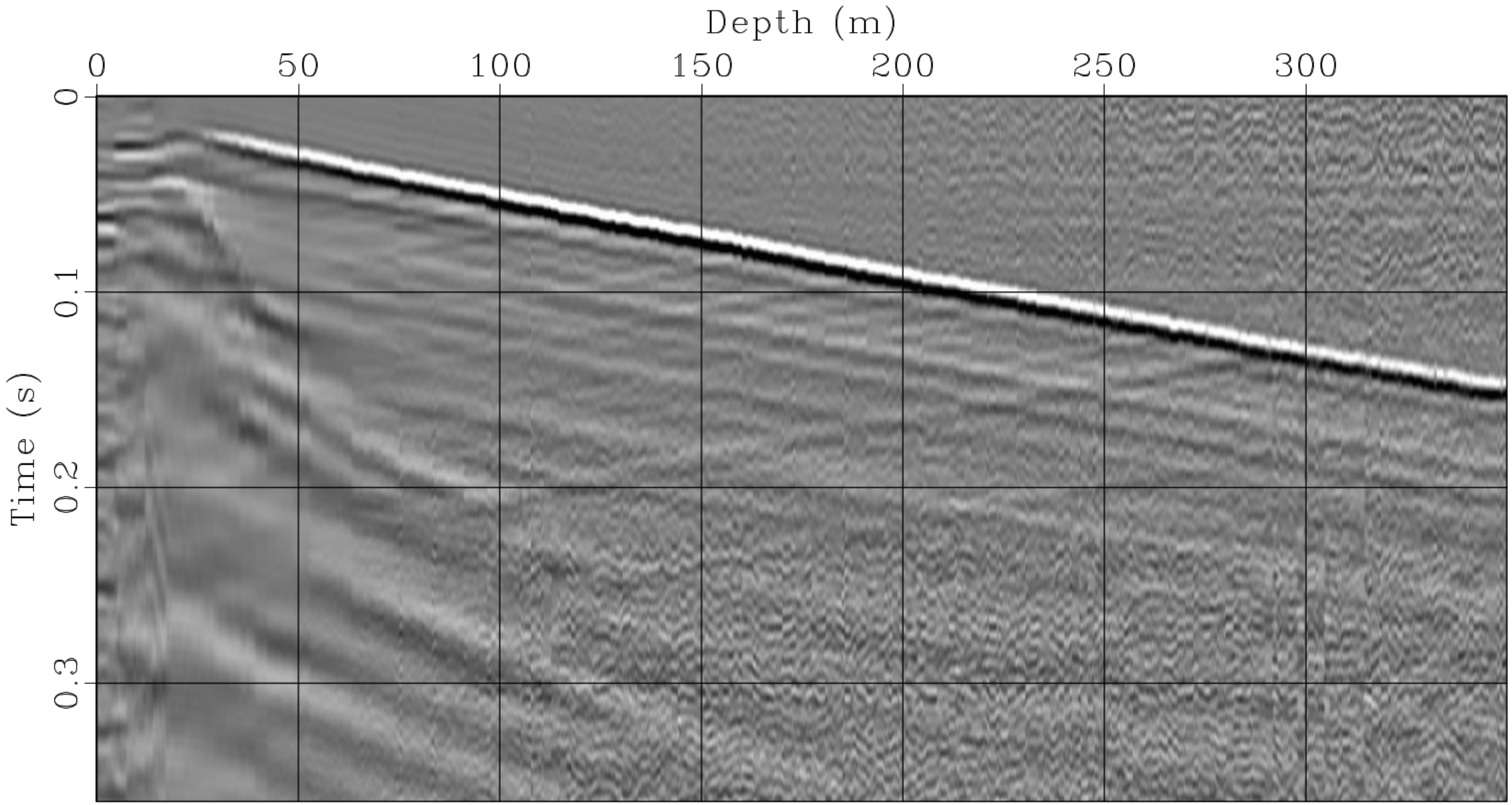
LS inversion based on the particle velocity to strain rate linear operator

$$\vec{d} = G\vec{m},$$

$$\begin{bmatrix} G \\ \epsilon R \end{bmatrix} \vec{m} = \begin{bmatrix} \vec{d} \\ \vec{0} \end{bmatrix}$$

