Shear Wave Reconstruction from Low Cost Randomized Acquisition

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EAGE Paris

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SLIM
University of British Columbia

Advantages of S-waves

- Imaging through gas chimneys

Advantages of *S*-waves

- Imaging through gas chimneys
- High resolution imaging (thin layers)

Advantages of S-waves

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- Reservoir detection and monitoring

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- Elastic rock properties

SLIM

Advantages of S-waves

- Imaging through gas chimneys
- High resolution imaging (thin layers)
- Reservoir detection and monitoring
- Elastic rock properties
- Improve accuracy and confidence

Why S-wave is not used in practice?

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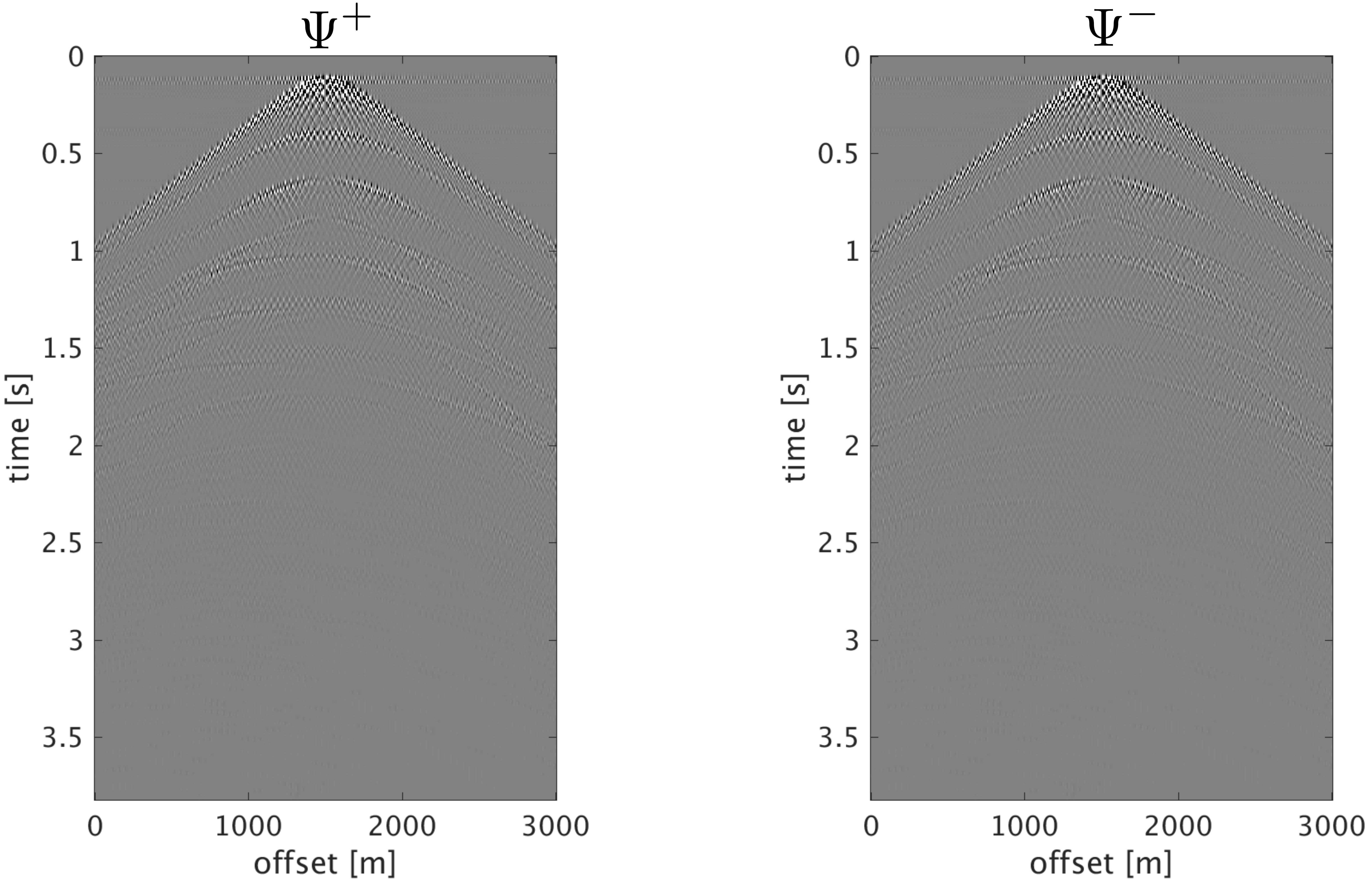

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Low S-wave velocity

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Nyquist criterion

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Denser sampling

Higher acquisition costs

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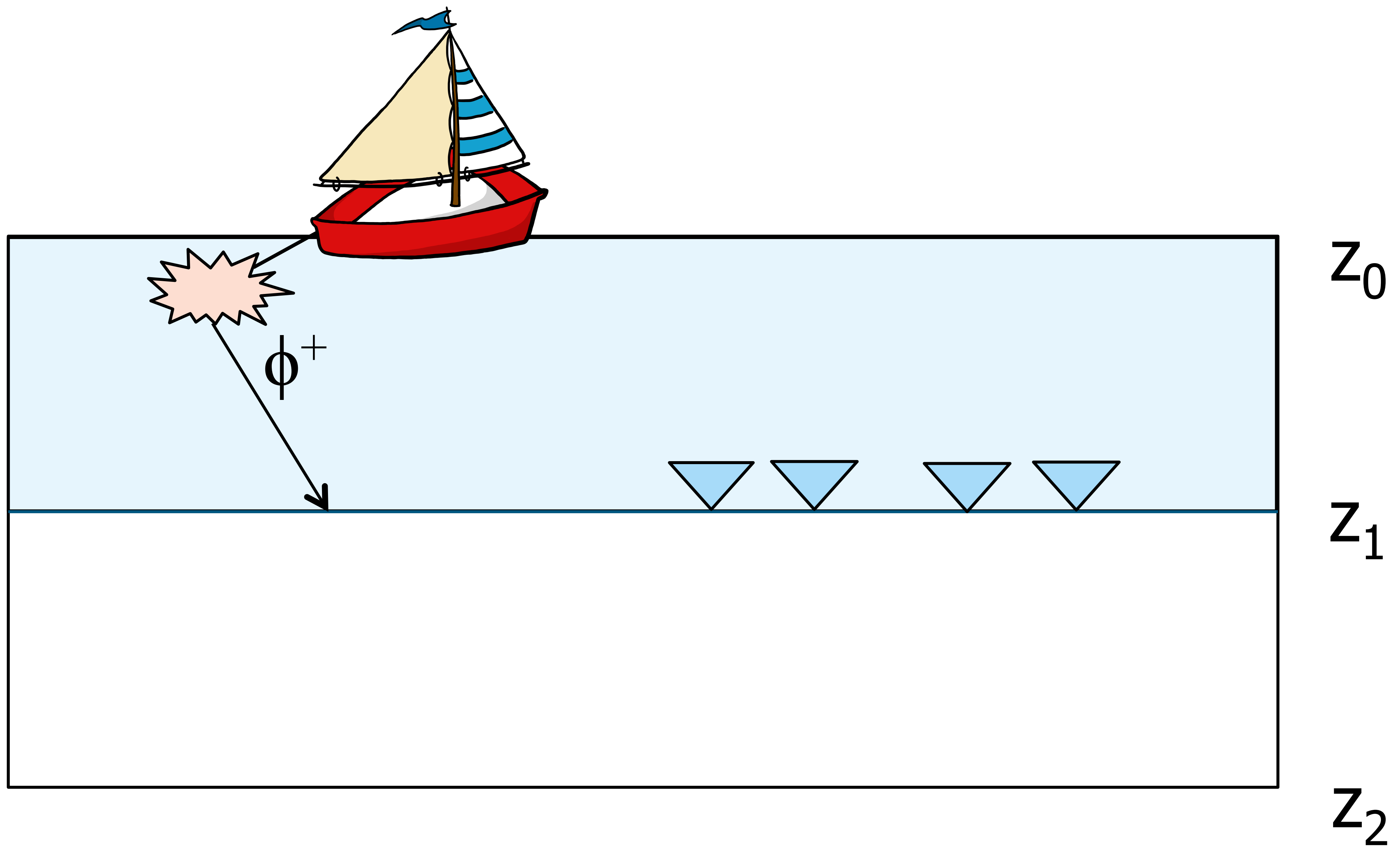
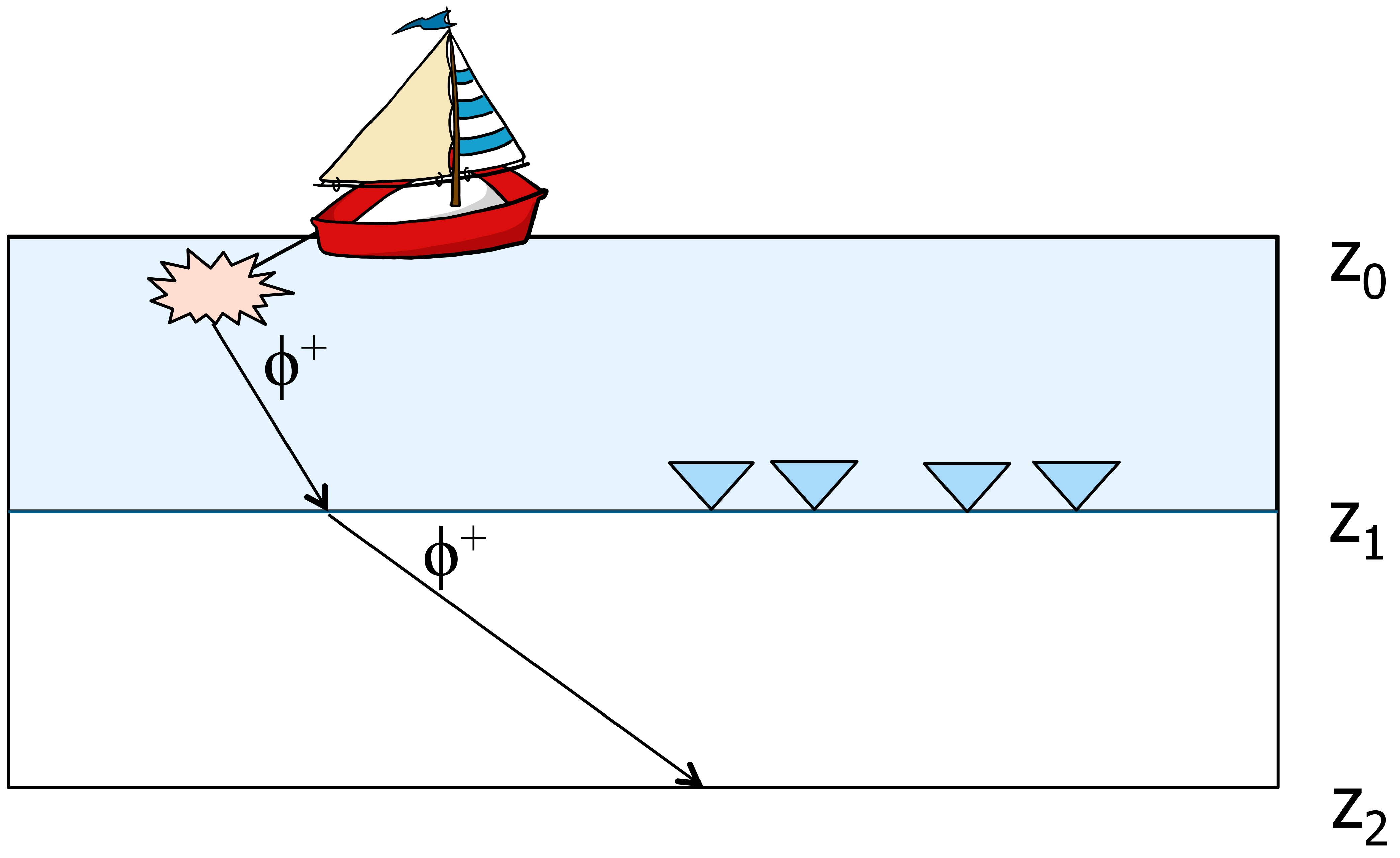
Randomized undersampling

Lower acquisition costs

Ocean bottom acquisition



Ocean bottom acquisition



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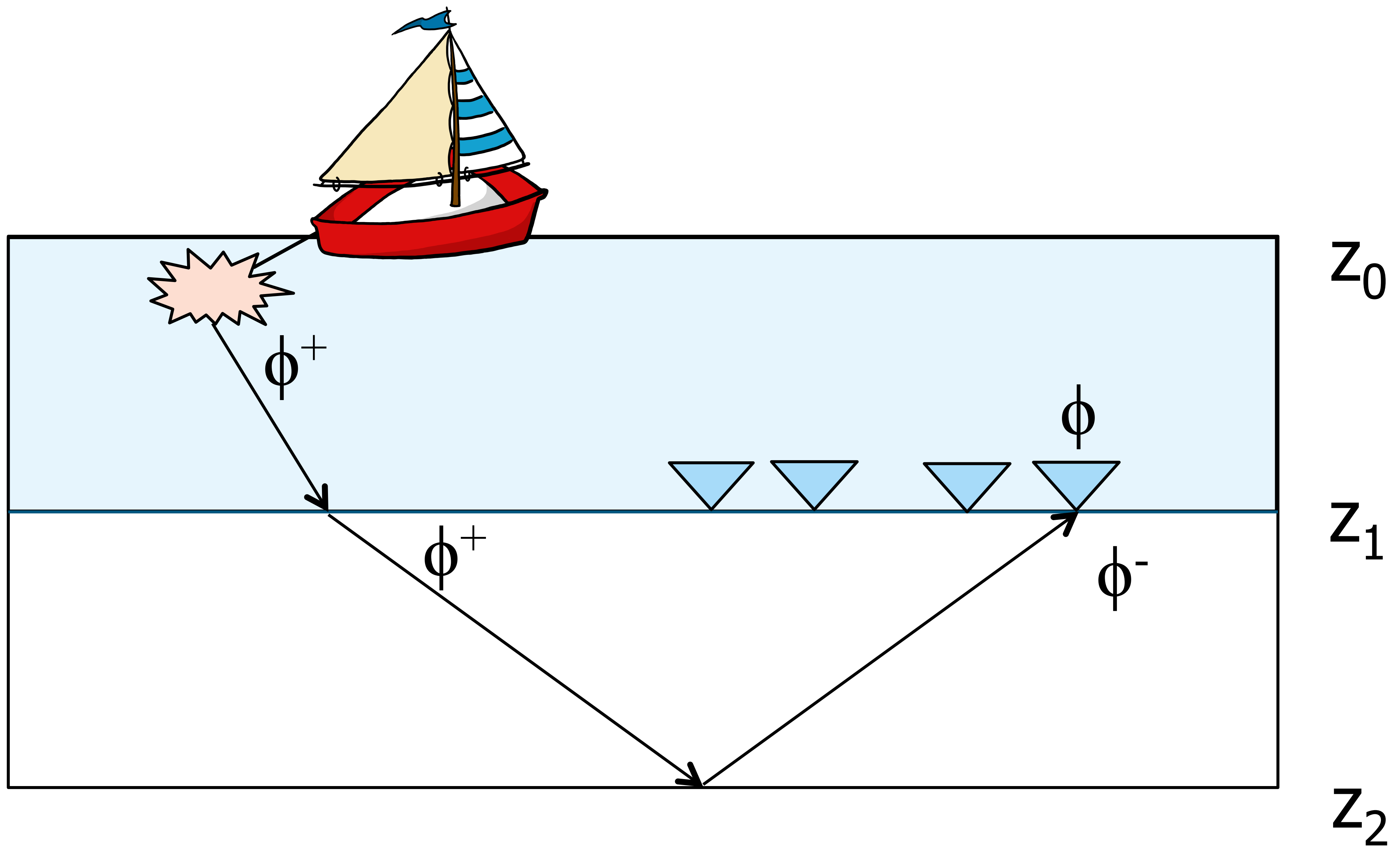

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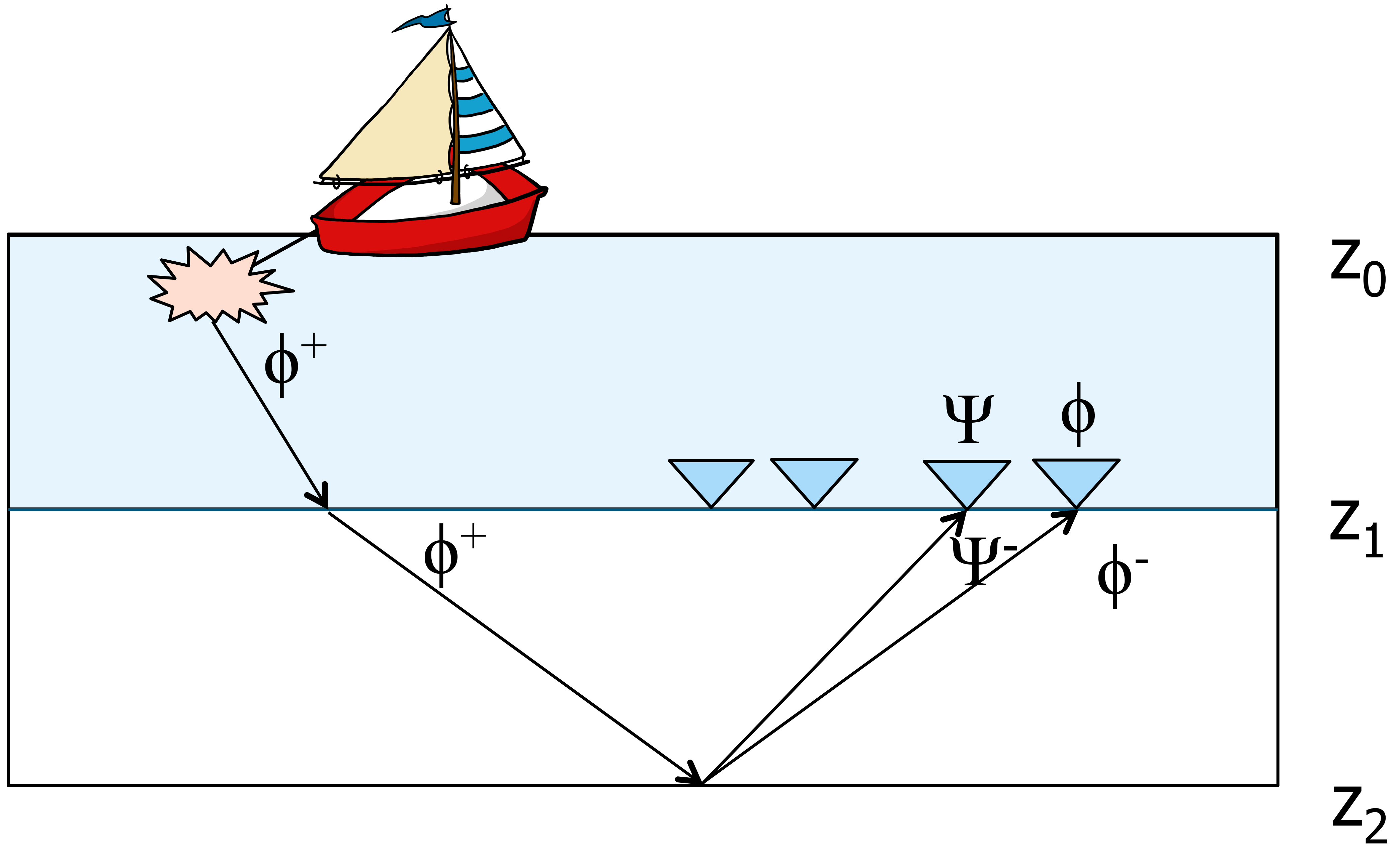

