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Copenhagen '12

Only dither: efficient simultaneous marine acquisition

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http://bigdatablog.emc.com/wp-content/uploads/2012/03/gotbigdata.png

Motivation

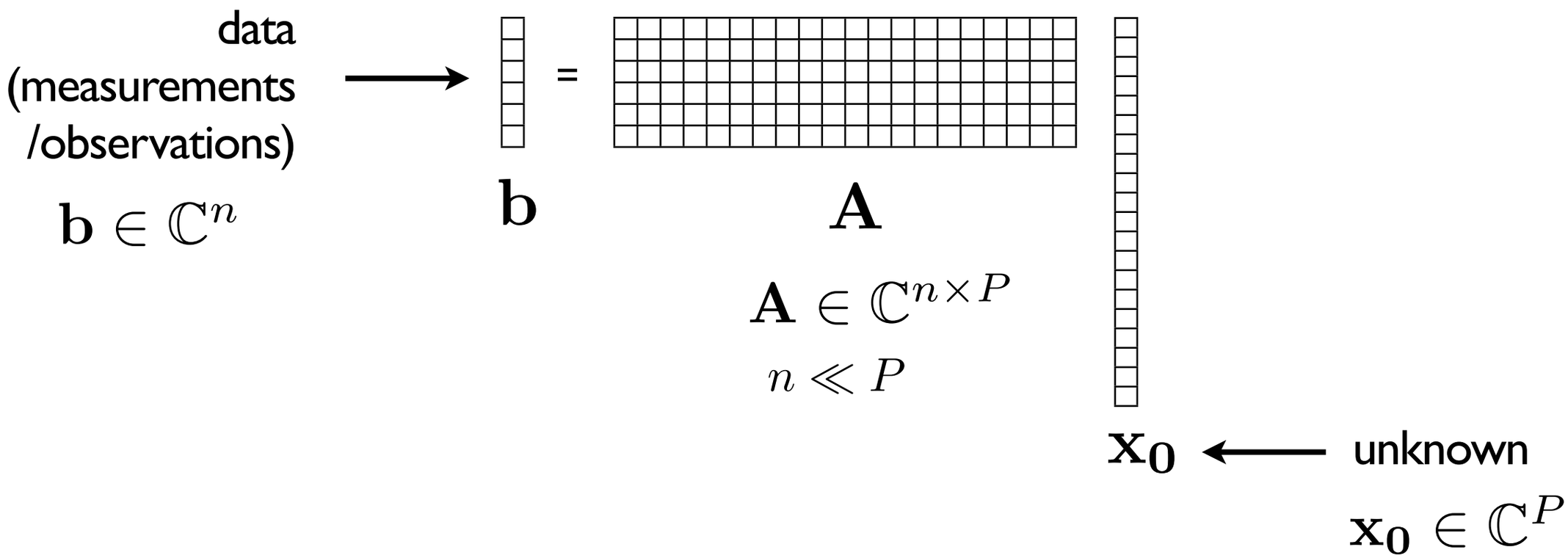
- Is there a way to circumvent the Nyquist-related acquisition/processing costs?
- Design seismic acquisition within the compressed sensing framework
- Rethink marine acquisition (with ocean-bottom nodes)

Outline

- Compressed sensing (CS) overview
  - design
  - recovery
- *Design* of *efficient* marine acquisition
- Experimental results of *sparsity*-promoting processing
  - "without" simultaneous sources
  - with simultaneous sources