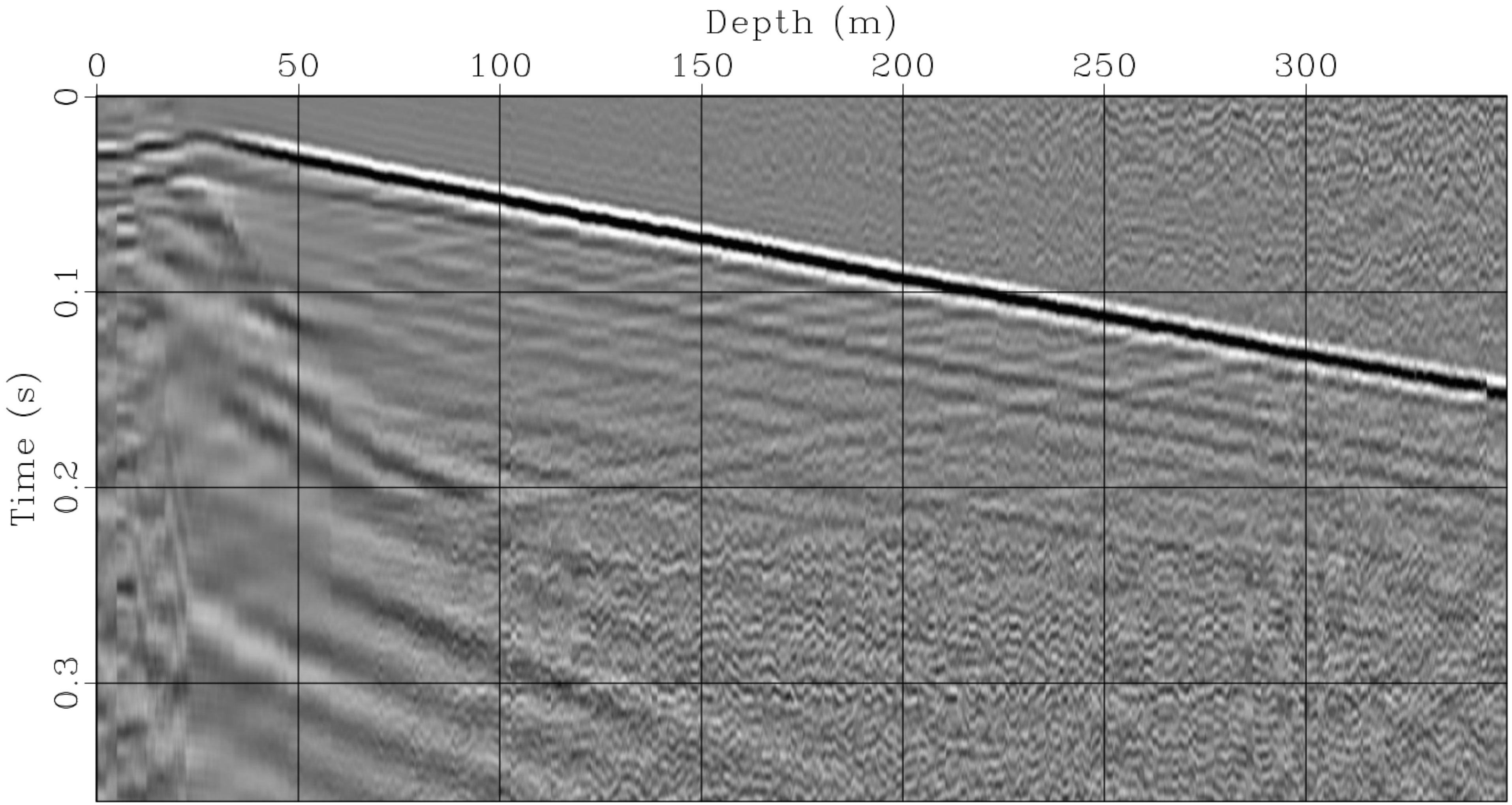
- Solved with a **Conjugate Gradient Least Squares Method**.
- R=I to obtain the **smallest** model.
- R=derivative to obtain the **flattest** model.