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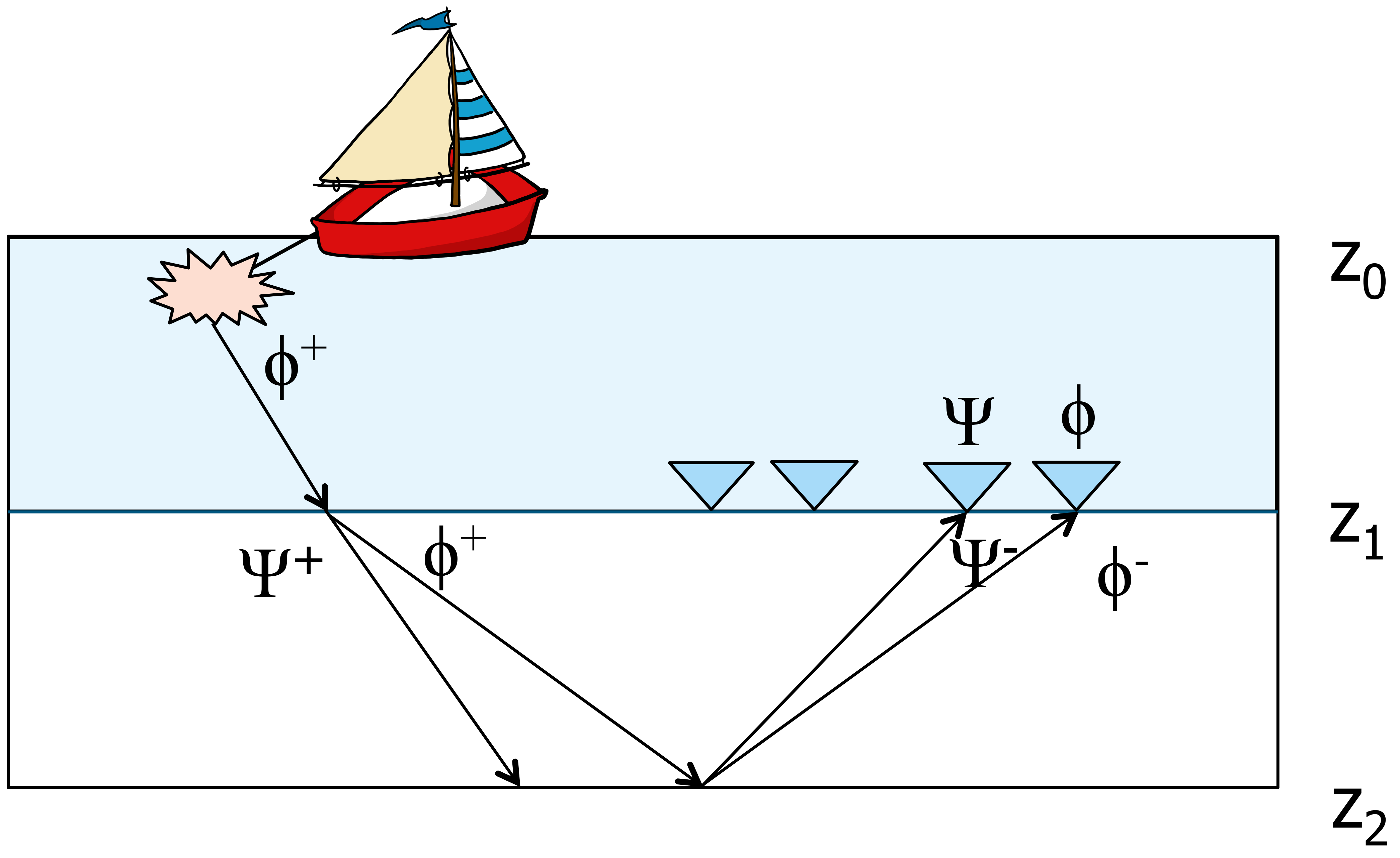

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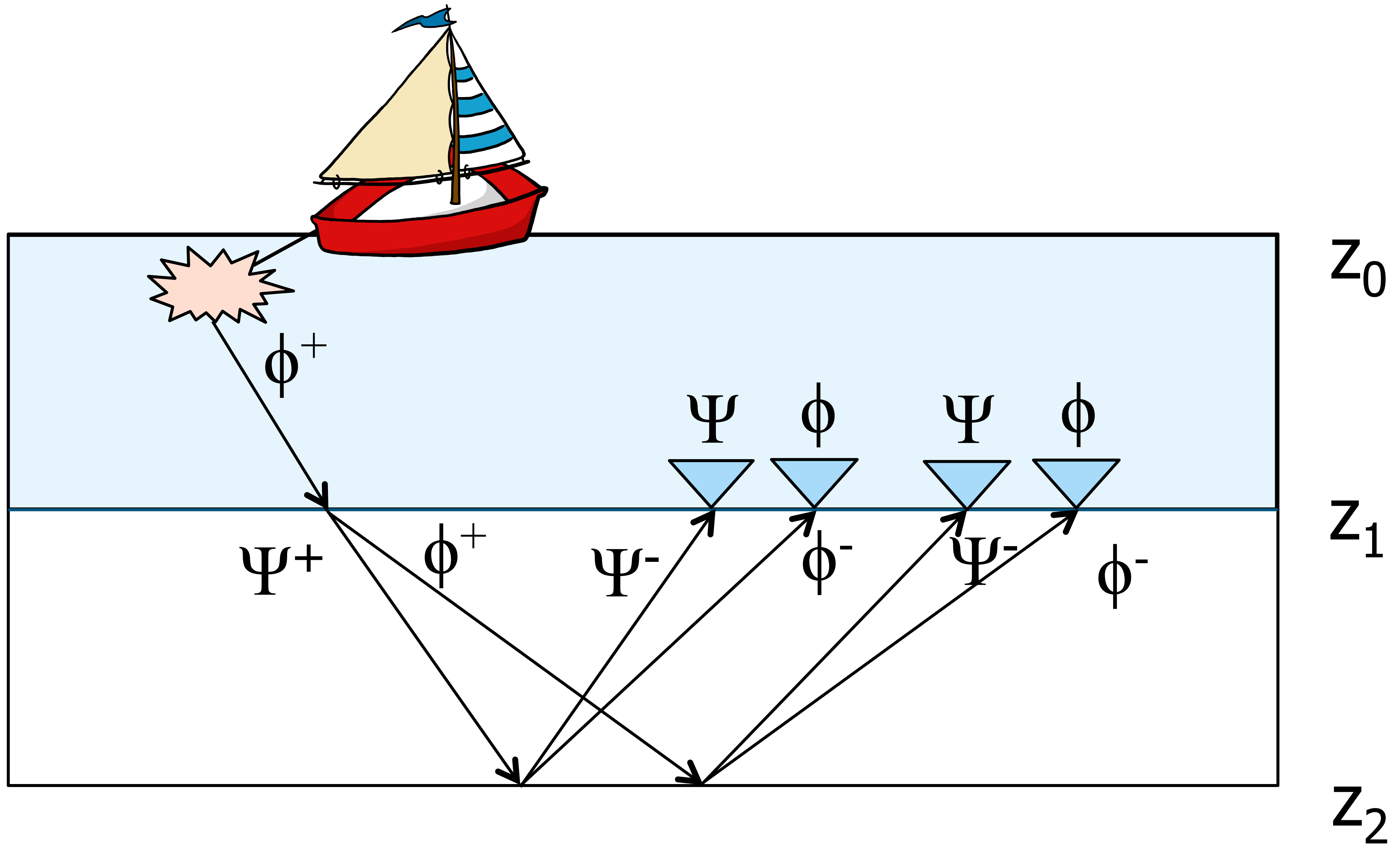

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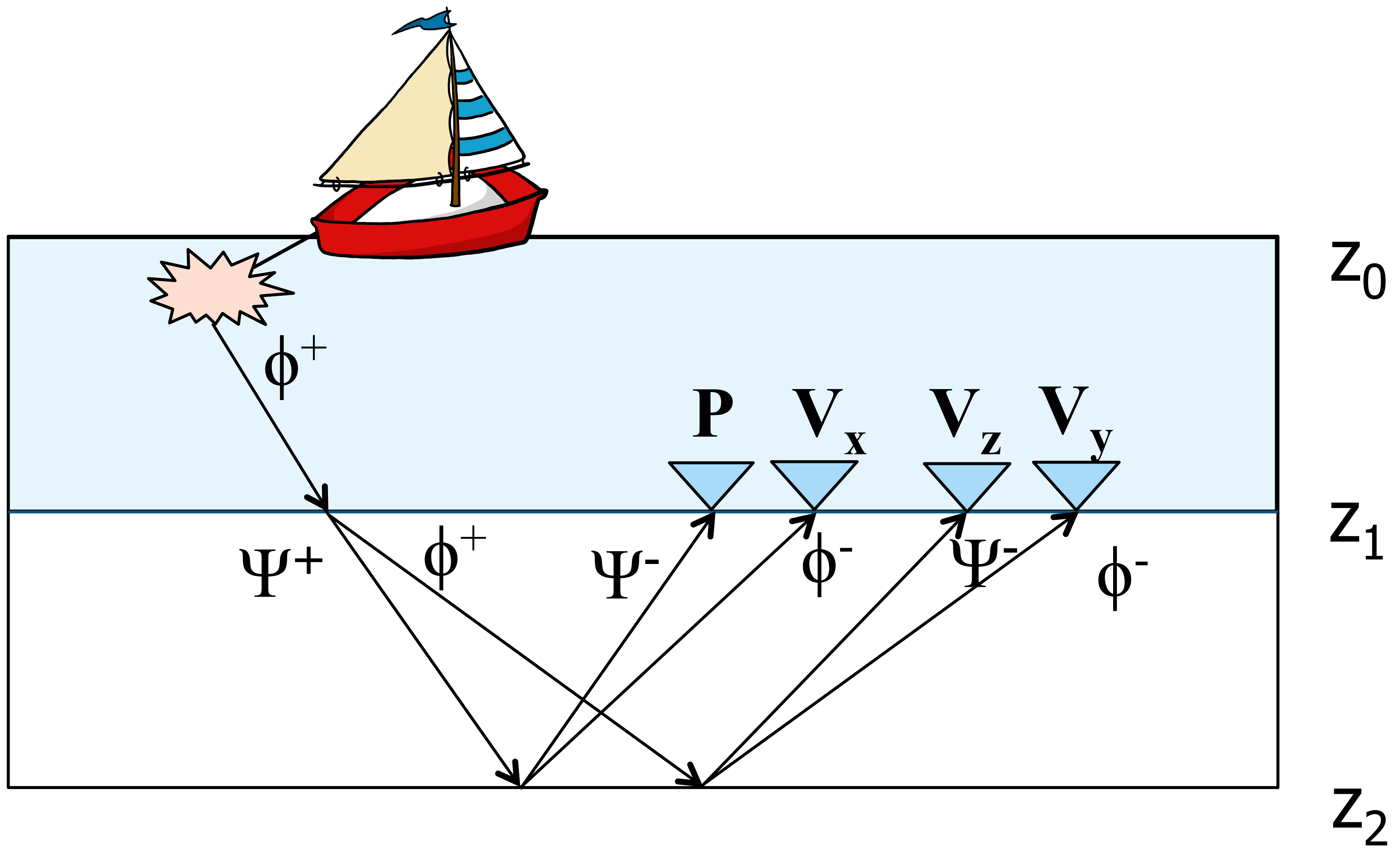

Wavefield decomposition

Wapenaar, C., and A. Berkhout, 2014, Elastic wave field extrapolation: Redatuming of single- and multi-component seismic data: Elsevier Science. Advances in Exploration Geophysics.

Elastic wavefield decomposition

$$\mathbf{d} = \mathbf{N}\mathbf{q}$$

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Elastic wavefield decomposition

$$\mathbf{d} = \mathbf{N}\mathbf{q}$$

$$\begin{pmatrix} \phi^{+} \\ \psi_y^{+} \\ \phi^{-} \\ \psi_y^{-} \end{pmatrix} = \begin{pmatrix} \mathbf{N}_1^{+} & \mathbf{N}_2^{+} \\ \mathbf{N}_1^{-} & \mathbf{N}_2^{-} \end{pmatrix} \begin{pmatrix} -\tau_{xz} \\ -\tau_{zz} \\ v_x \\ v_z \end{pmatrix}$$

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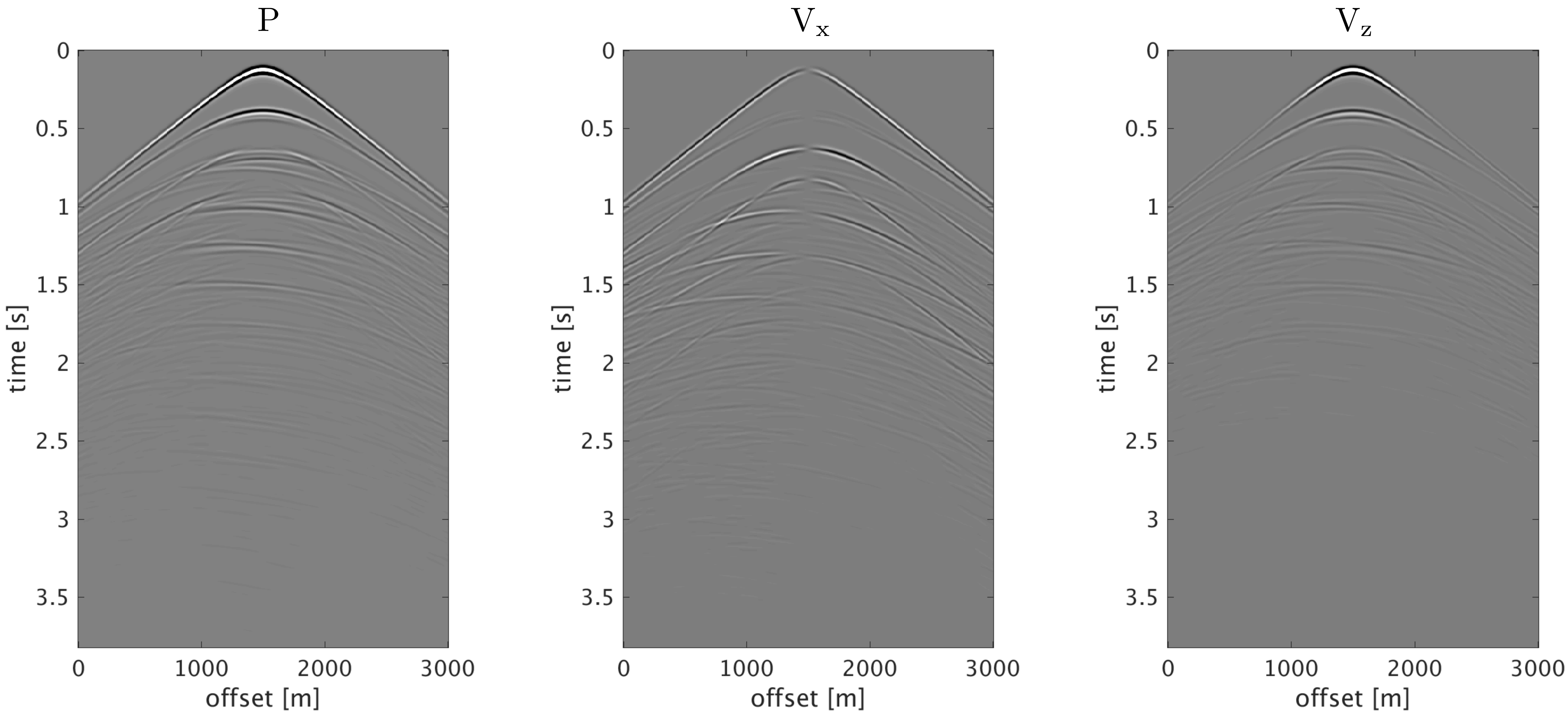
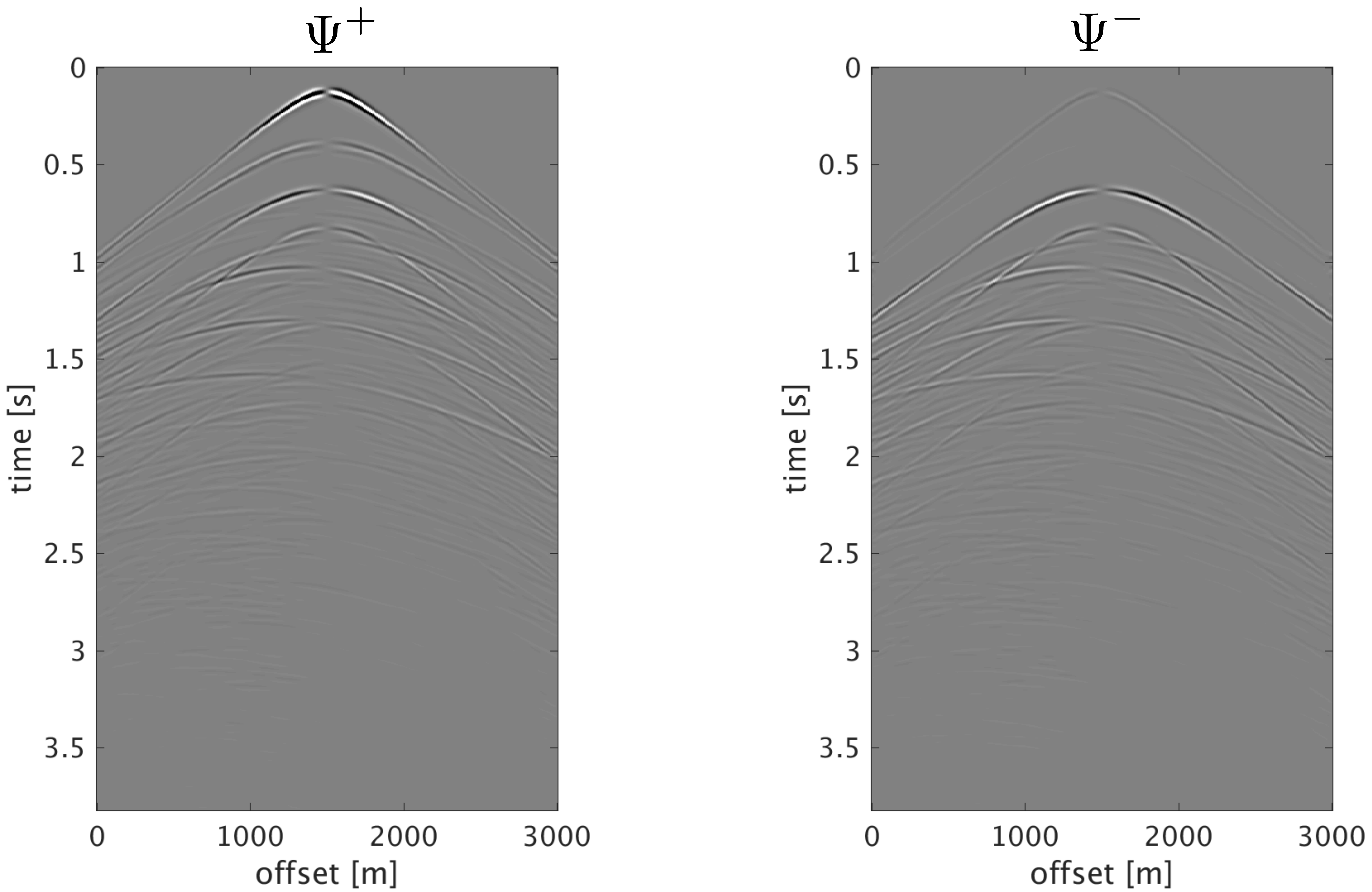
At the ocean bottom:

$$\tau_{xz} = 0 \qquad \tau_{zz} = -p$$

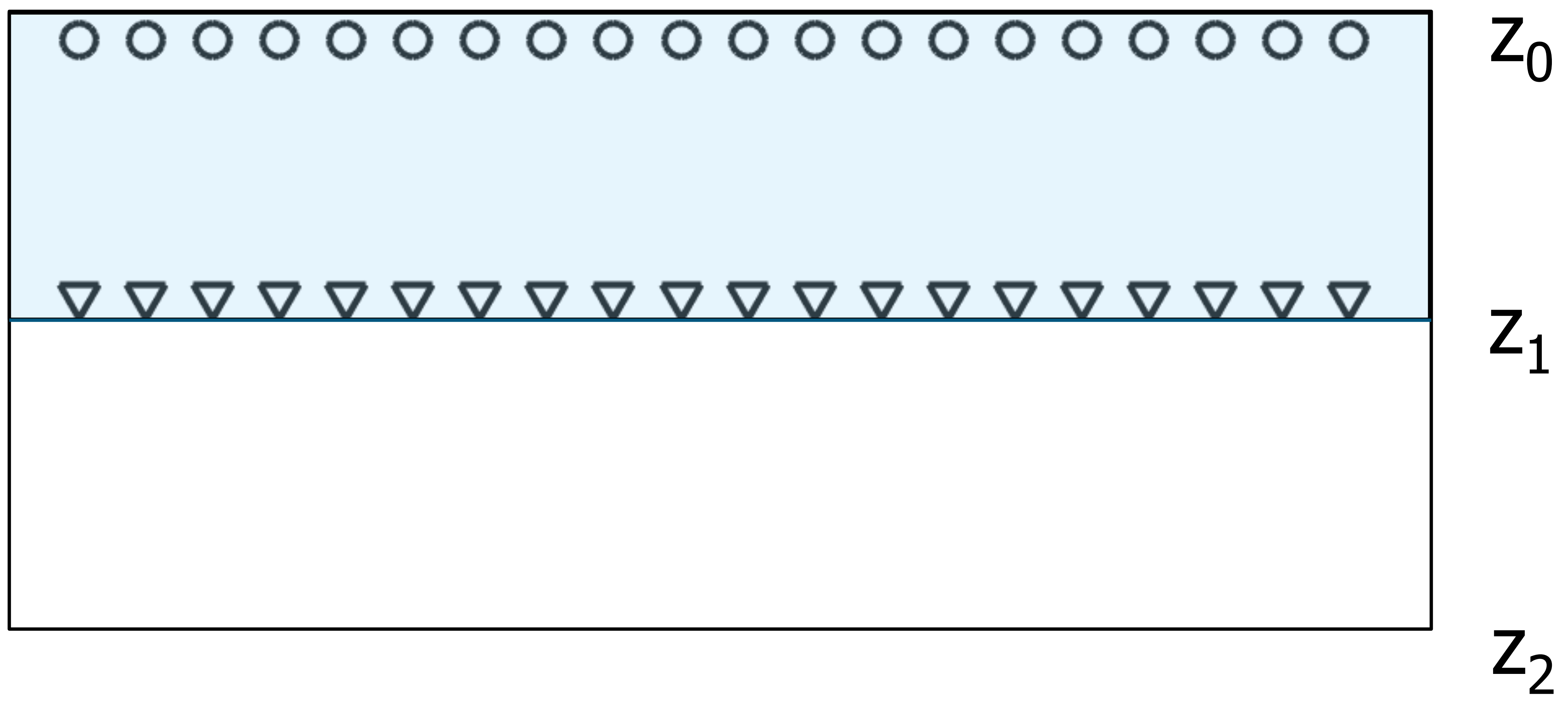
Multicomponent data



Elastic decomposition

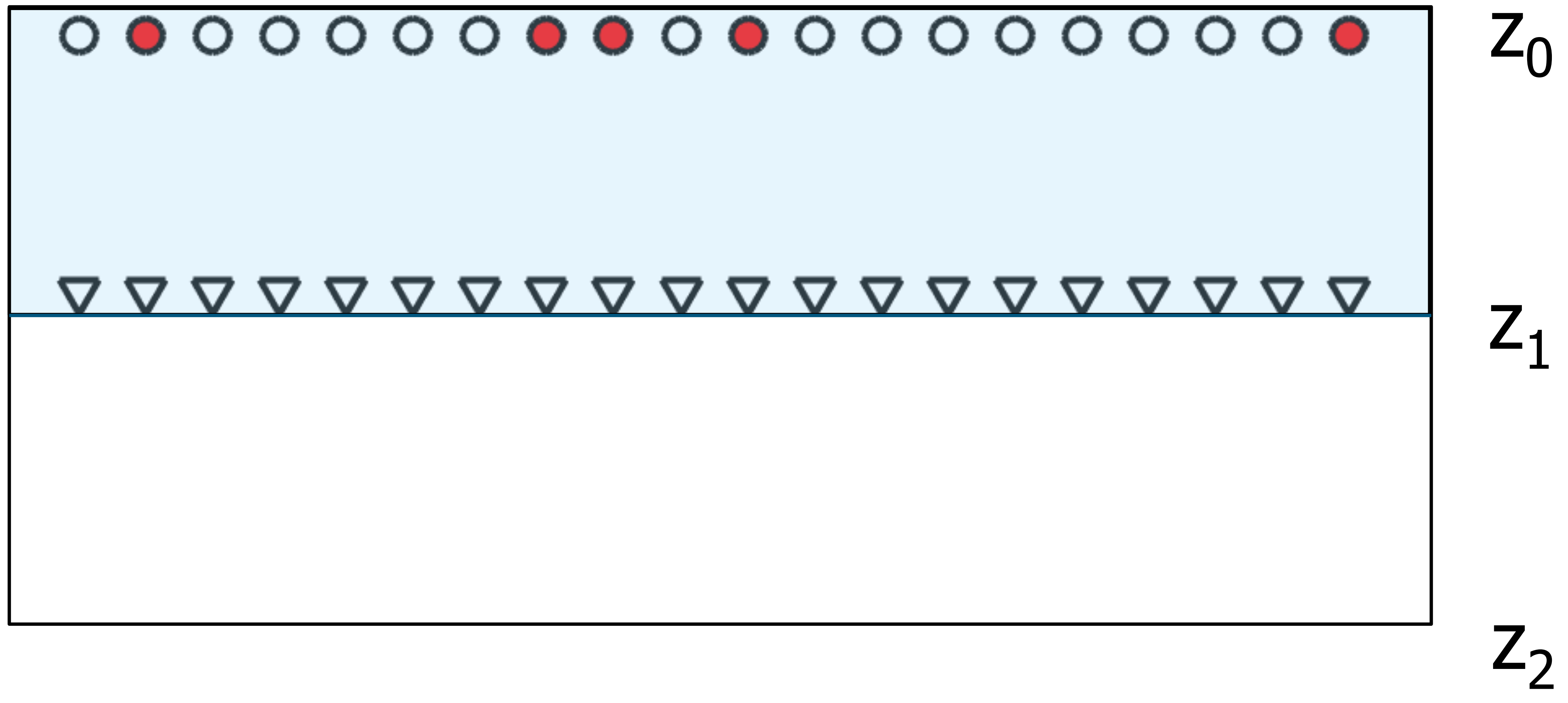


Can't afford dense acquisition

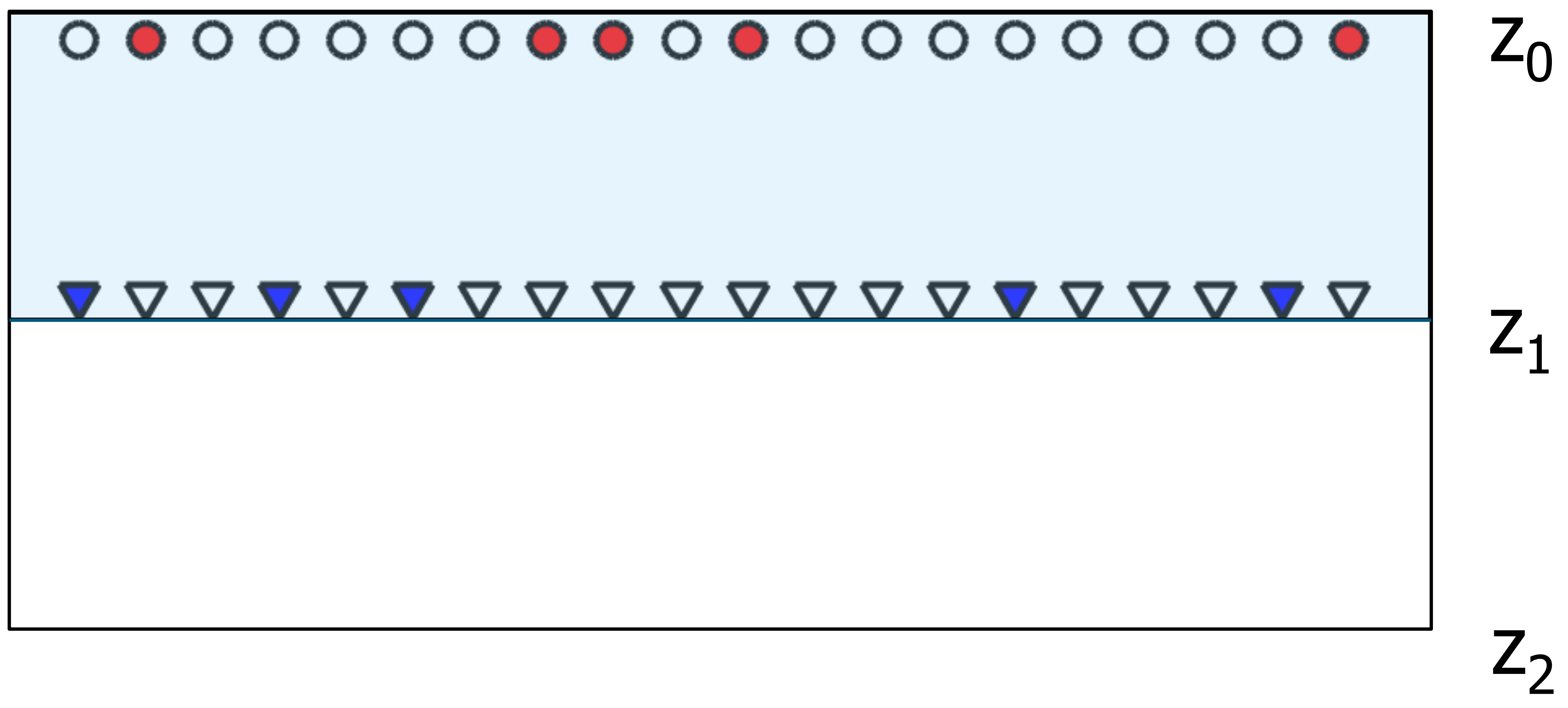


Hennenfent, G., and F. J. Herrmann, 2008, Simply denoise: Wavefield reconstruction via jittered undersampling: Geophysics, 73, V19–V28.

Randomized under-sampled acquisition



Randomized under-sampled acquisition



Reconstruction with rank minimization

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$$\min_{\mathbf{X}} \|\mathbf{X}\|_* \quad \text{subject to} \quad \|\mathcal{A}(\mathbf{X}) - b\|_2 \leq \sigma \qquad (\mathrm{BPDN}_\sigma)$$

$$\mathcal{A} = \mathbf{M}\mathbf{S}^H \qquad \|\mathbf{X}\|_* = \|\lambda\|_1$$

Kumar, R., Silva, C.D., Akalin, O., Aravkin, A.Y., Mansour, H., Recht, B. and Herrmann, F.J. [2015] Efficient matrix completion for seismic data reconstruction. Geophysics, 80(05), V97–V114. (Geophysics).

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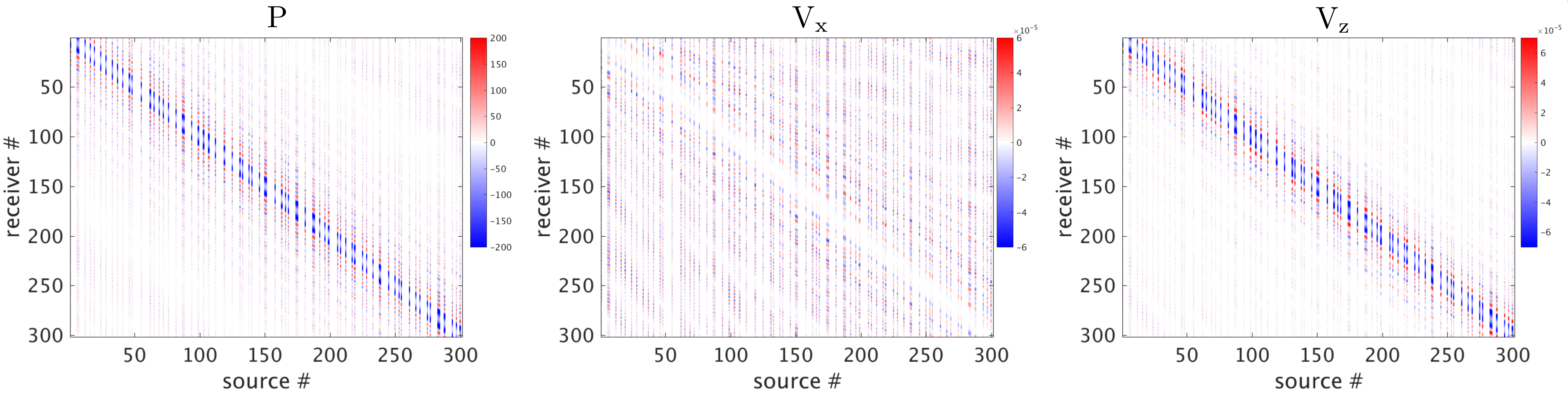
SPGℓ1

$$\min_{\mathbf{X}} \|\mathcal{A}(\mathbf{X}) - b\|_2 \quad \text{subject to } \|\mathbf{X}\|_* \leq \tau \qquad (\text{LASSO}_\tau)$$