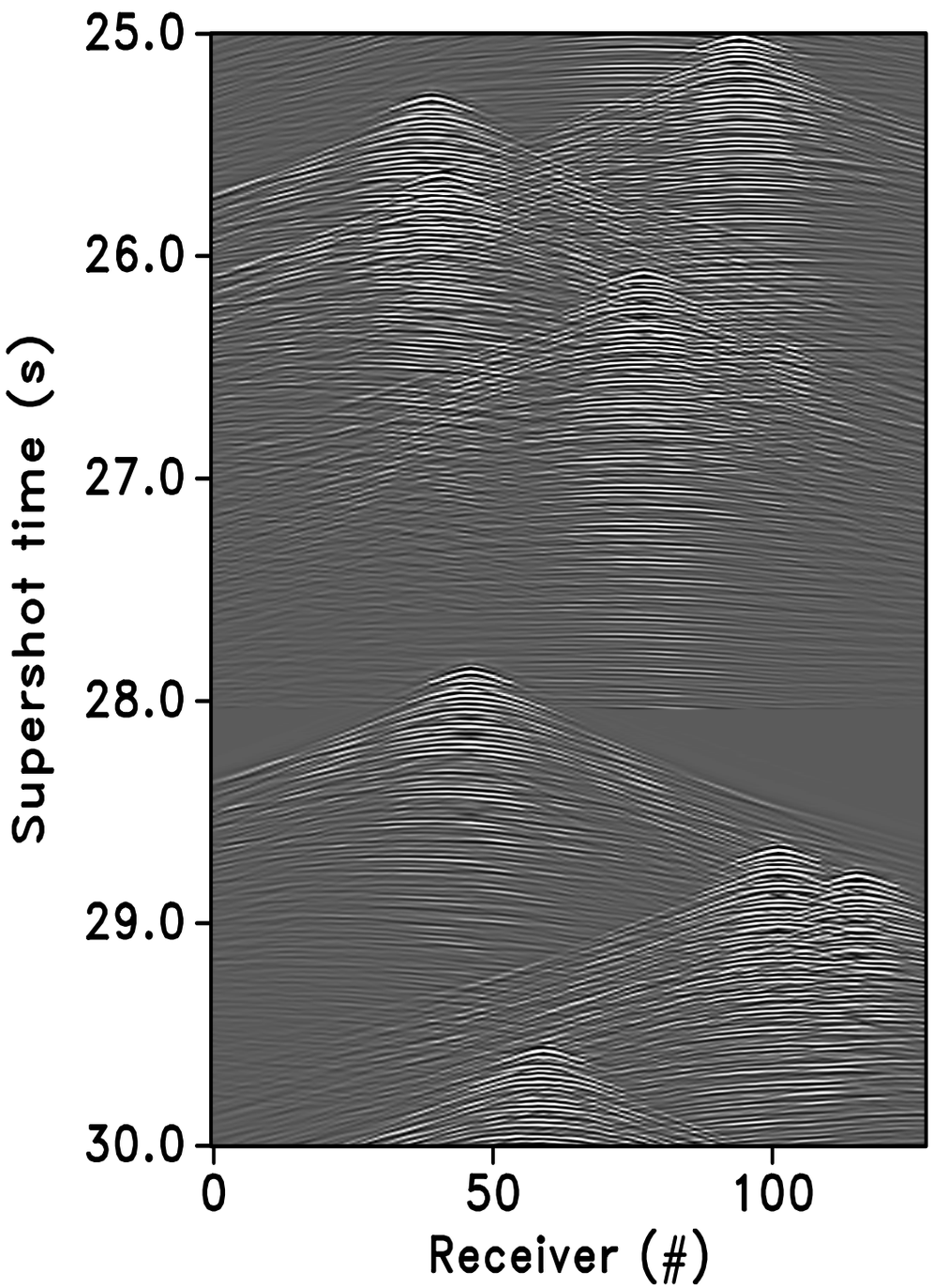
Problem statement