DAS



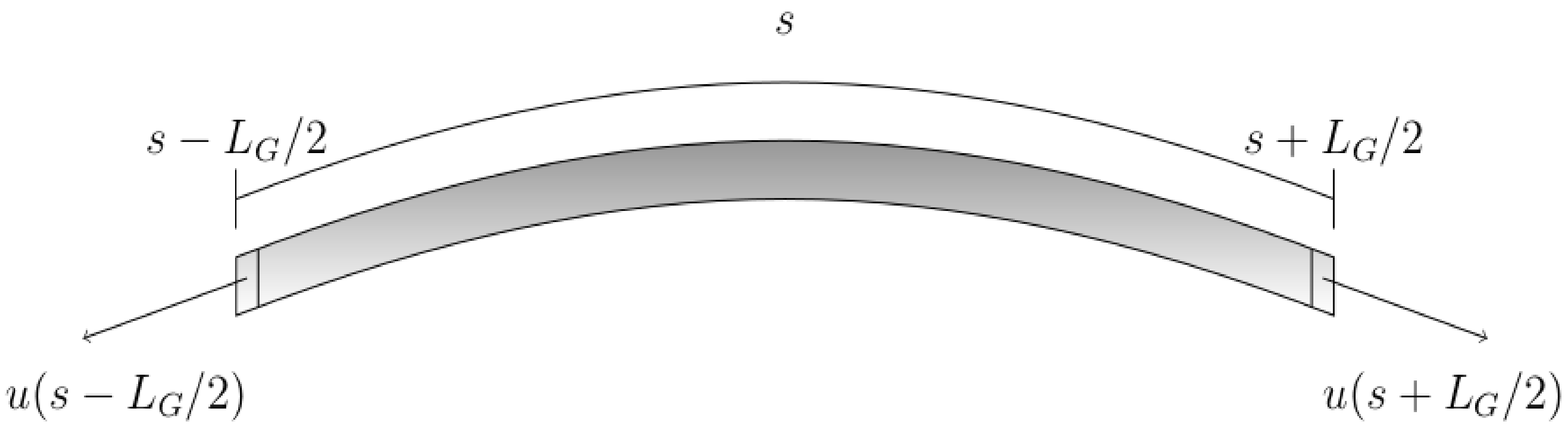
Straight DAS

Smallest inverted geophone from DAS



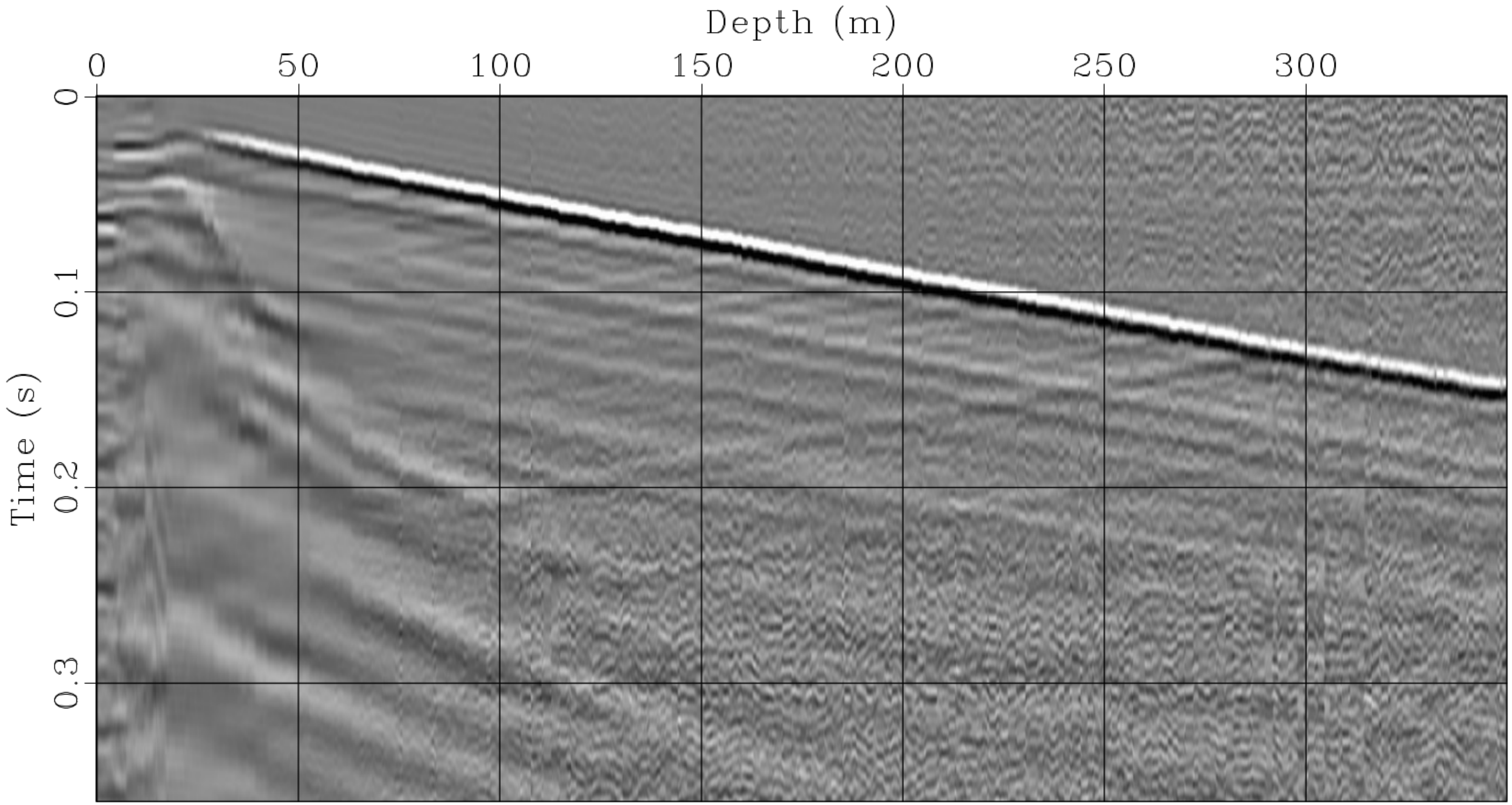
Smallest inverted particle velocity from DAS