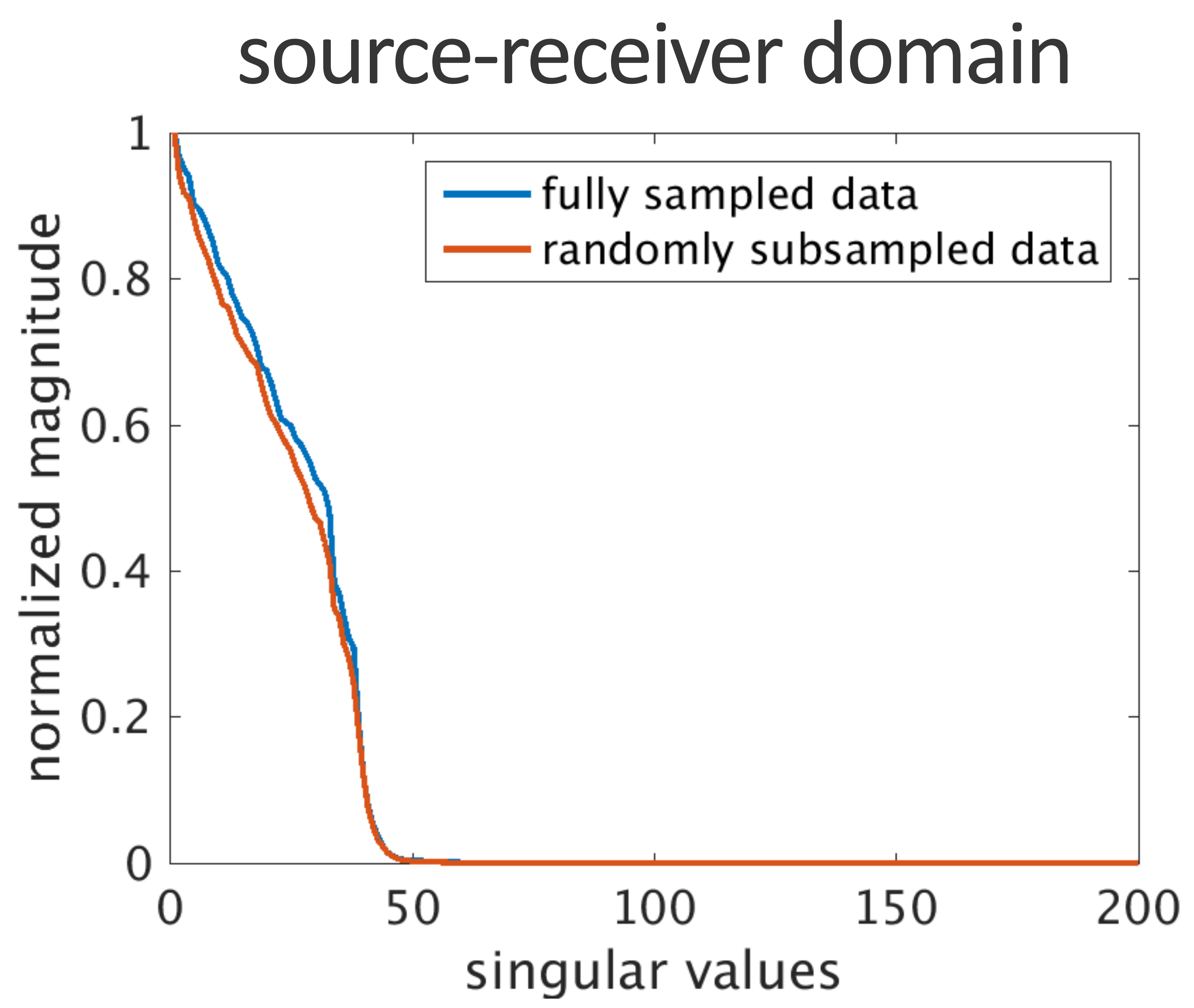
$$\mathbf{X} = \mathbf{LR}^H \qquad \|\mathbf{X}\|_* \leq \frac{1}{2}(\|\mathbf{L}\|_F^2 + \|\mathbf{R}\|_F^2)$$

$$\mathbf{X} \in \mathbf{C}^{n\times m}, \quad \mathbf{L} \in \mathbf{C}^{n\times k}, \quad \mathbf{R} \in \mathbf{C}^{m\times k}, \quad k \ll m, n$$

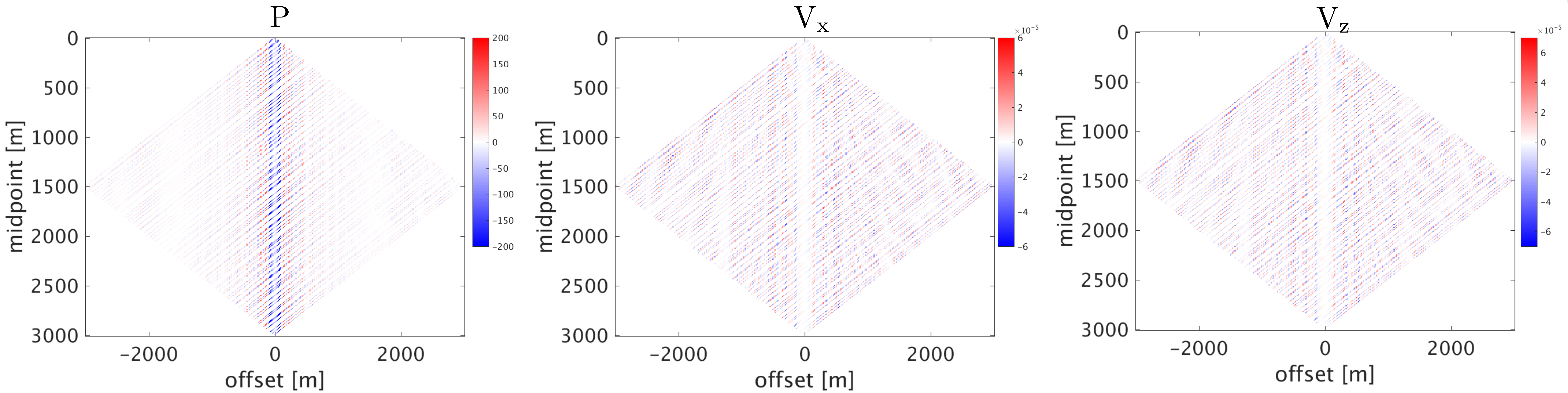
Randomly subsampled frequency slices, 25 Hz