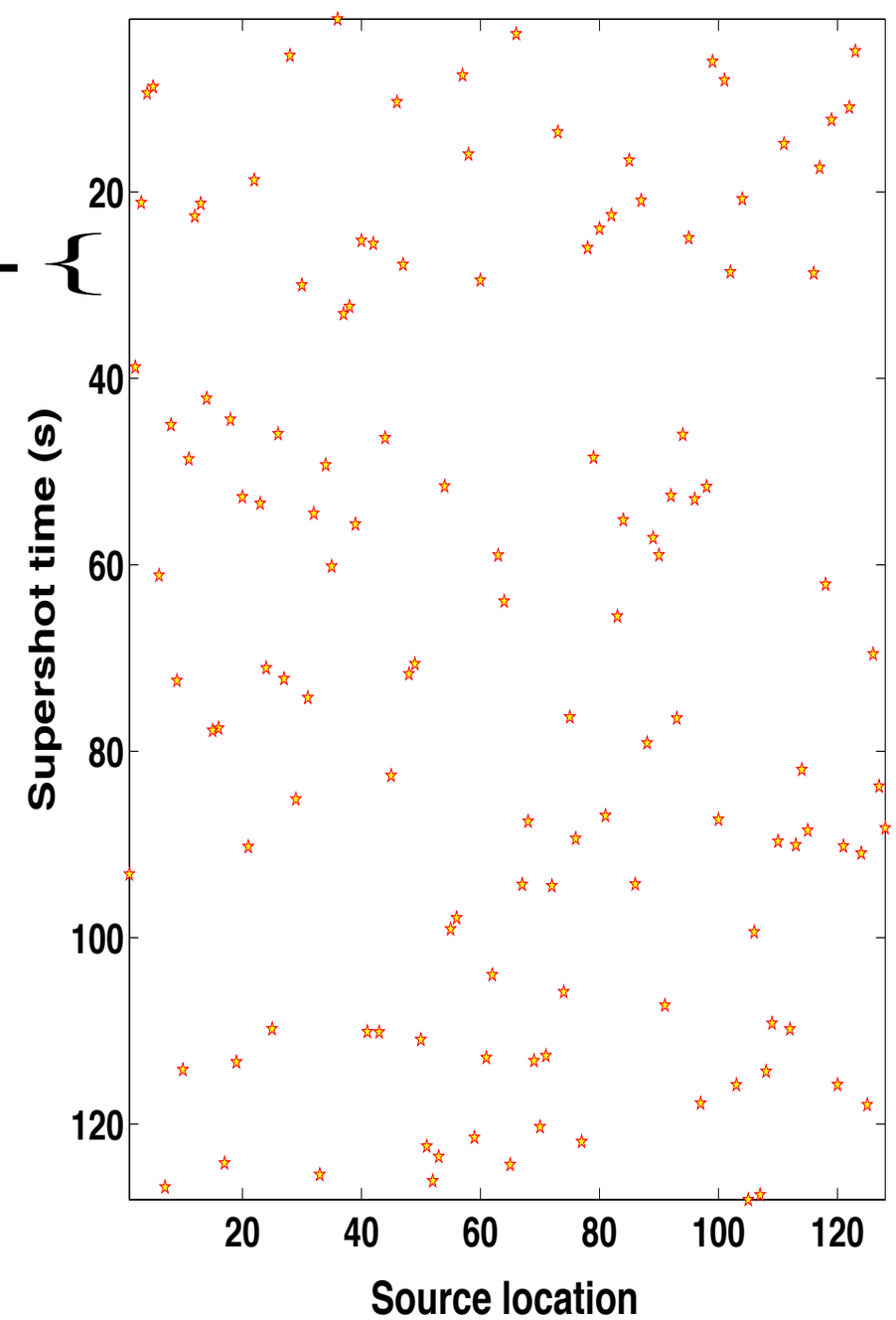
Solve an *underdetermined* system of *linear* equations:



b

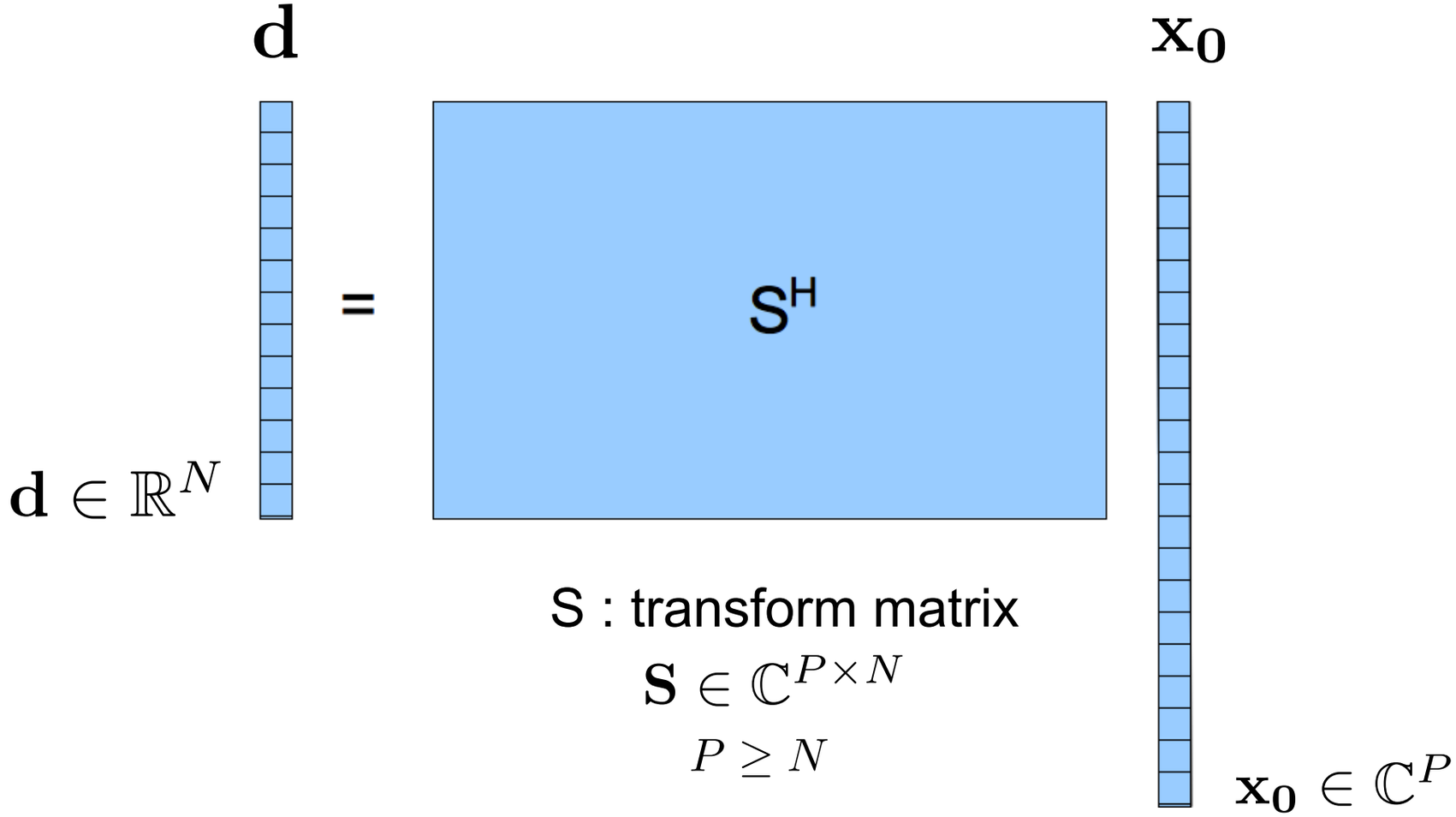
Simultaneous acquisition