Lateral shift



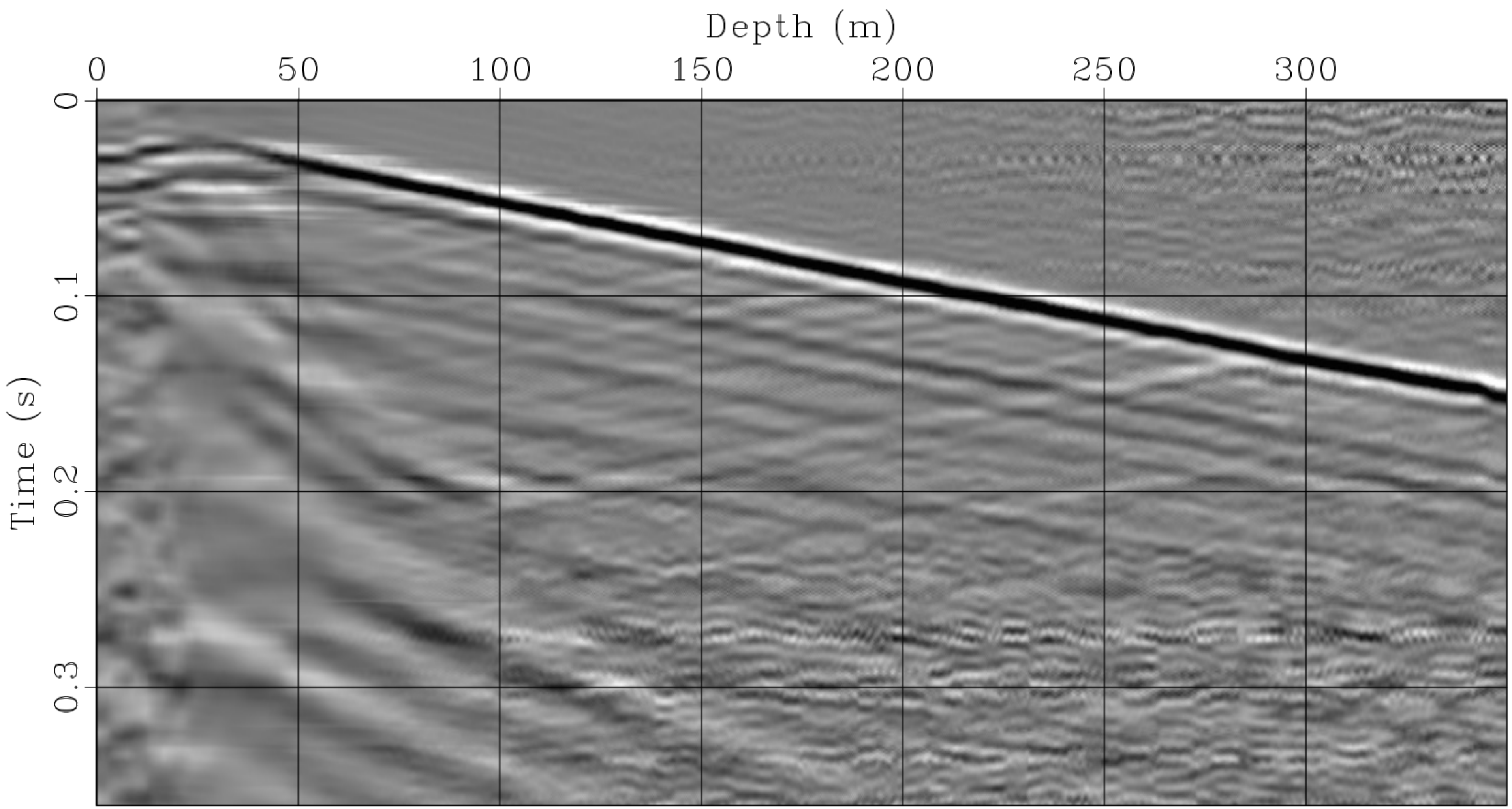
$$\dot{\epsilon}_f(s_i) = \frac{1}{L_G}\left(v_z(s_{i+N/2}) - v_z(s_{i-N/2})\right).$$