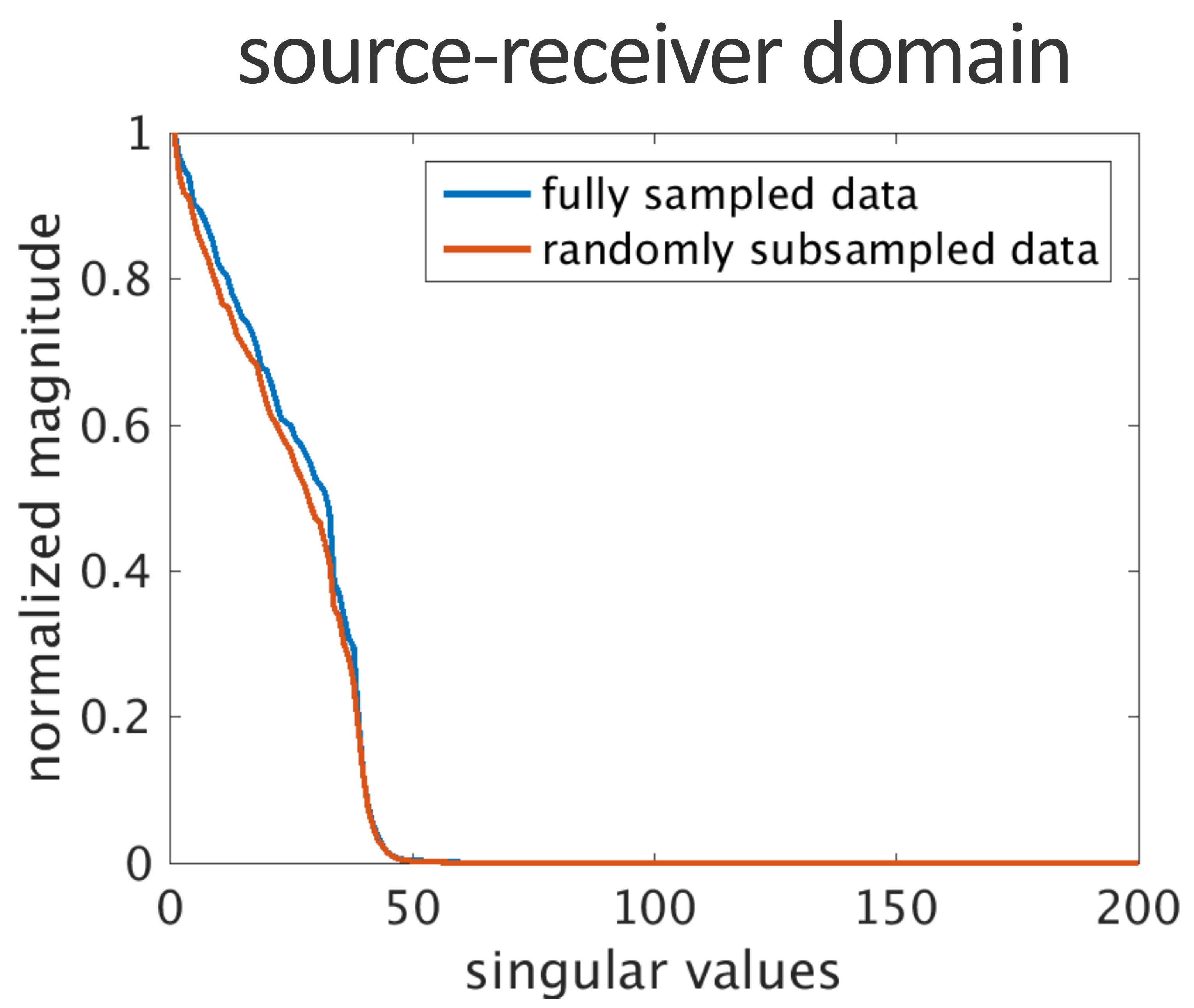
Singular values decay

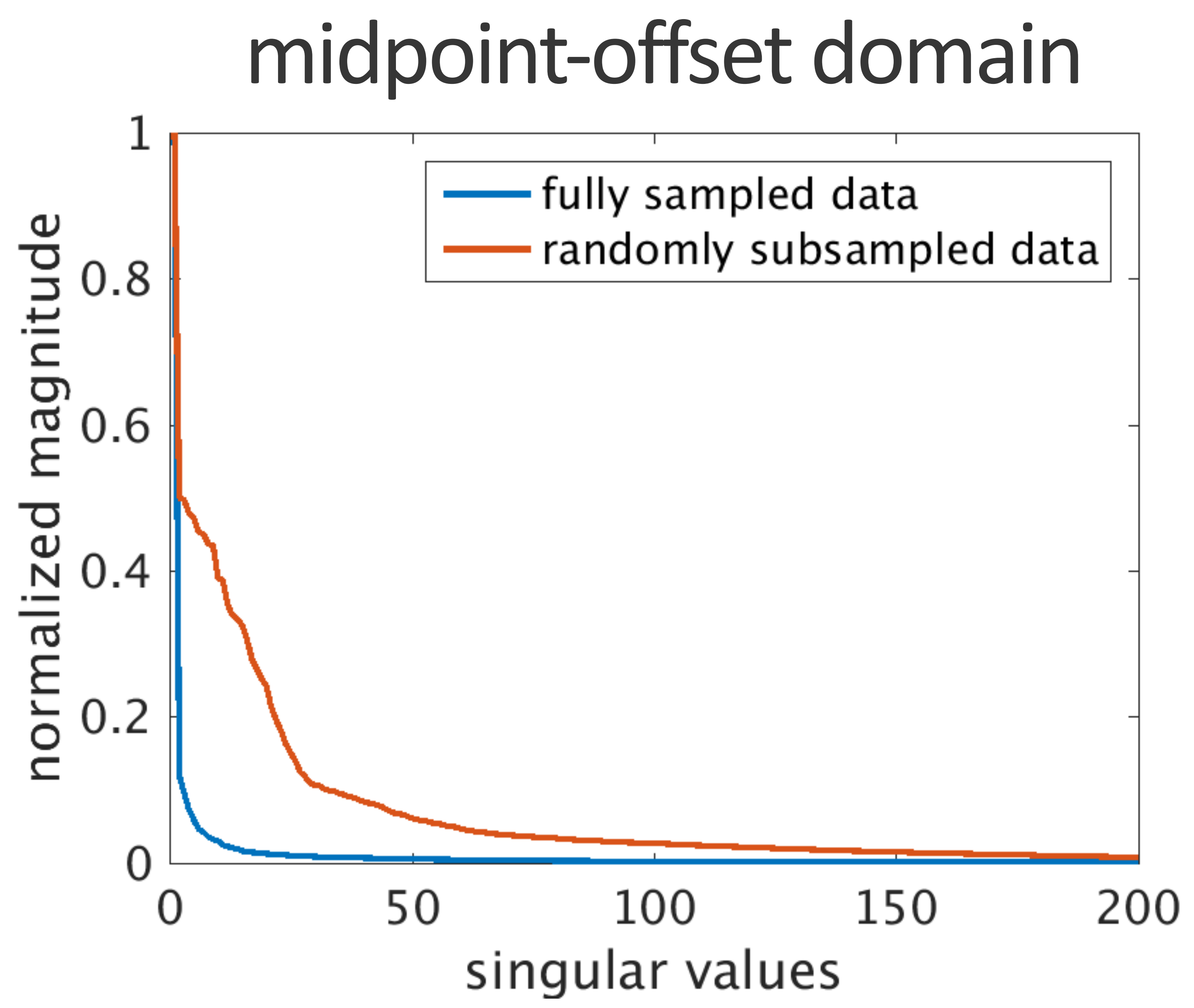


Midpoint-offset domain

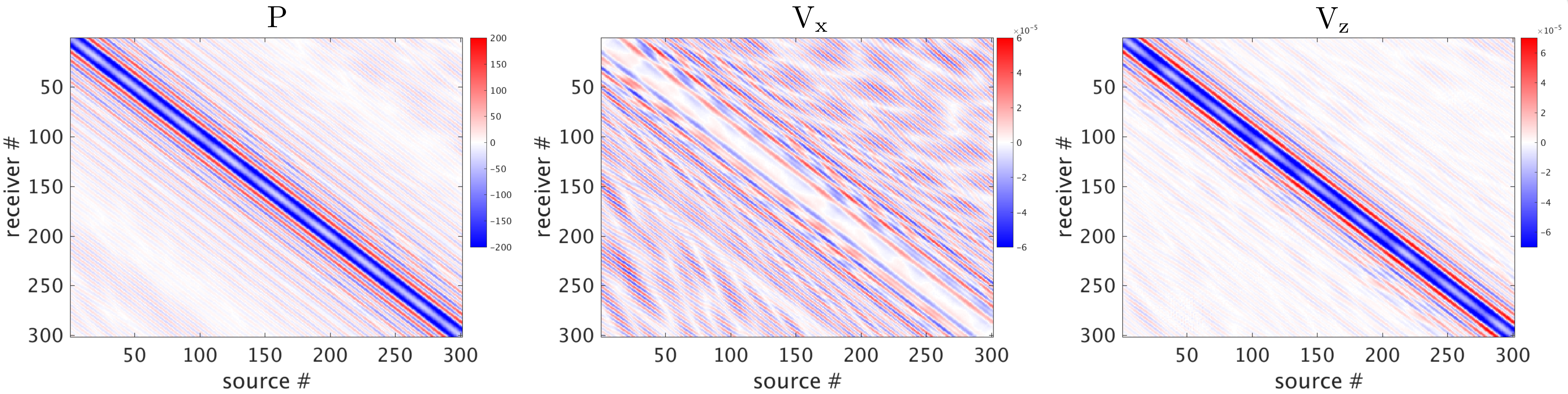


Singular values decay

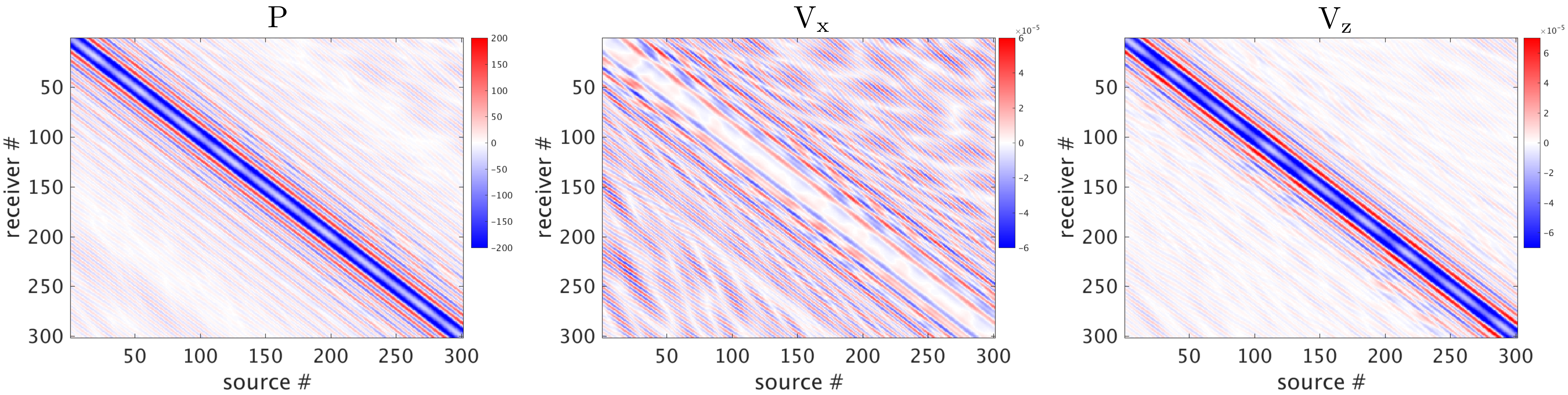




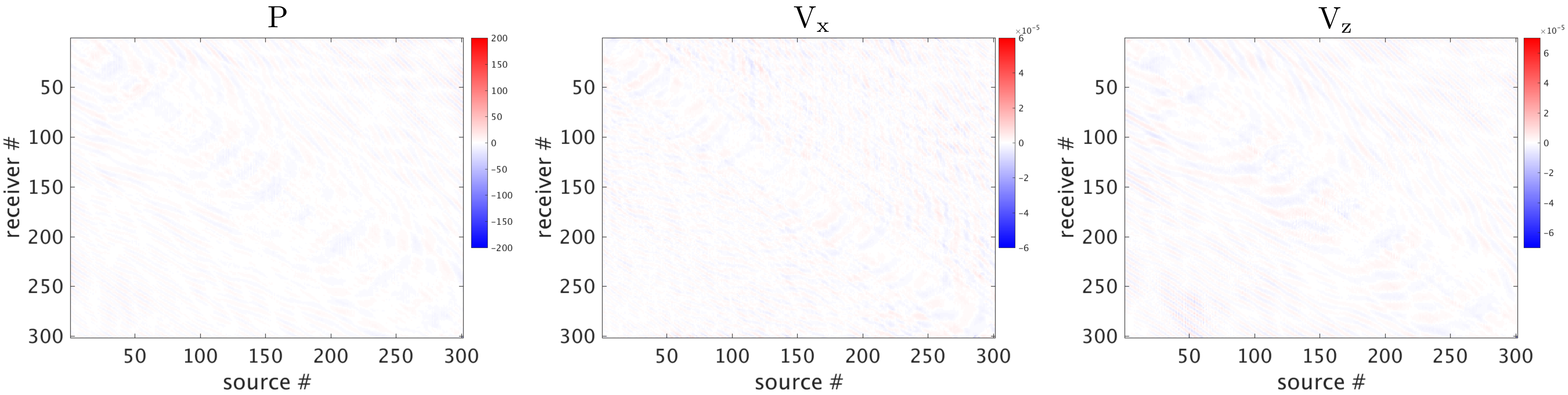
Reconstructed frequency slices, 25 Hz



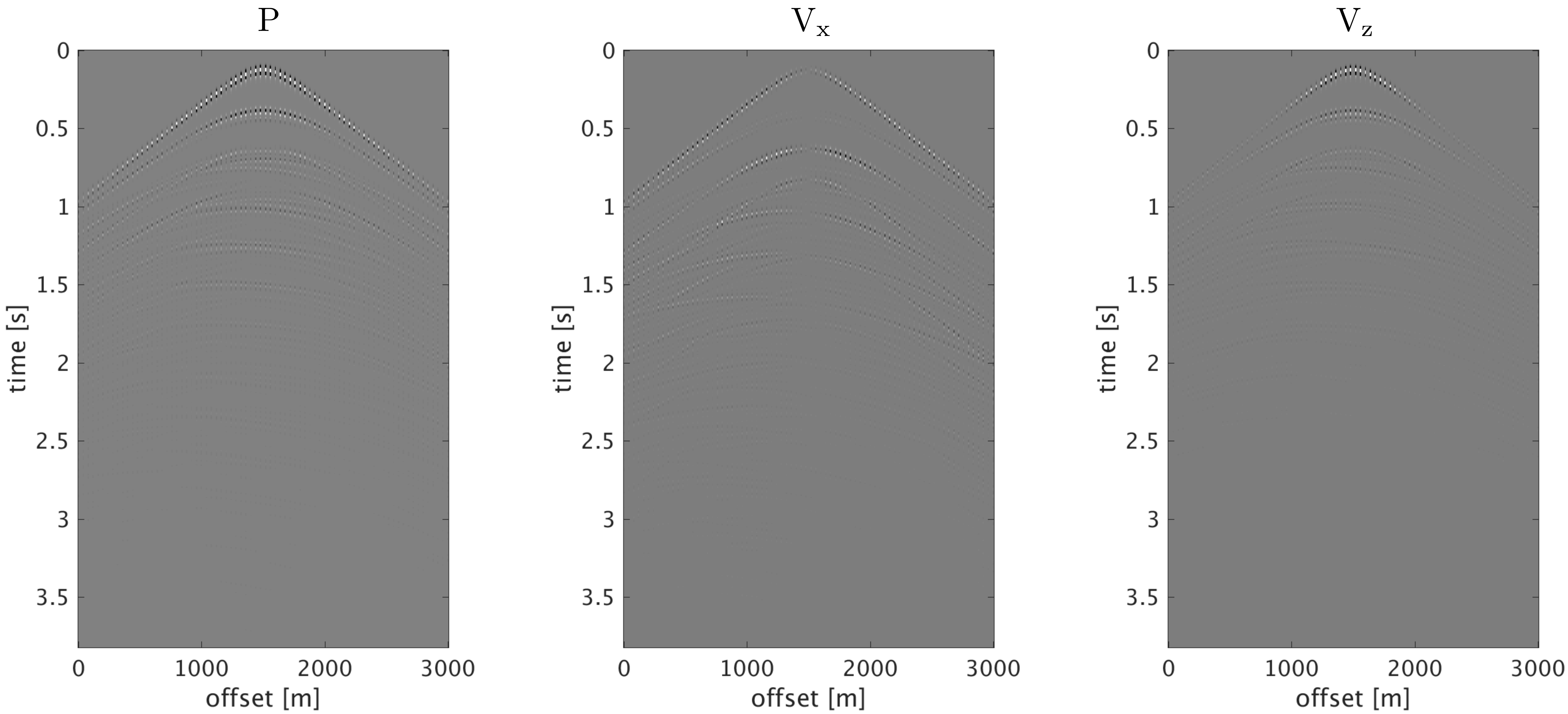
Densely sampled frequency slices, 25 Hz



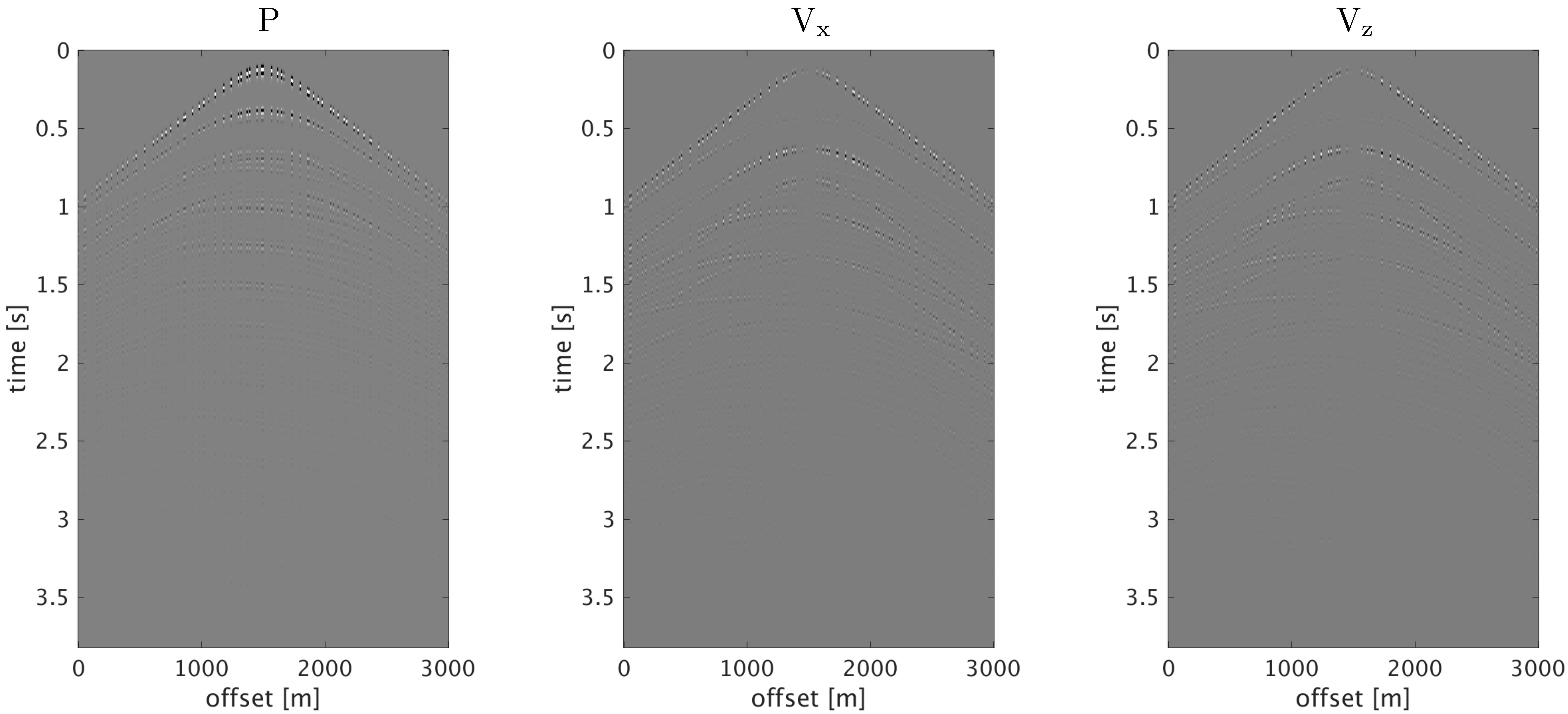
Residual


P
Vx
Vz
receiver #
source #
50
100
150
200
250
300
200
150
100
50
0
-50
-100
-150
-200
×10^-5
6
4
2
0
-2
-4
-6