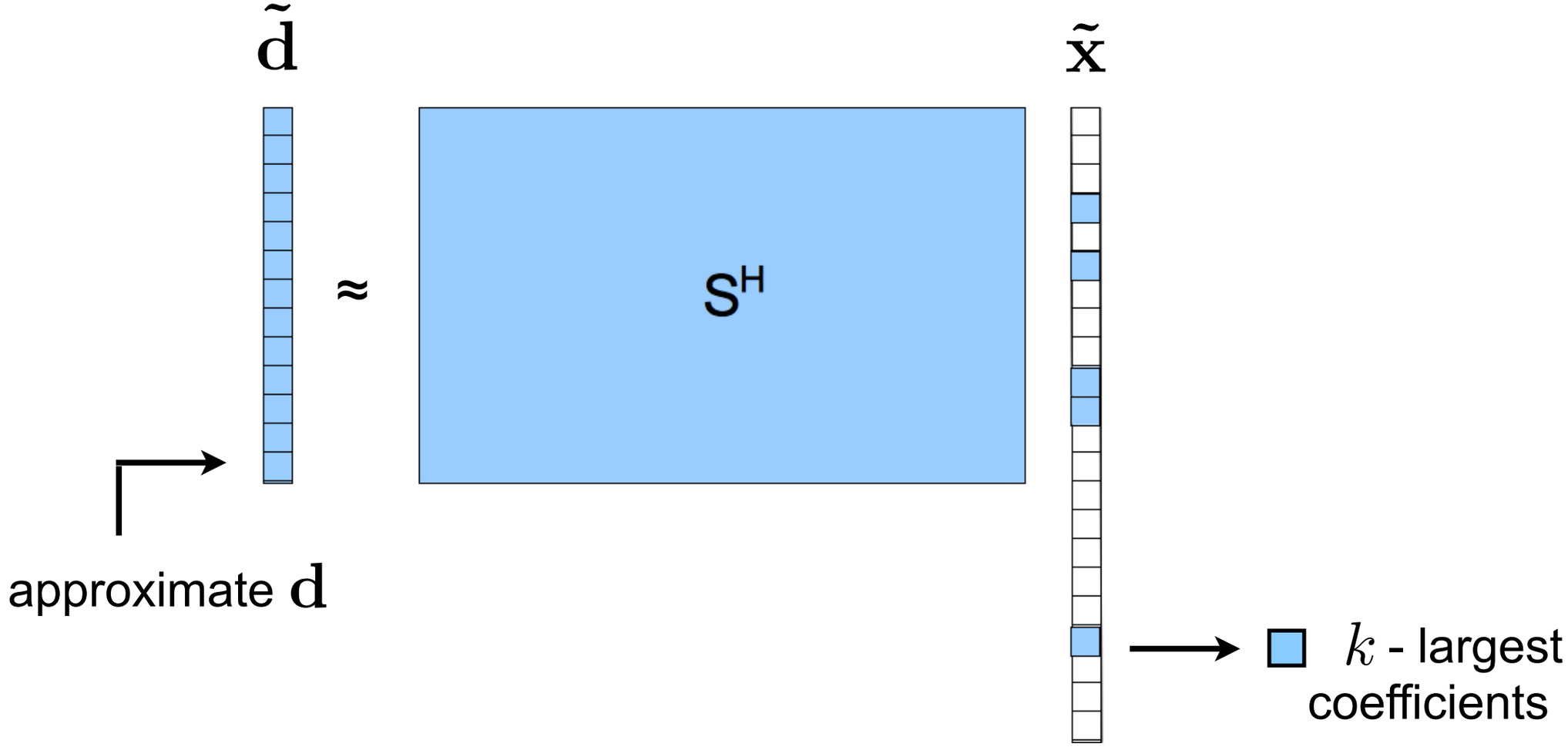
Compressed sensing

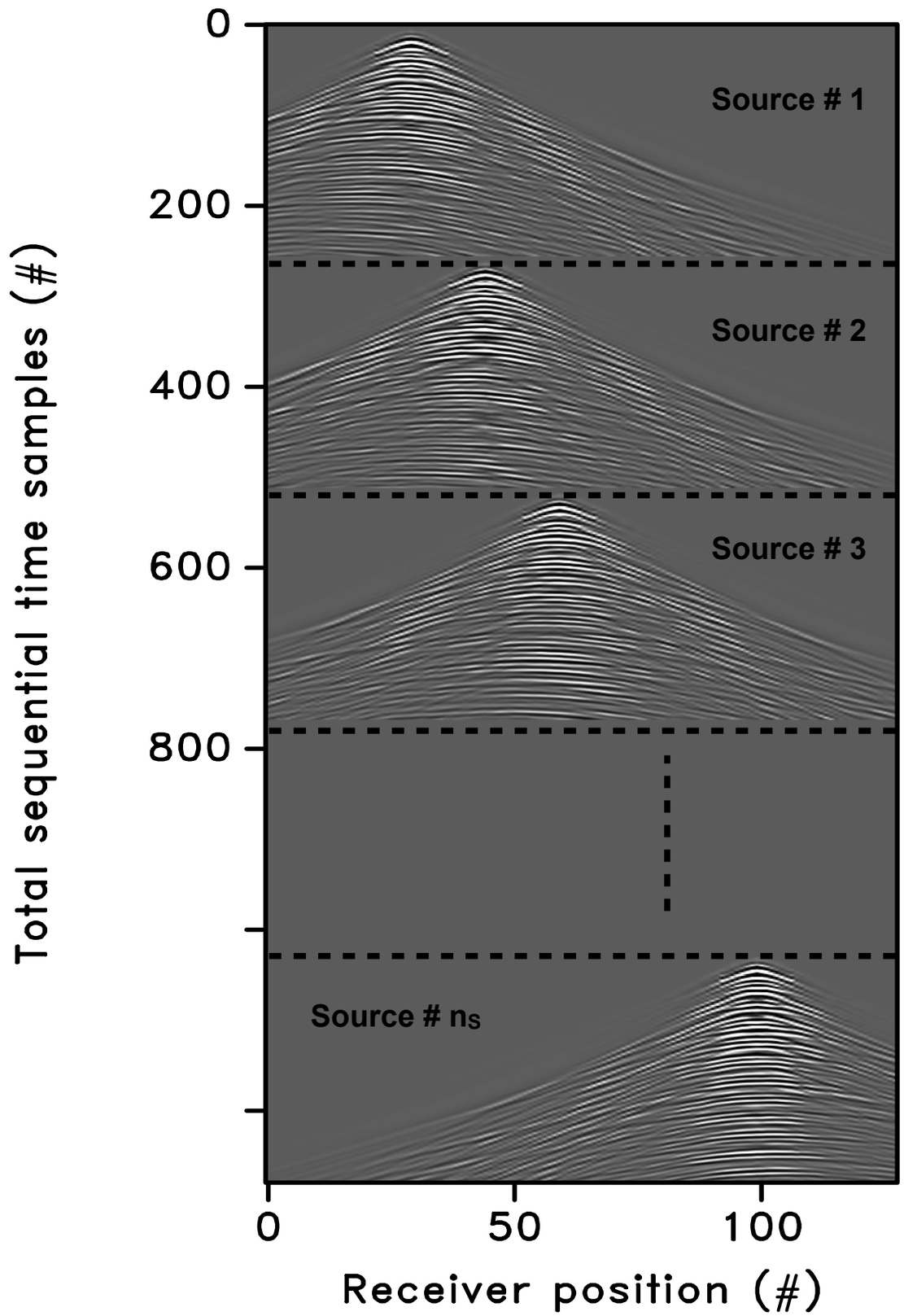
Acquisition paradigm for signals that are *sparse* (or *compressible*) in some transform domain