DAS



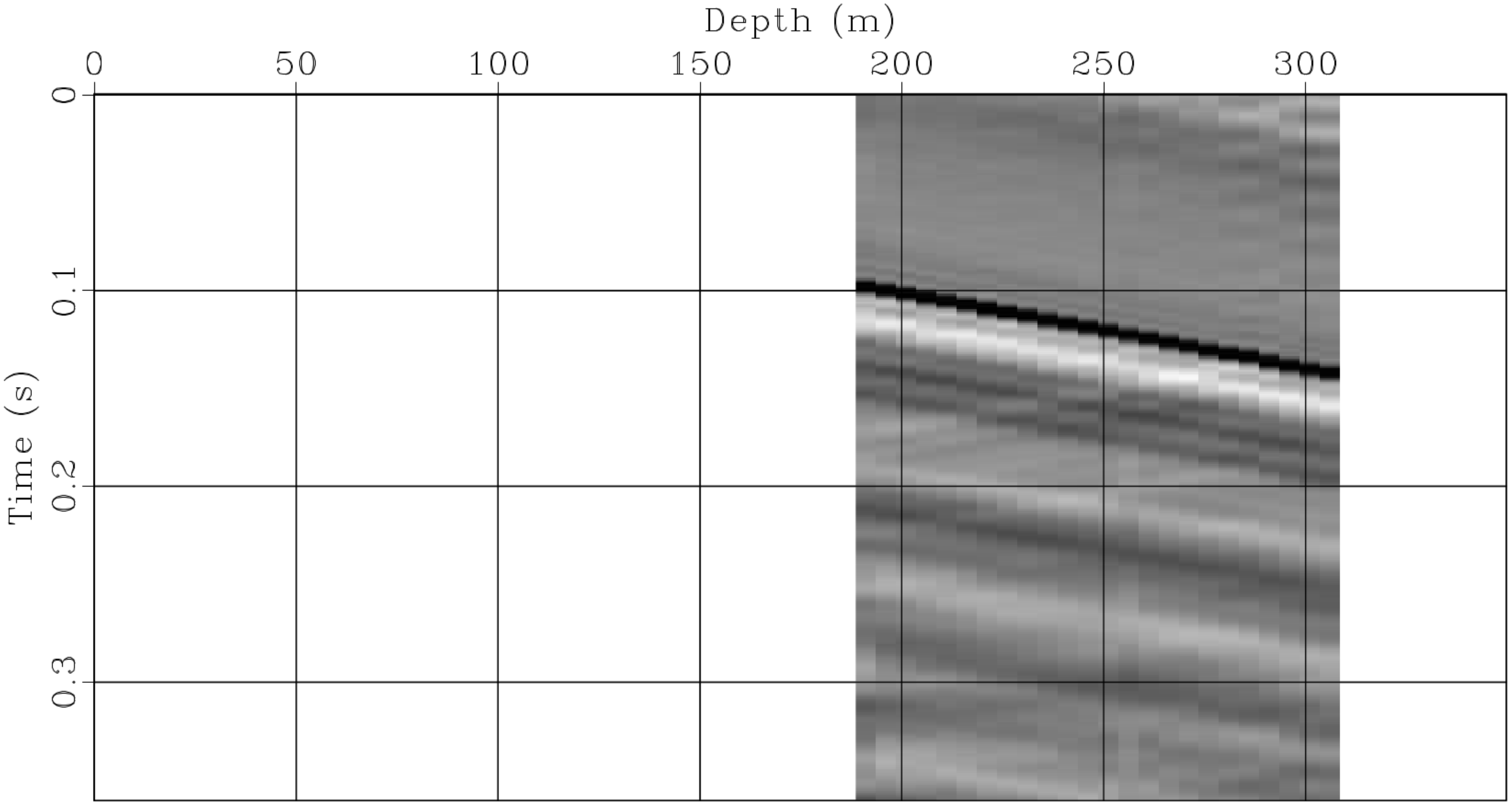
Straight DAS

Flattest inverted geophone from DAS



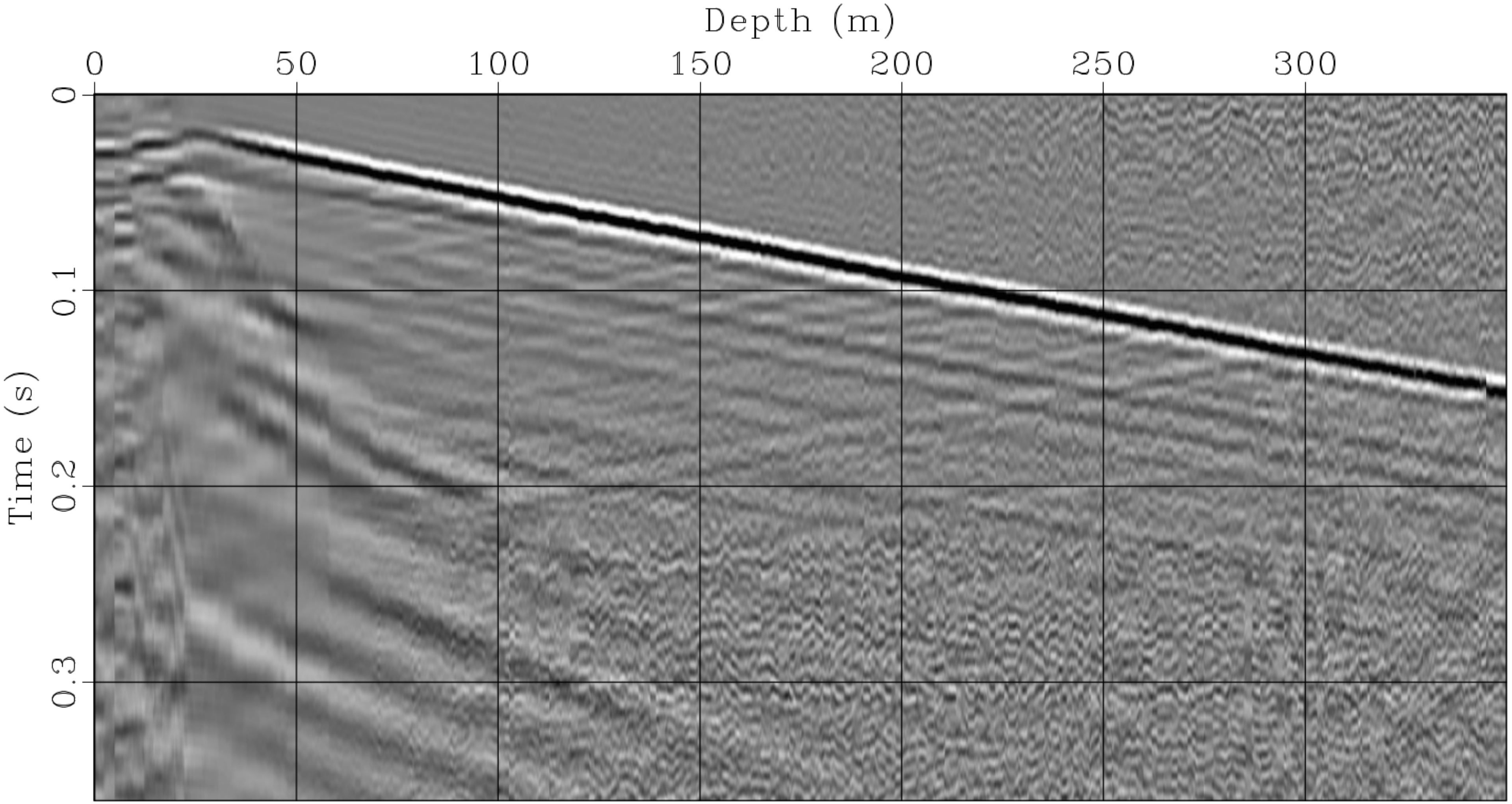
Flattest inverted particle velocity from DAS