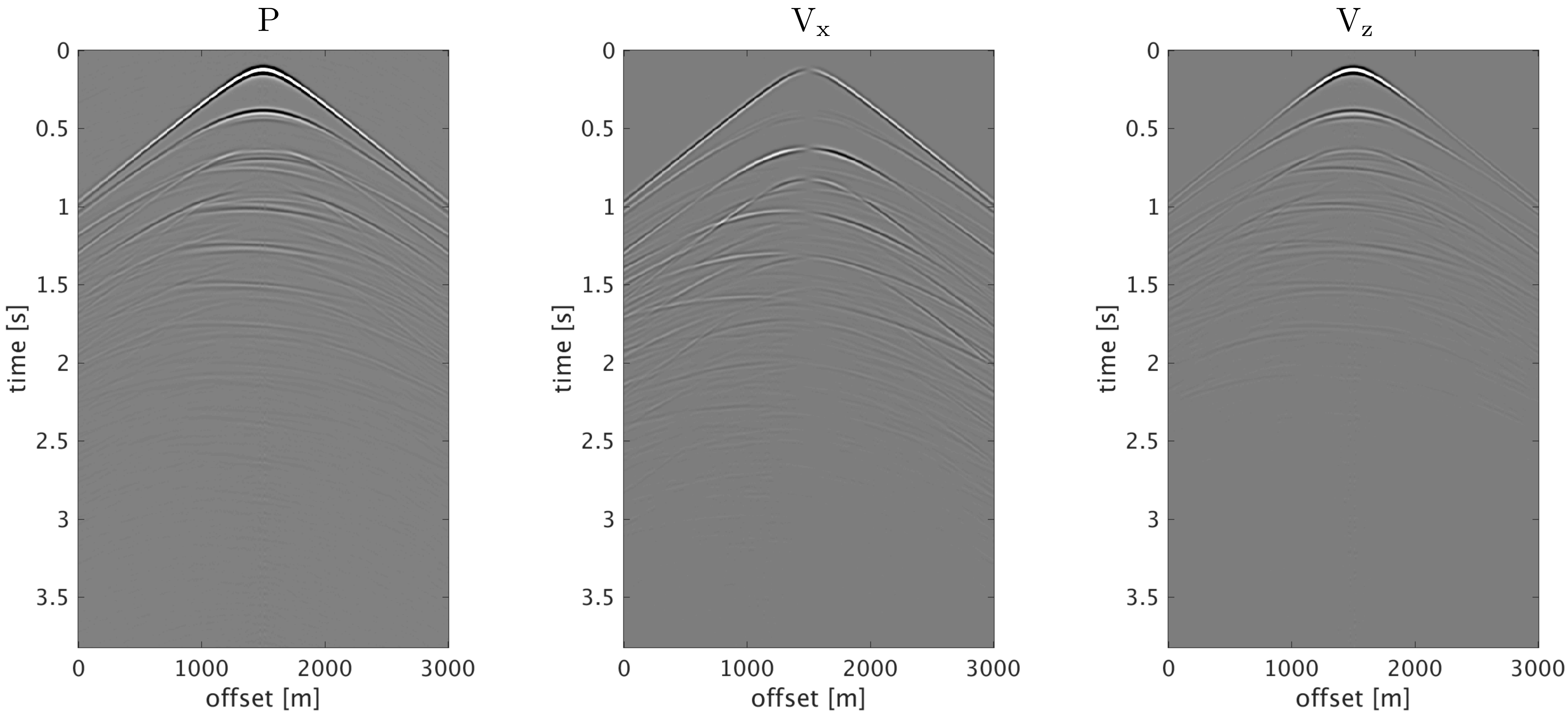
40 m source interval receiver gathers



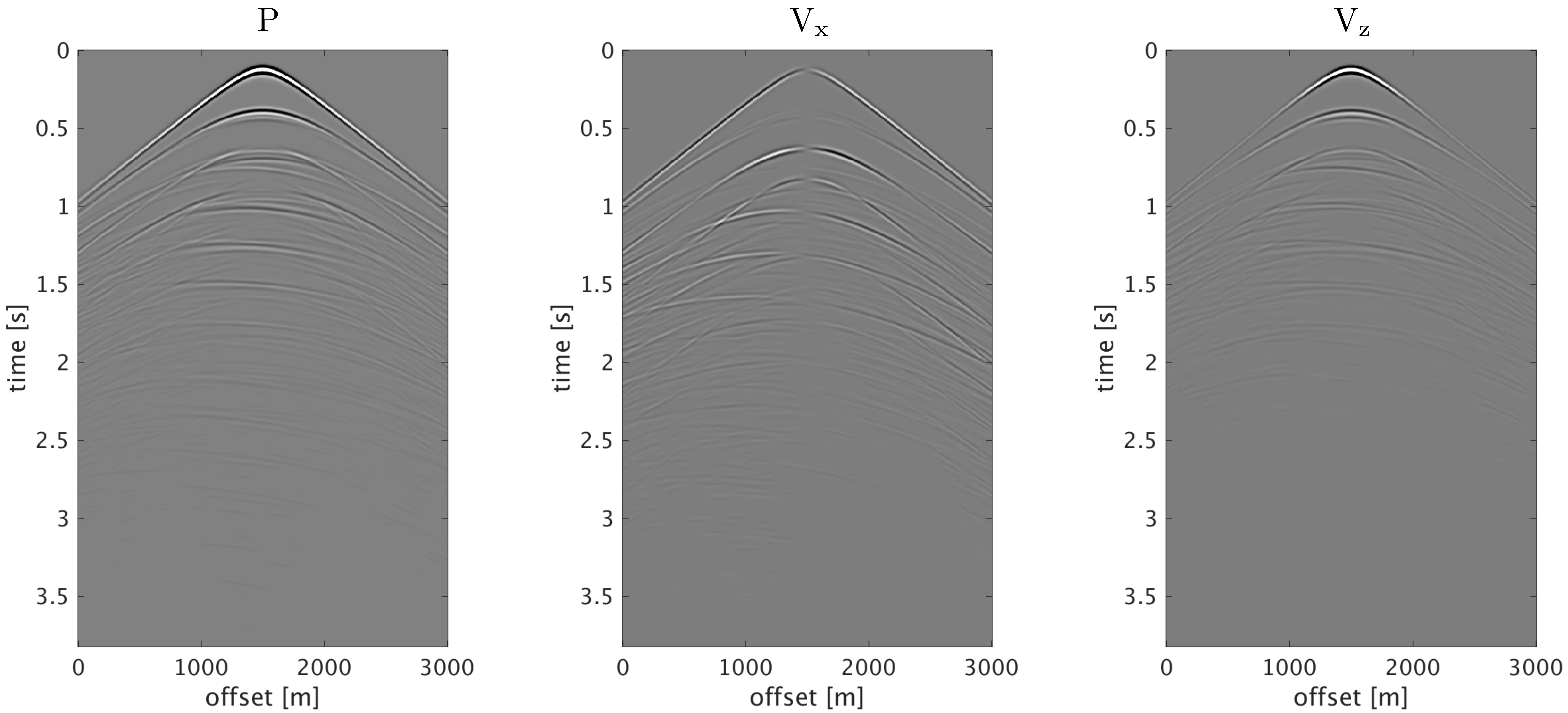
75% jittered subsampling



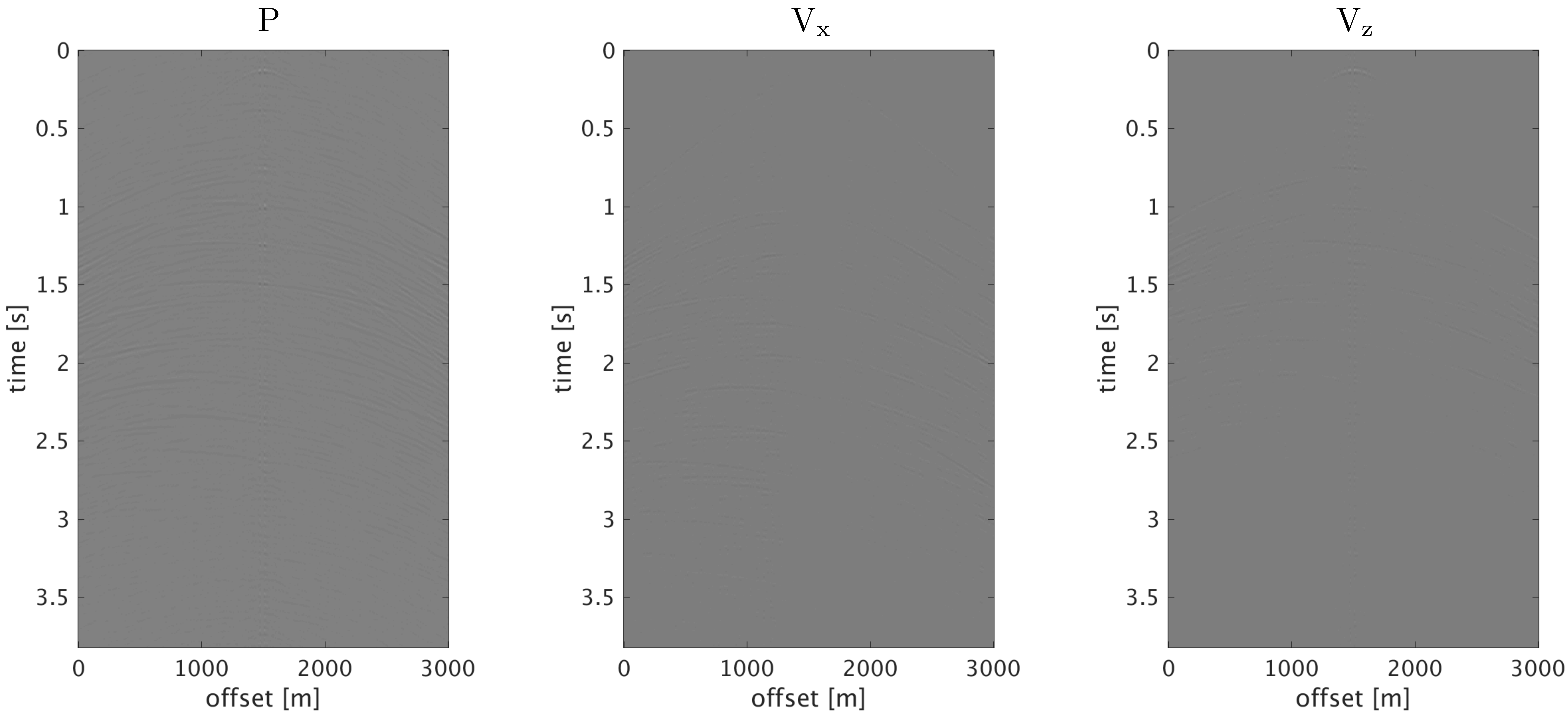
Reconstructed receiver gathers



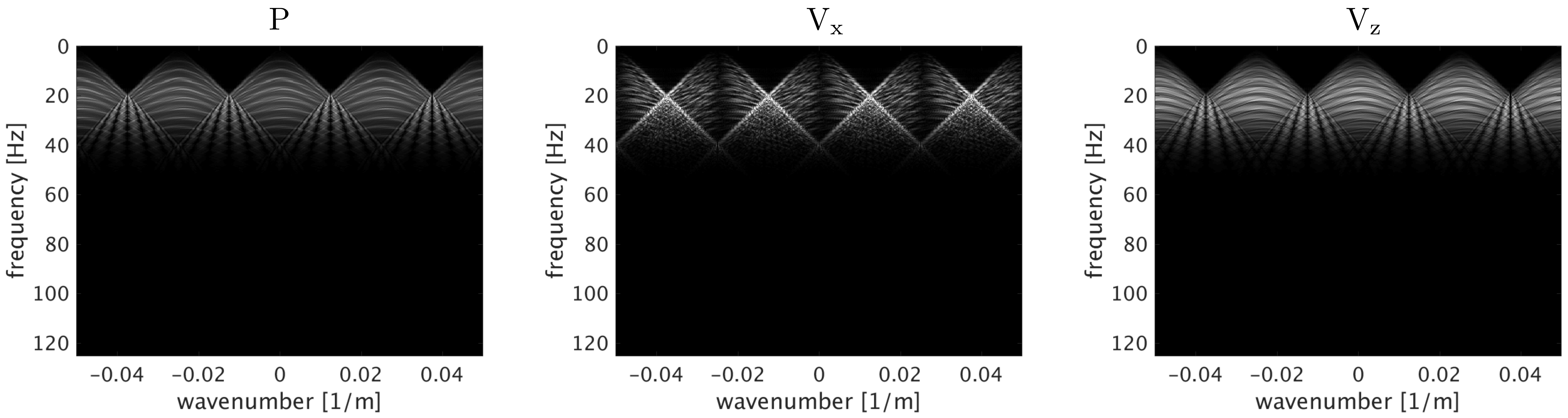
Densely sampled receiver gathers, 10 m



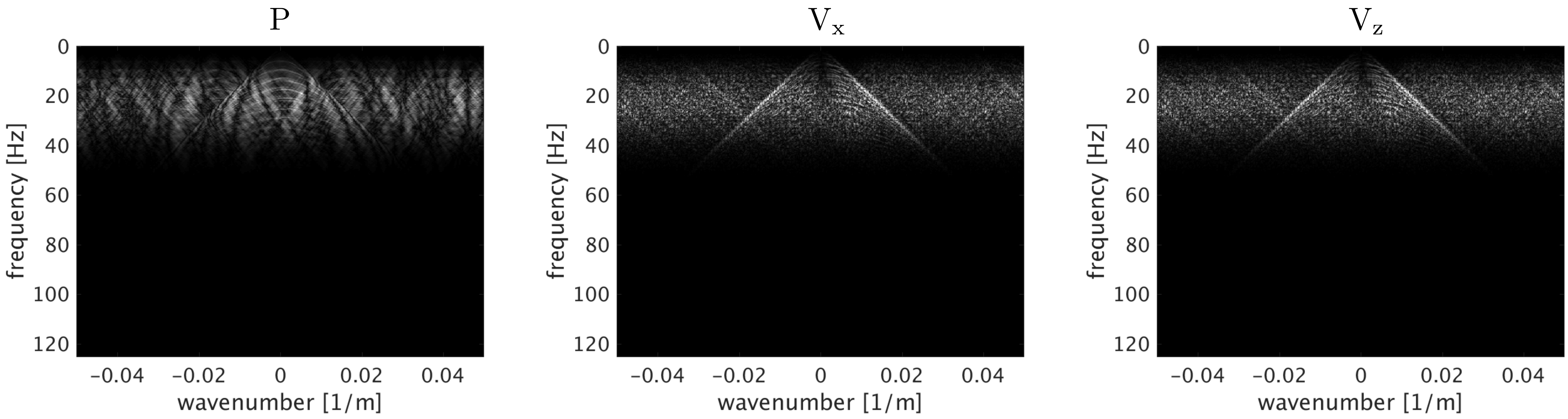
Residual



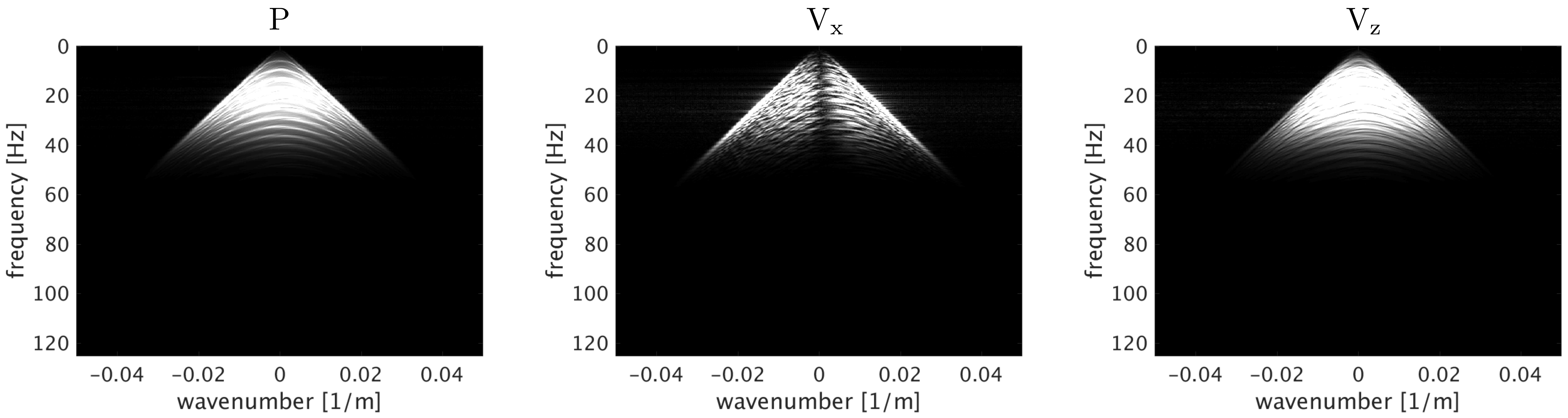
f-k spectrum, 40 m source interval



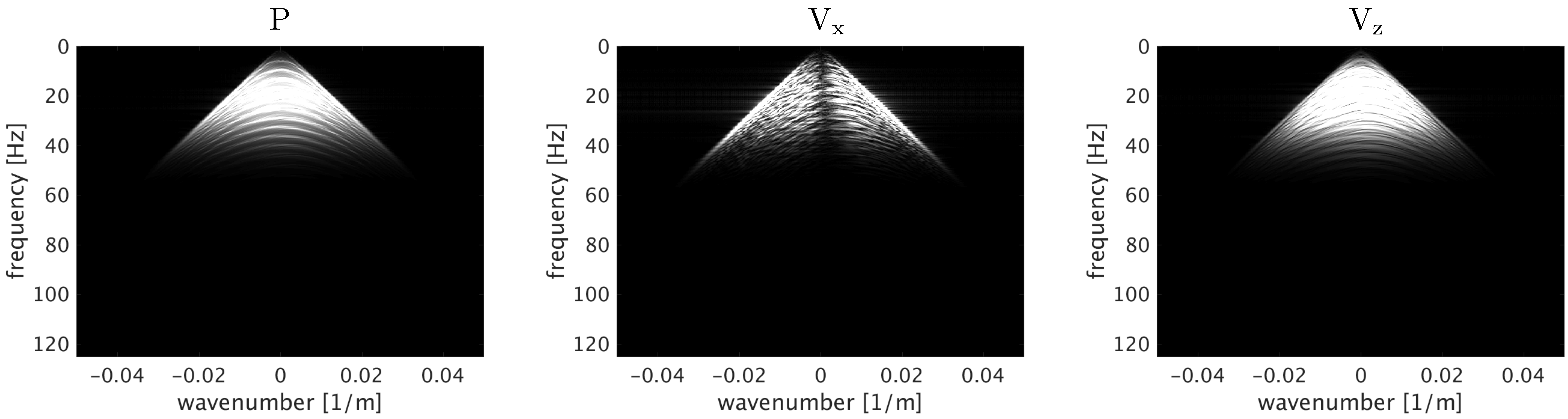
f-k spectrum, 75% jittered subsampling



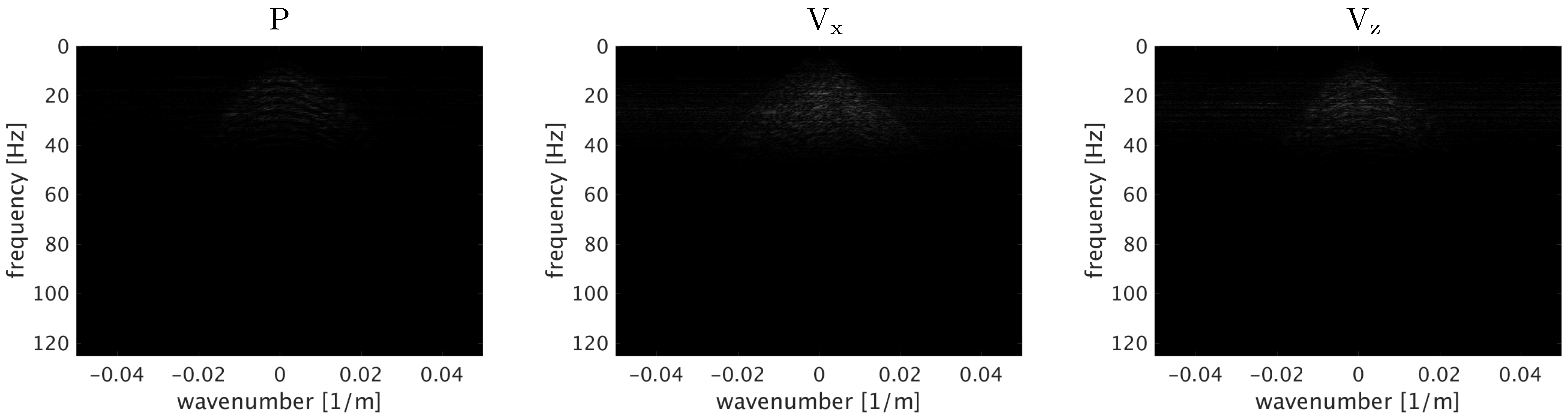
f-k spectrum, reconstruction



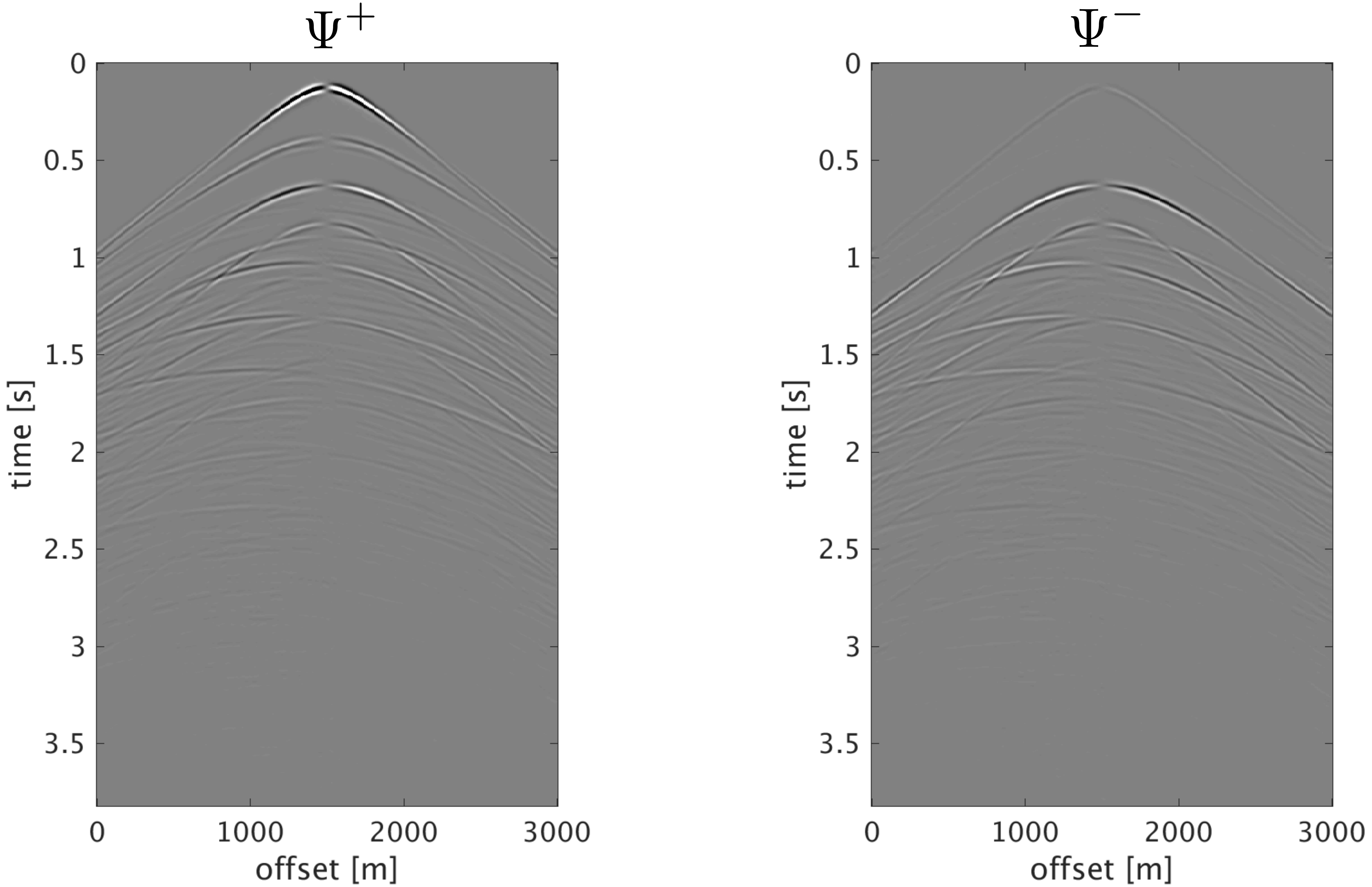
f-k spectrum, densely sampled



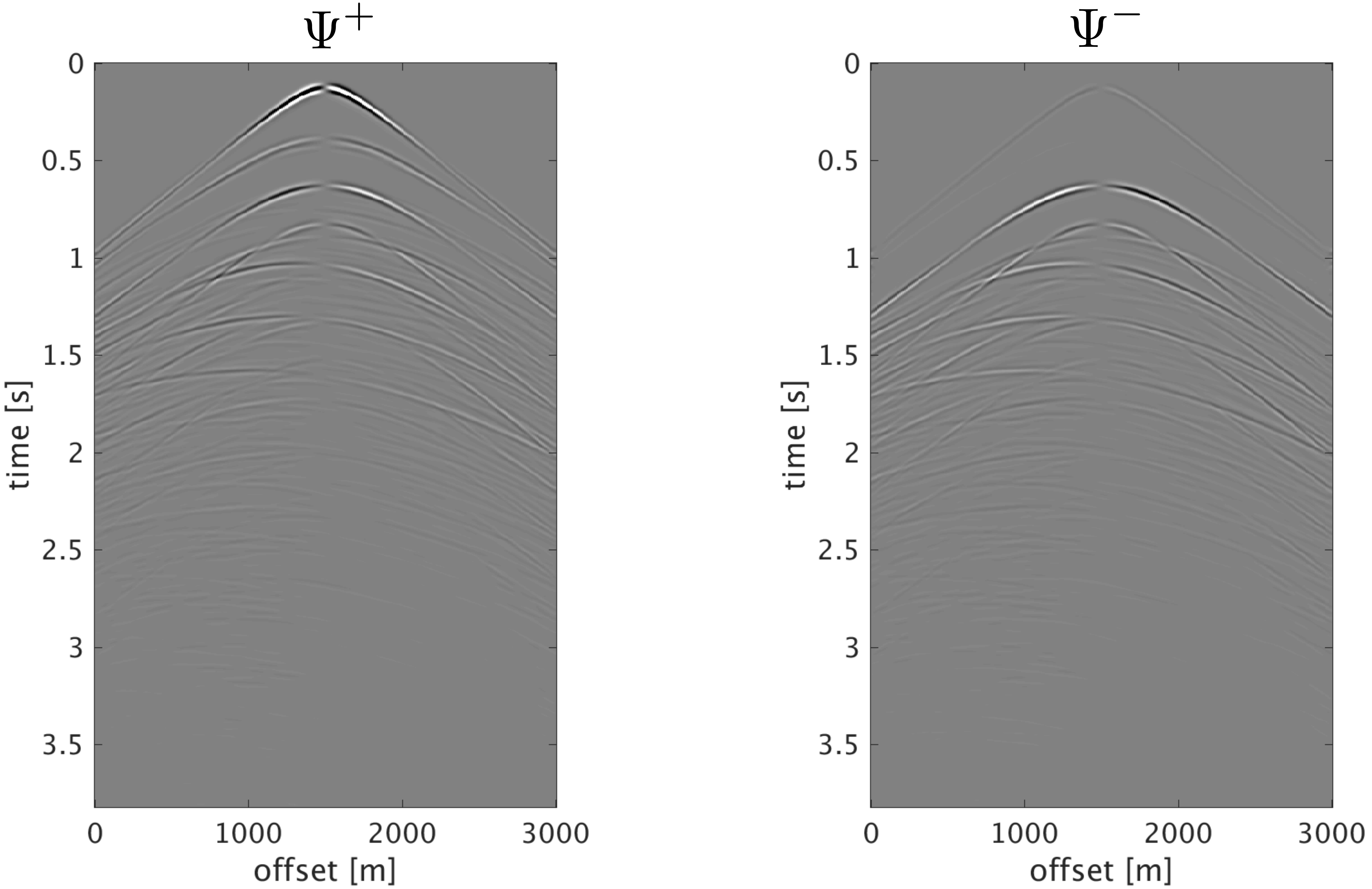
f-k spectrum, residual



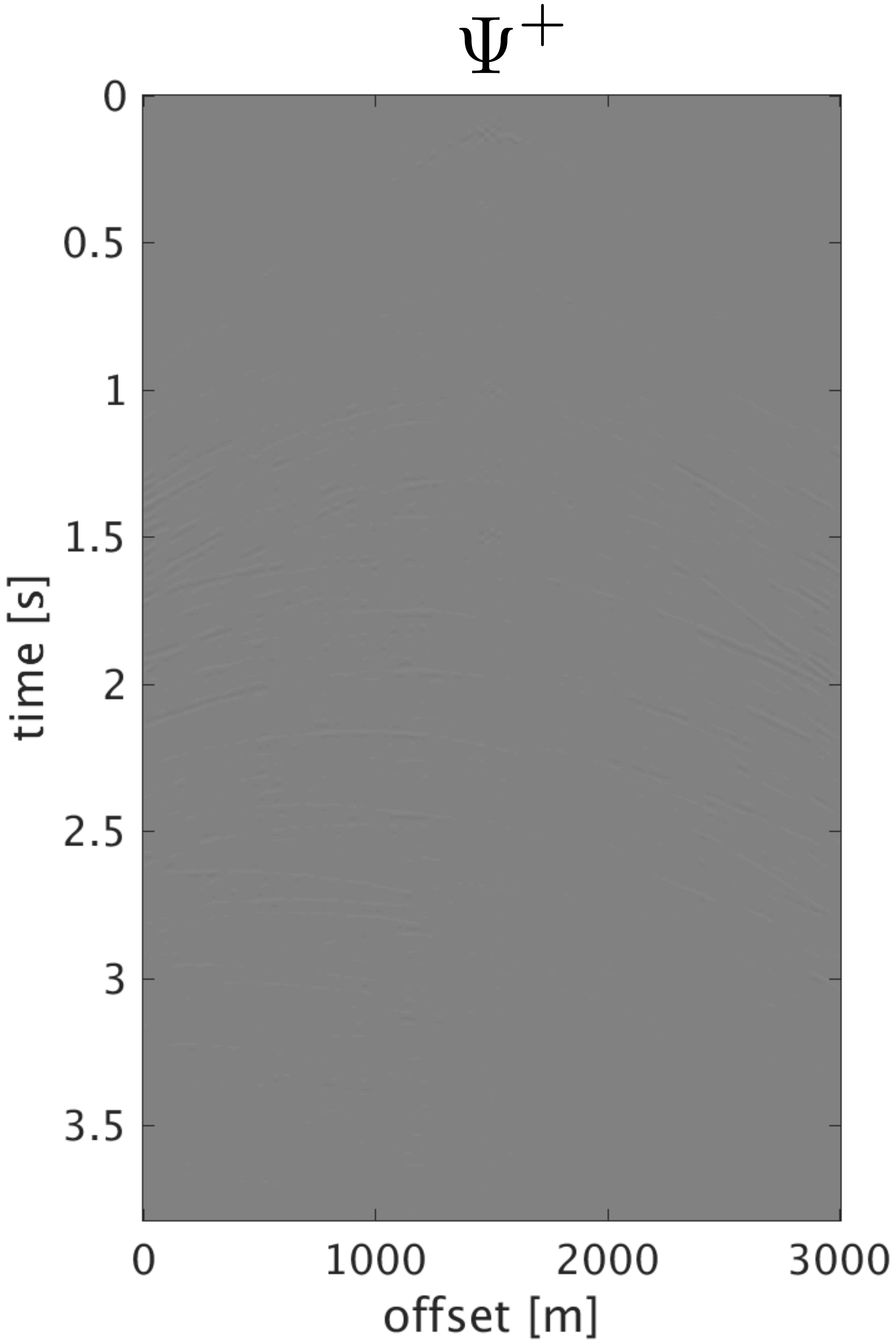
Reconstructed S-waves



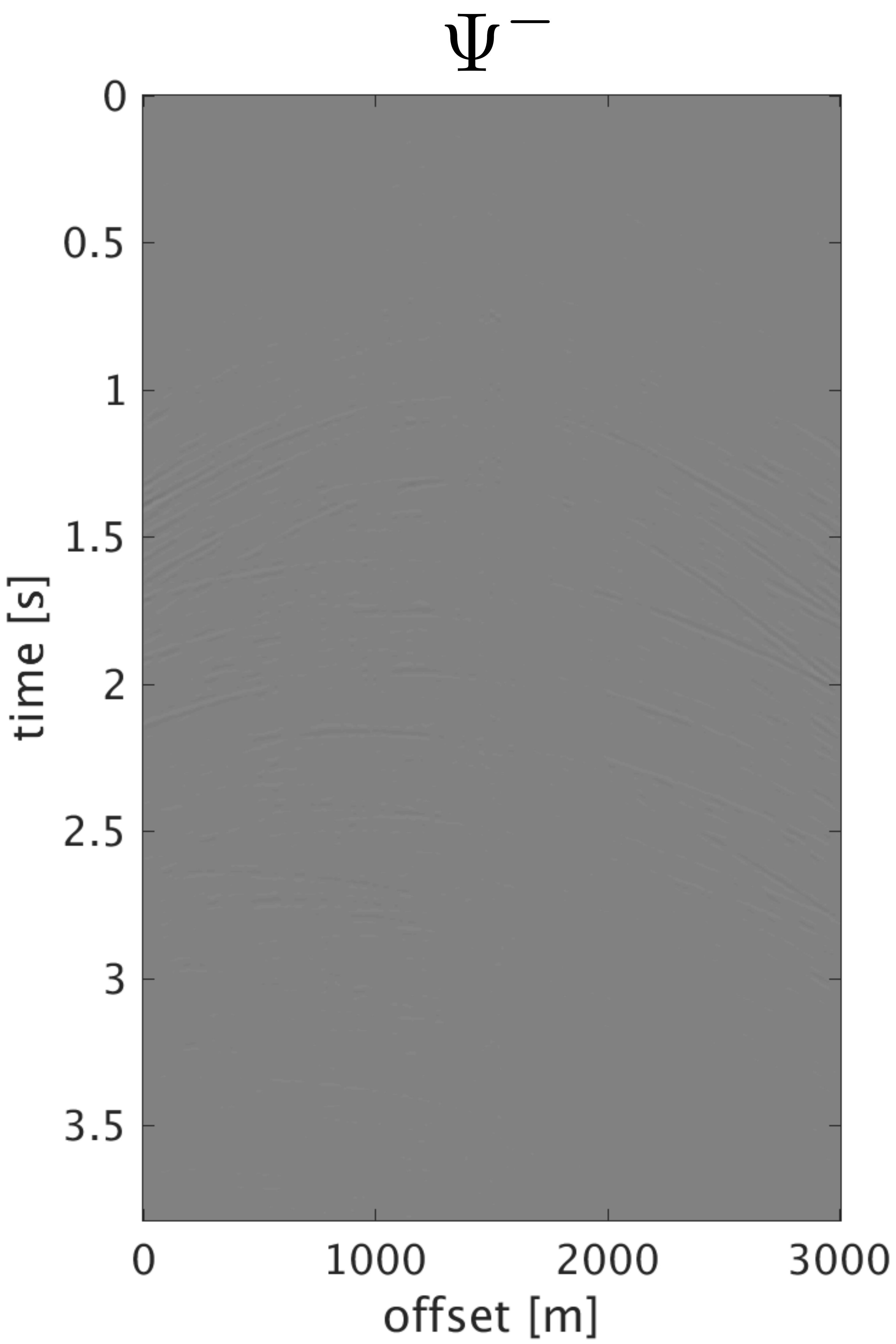
True S-waves



Residual

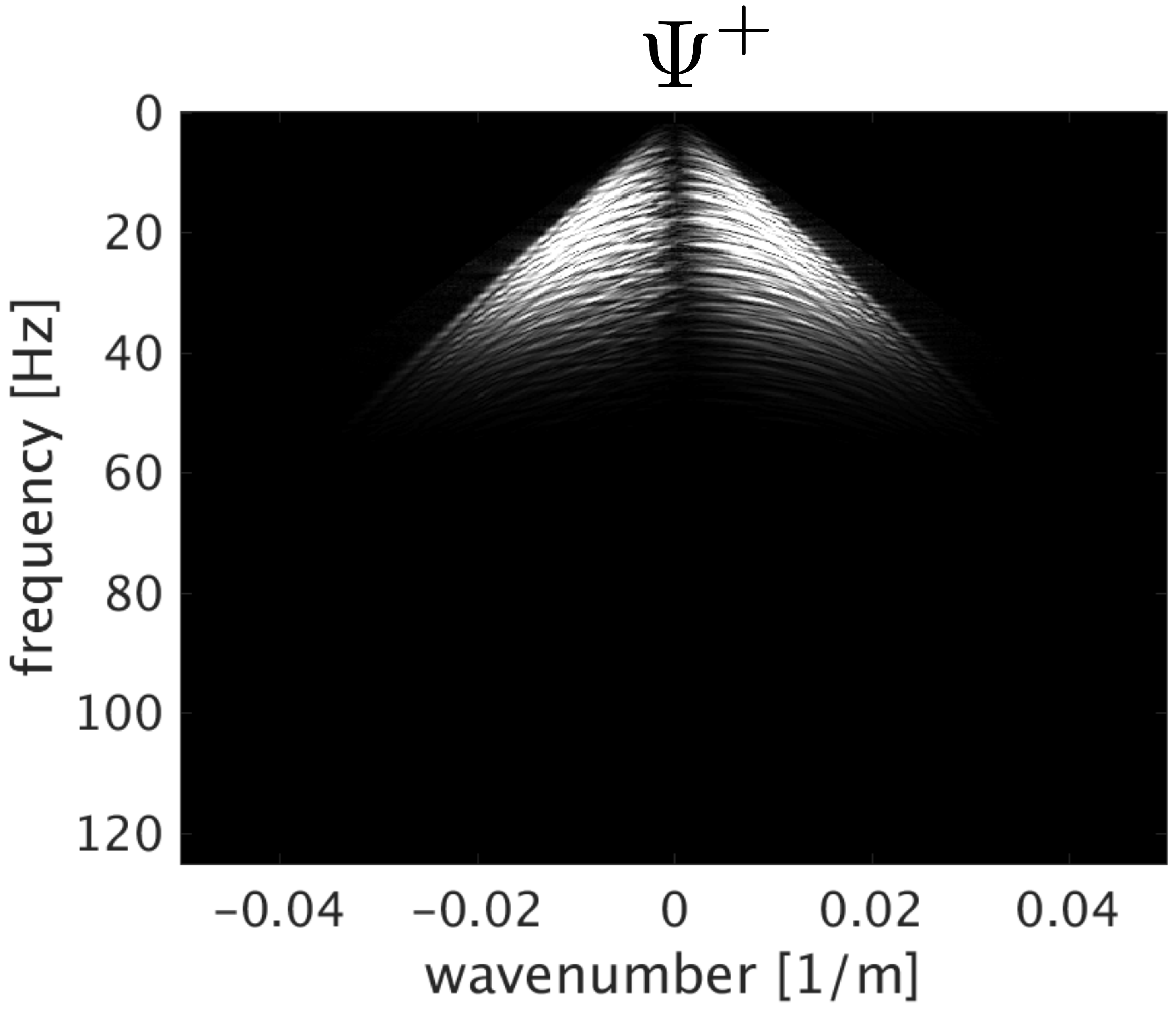


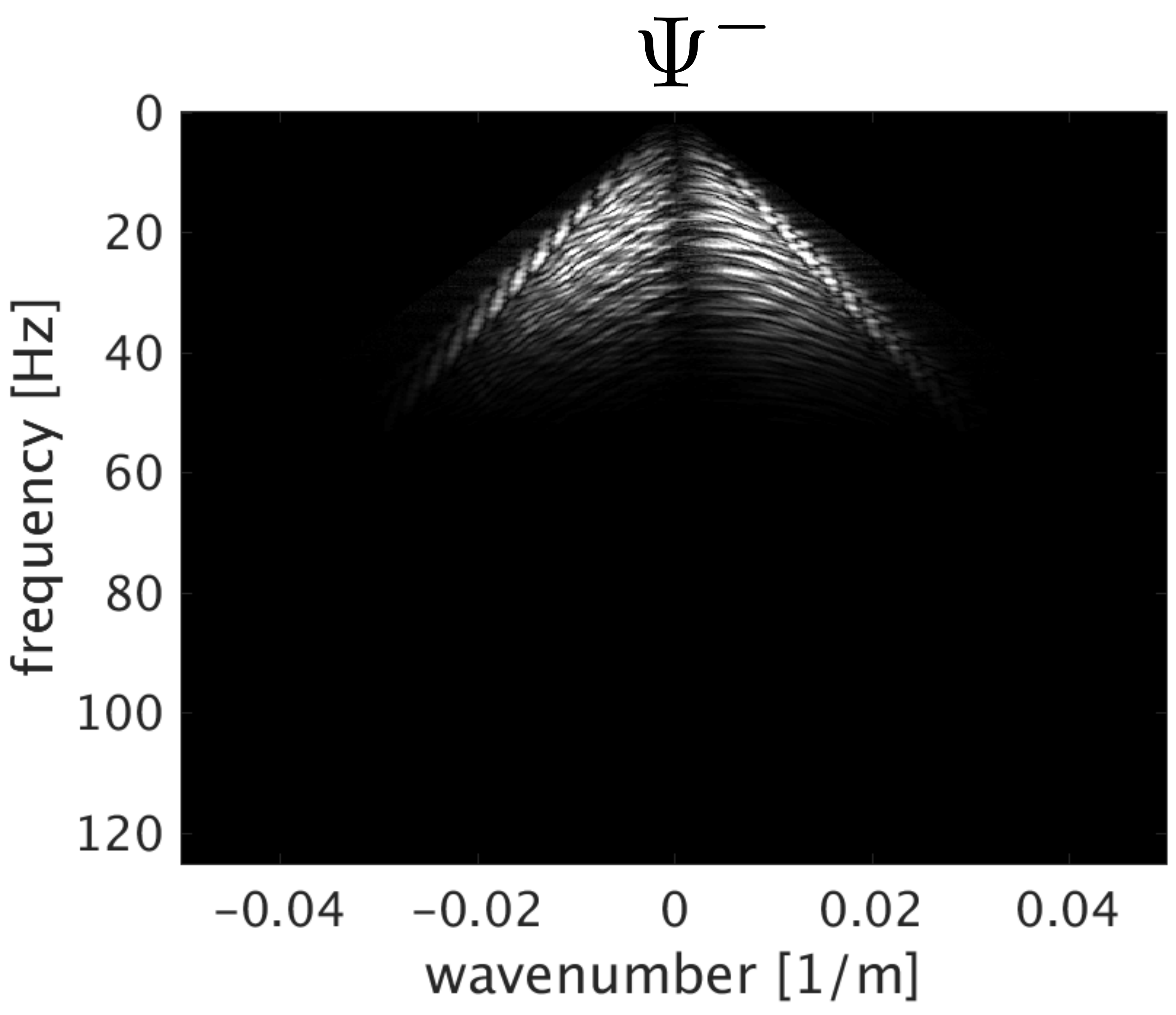
Ψ^+
0
0.5
1
1.5
2
2.5
3
3.5
time [s]
0
1000
2000
3000
offset [m]