Geophone



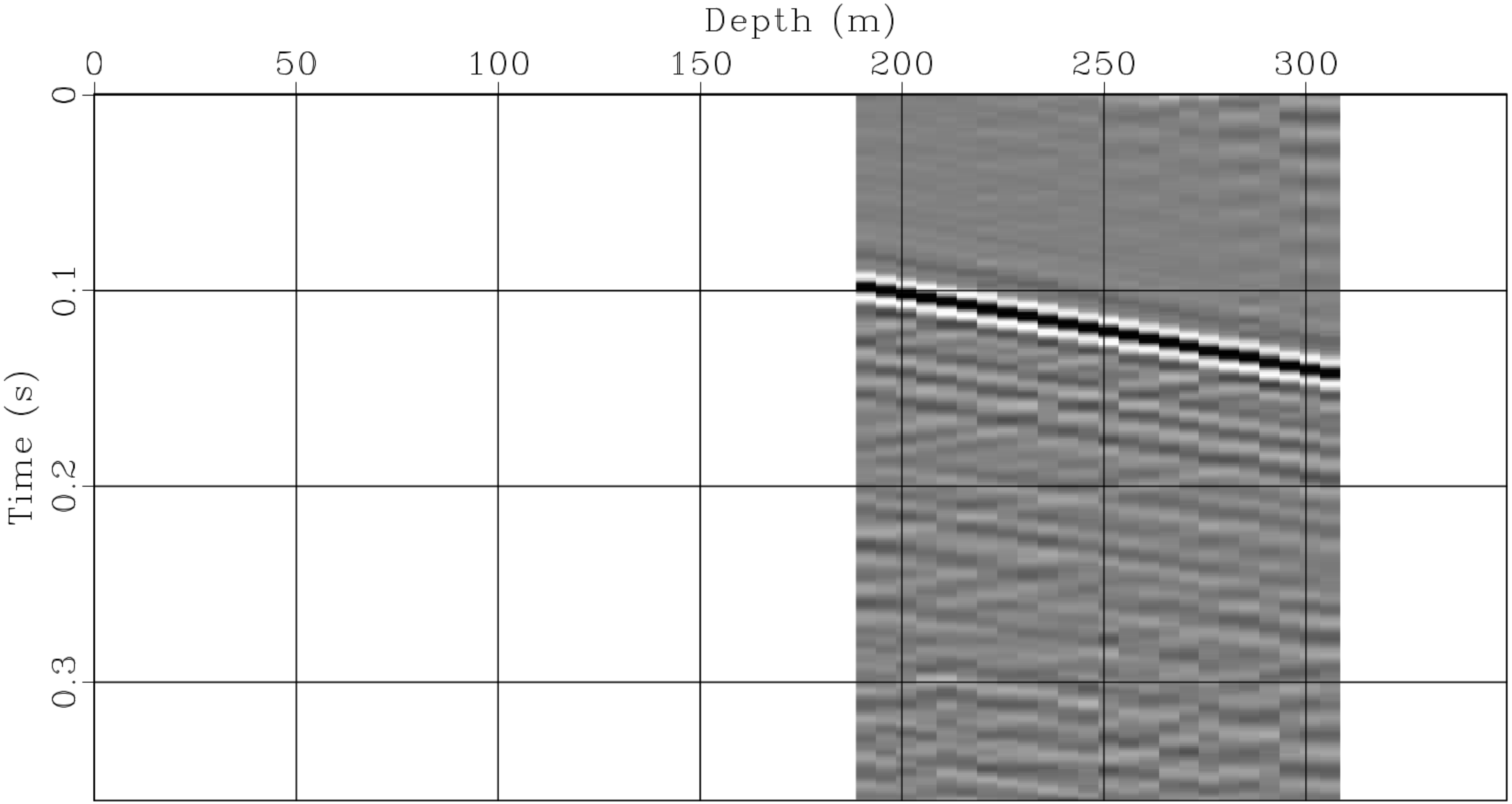
Vertical geophone

Smallest inverted geophone from DAS