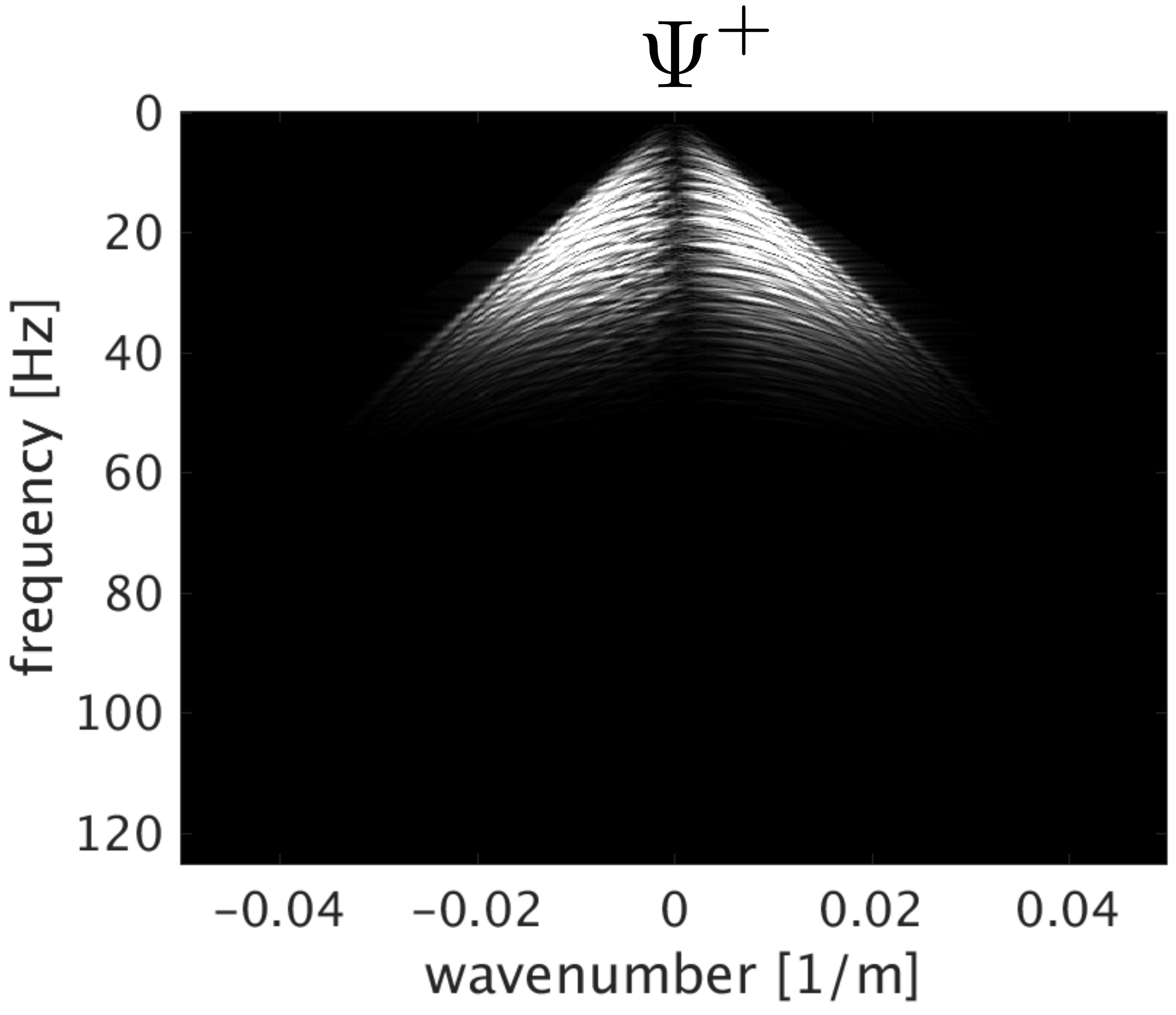
Ψ^-
0
0.5
1
1.5
2
2.5
3
3.5
time [s]
0
1000
2000
3000
offset [m]

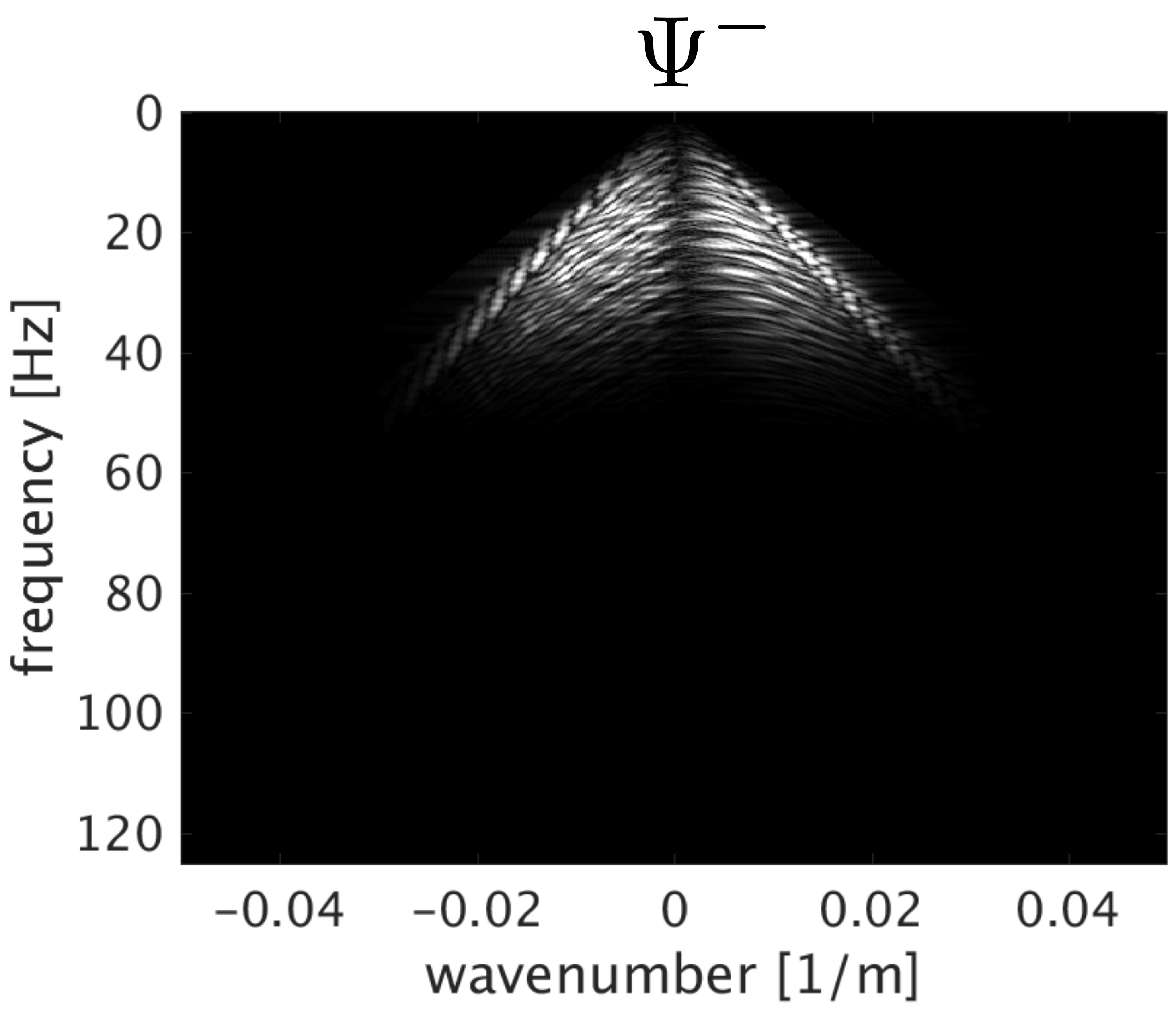
f-k spectrum, reconstructed S-waves



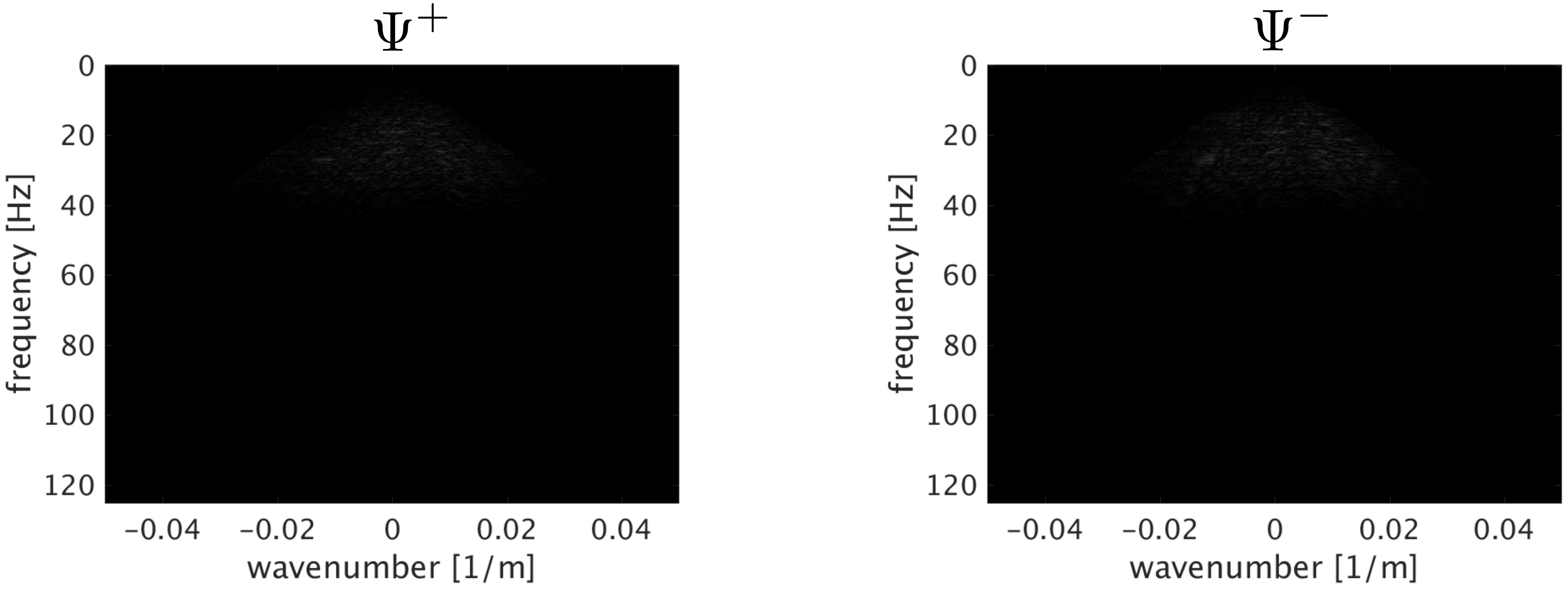


f-k spectrum, densely sampled S-waves



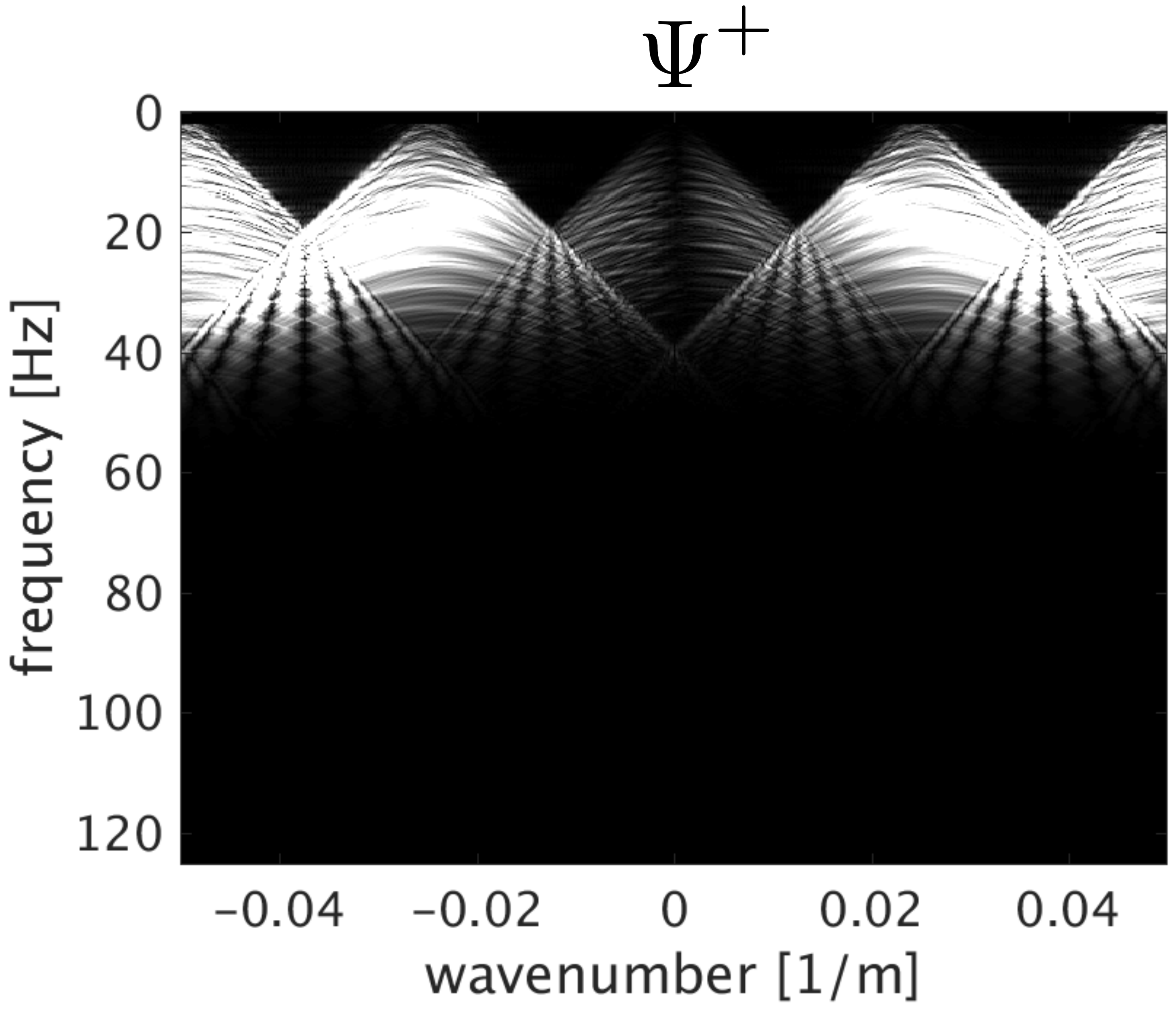


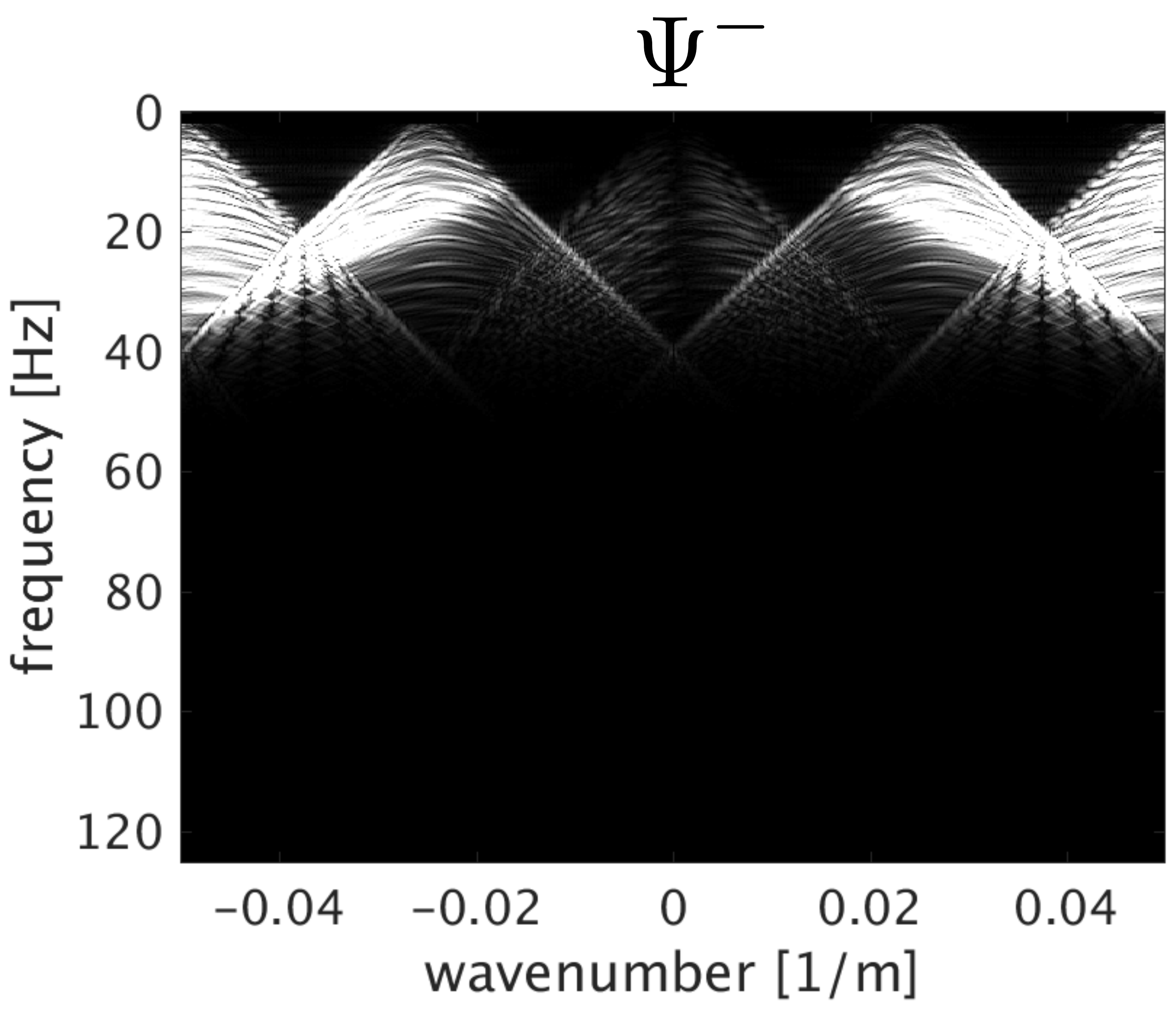
Residual



Ψ^{+}
Ψ^{-}
frequency [Hz]
0
20
40
60
80
100
120
wavenumber [1/m]
−0.04
−0.02
0
0.02
0.04

f-k spectrum, 40 m source interval





Conclusions

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Solution:

- Using **jittered acquisition** with **SVD-free rank minimization interpolation**, S-waves become feasible to acquire and utilize in practice.

References

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End of presentation

Thank you for your attention!