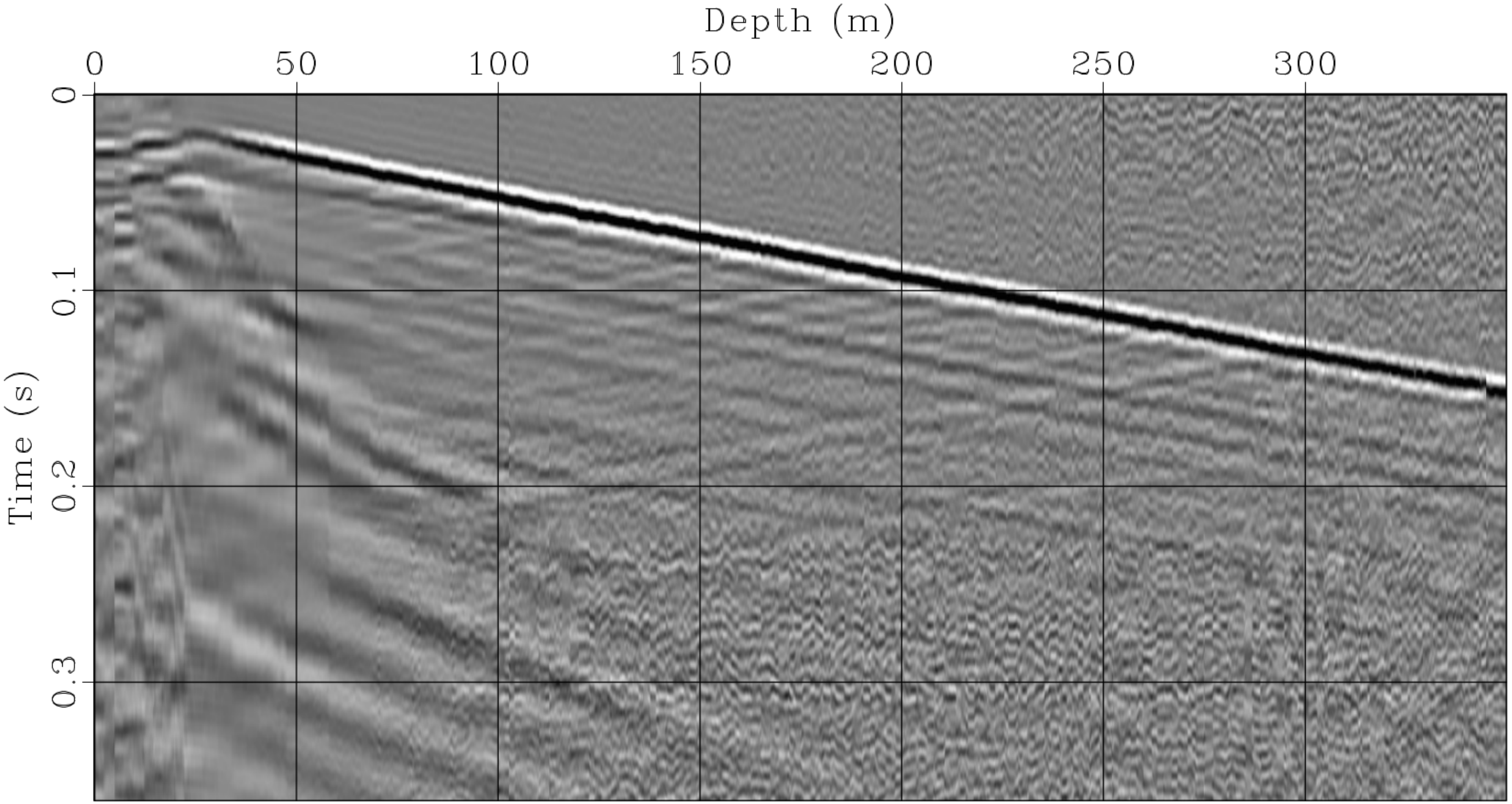
Smallest inverted particle velocity from DAS

Filtered geophone



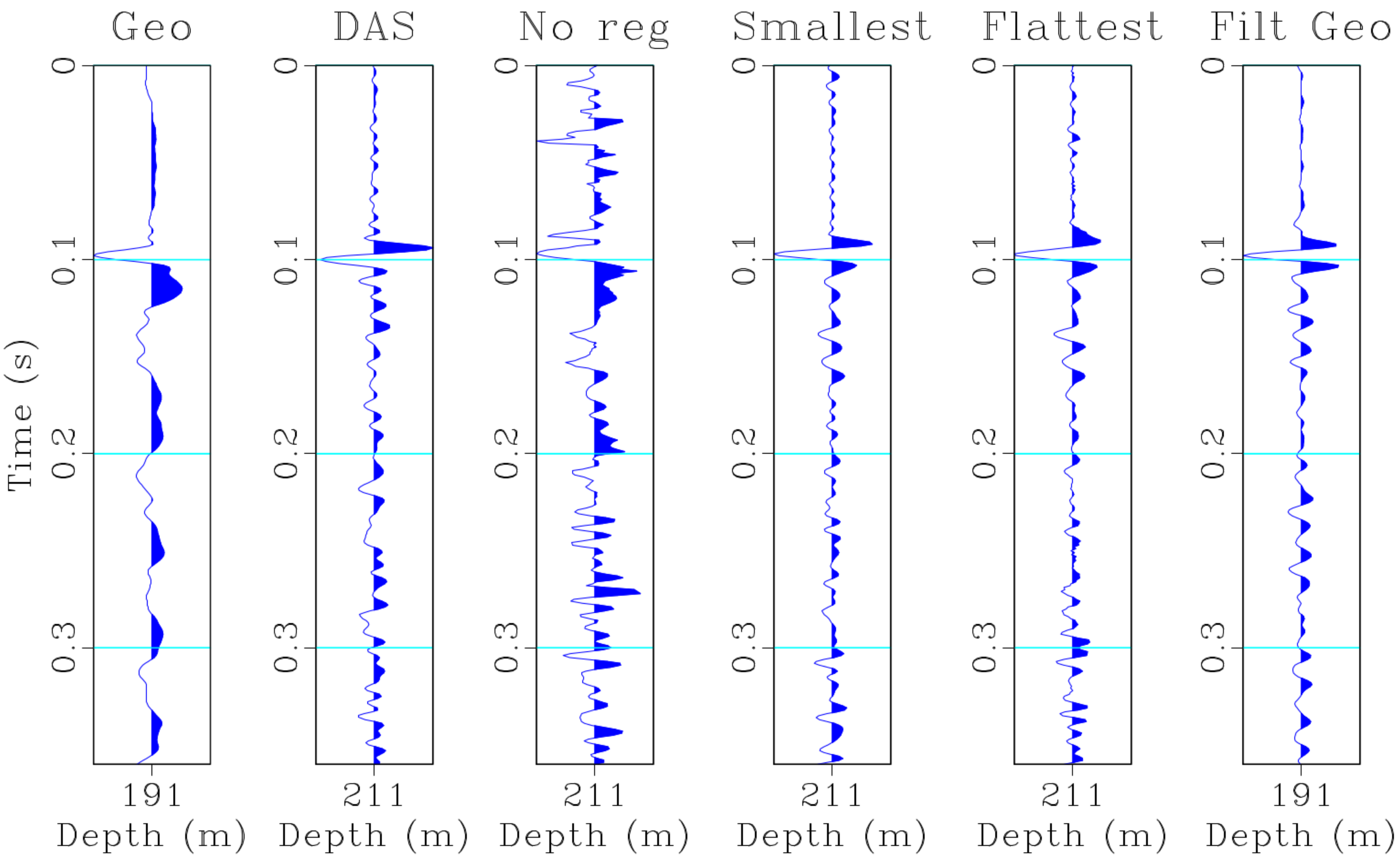
Filtered vertical geophone

Smallest inverted geophone from DAS



Smallest inverted particle velocity from DAS

Individual traces comparison



Summary

1. The least squares DAS to geophone transformation is based on a linear modelling operator that includes most of the known DAS aspects.

2. The least squares DAS to geophone transformation can invert the early times and the high frequency part of the geophone trace.

3. The regularization is fundamental in this least squares problem.

Acknowledgements

UNIVERSITY OF CALGARY
Global Research Initiative
in Energy Research

This research was undertaken thanks in part to funding from the Canada First Research Excellence Fund

CMC
Containment &
Monitoring Institute

CREWES

Any questions or comments?

You can find me at:

Jorge.monsegnyparra@ucalgary.ca