Compressed sensing

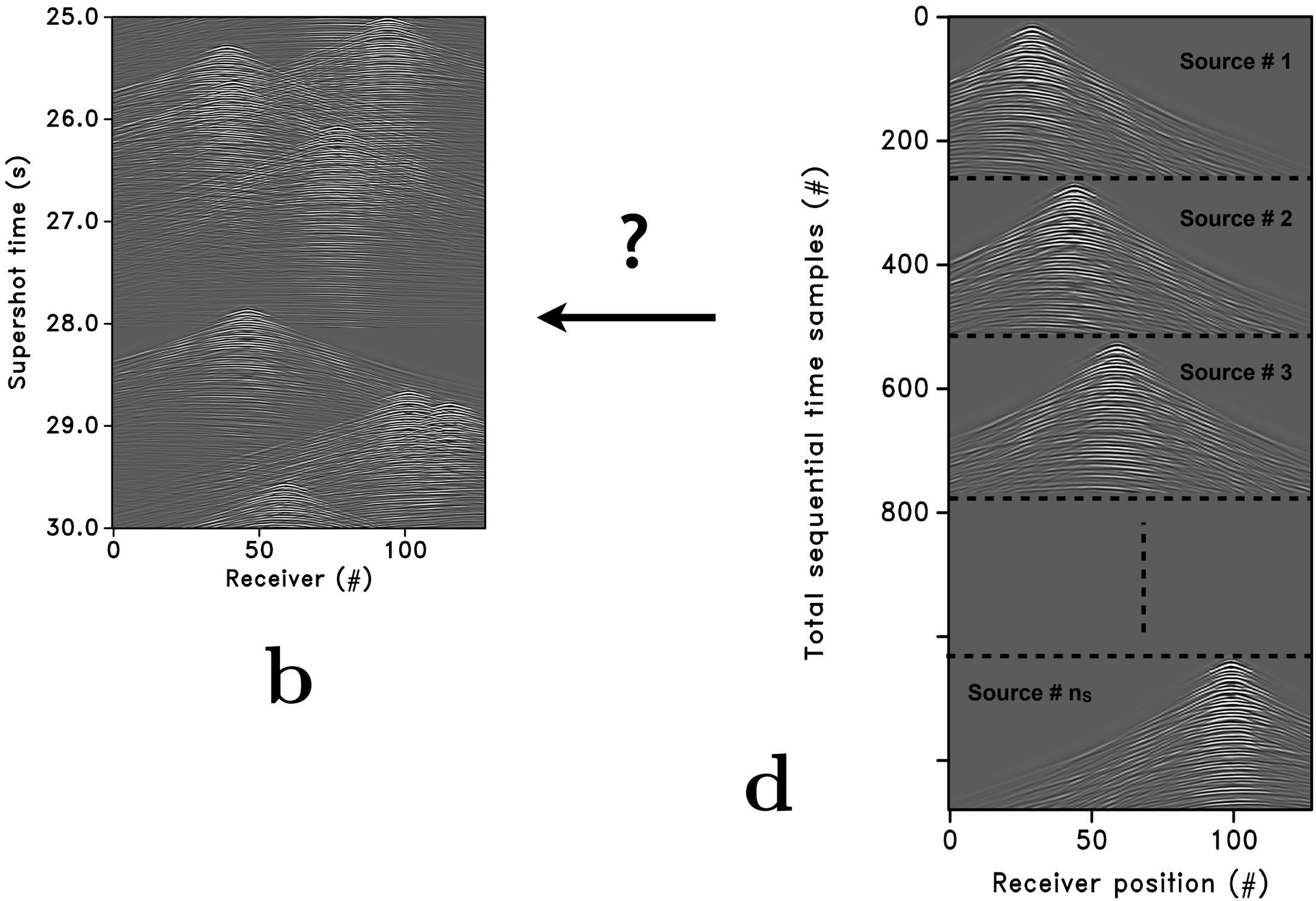
Acquisition paradigm for signals that are *sparse* (or *compressible*) in some transform domain




Source # 1
Source # 2
Source # 3
Source # n_S
0
200
400
600
800
Total sequential time samples (#)
0
50
100
Receiver position (#)

$\mathbf{d}$

Framework


25.0
26.0
27.0
28.0
29.0
30.0
Supershot time (s)
0
50
100
Receiver (#)
b
?
0
200
400
600
800
Total sequential time samples (#)
Source # 1
Source # 2
Source # 3
Source # n_S
d
0
50
100
Receiver position (#)

Framework

$$\mathbf{b} = \boxed{\text{Simultaneous measurement matrix}} \times \mathbf{d}$$

$$\downarrow$$

$$\tilde{\mathbf{d}} \approx \mathbf{S}^{\mathbf{H}}\tilde{\mathbf{x}}$$

$$\downarrow$$

$$\underbrace{\boxed{\text{Simultaneous measurement matrix}} \times \mathbf{S}^{\mathbf{H}}}_{\boxed{\mathbf{A}}}\ \tilde{\mathbf{x}}$$

Sparse recovery

Solve the convex optimization problem (one-norm minimization):

$$\tilde{\mathbf{x}} = \arg\min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{subject to} \quad \underbrace{\mathbf{A}\mathbf{x} = \mathbf{b}}_{\text{data-consistent amplitude recovery}}$$

Sparsity-promoting solver: $\mathbf{SPG}\ell_1$ [van den Berg and Friedlander, 2008]

Recover single-source prestack data volume: $\tilde{\mathbf{d}} = \mathbf{S}^{\mathbf{H}}\tilde{\mathbf{x}}$

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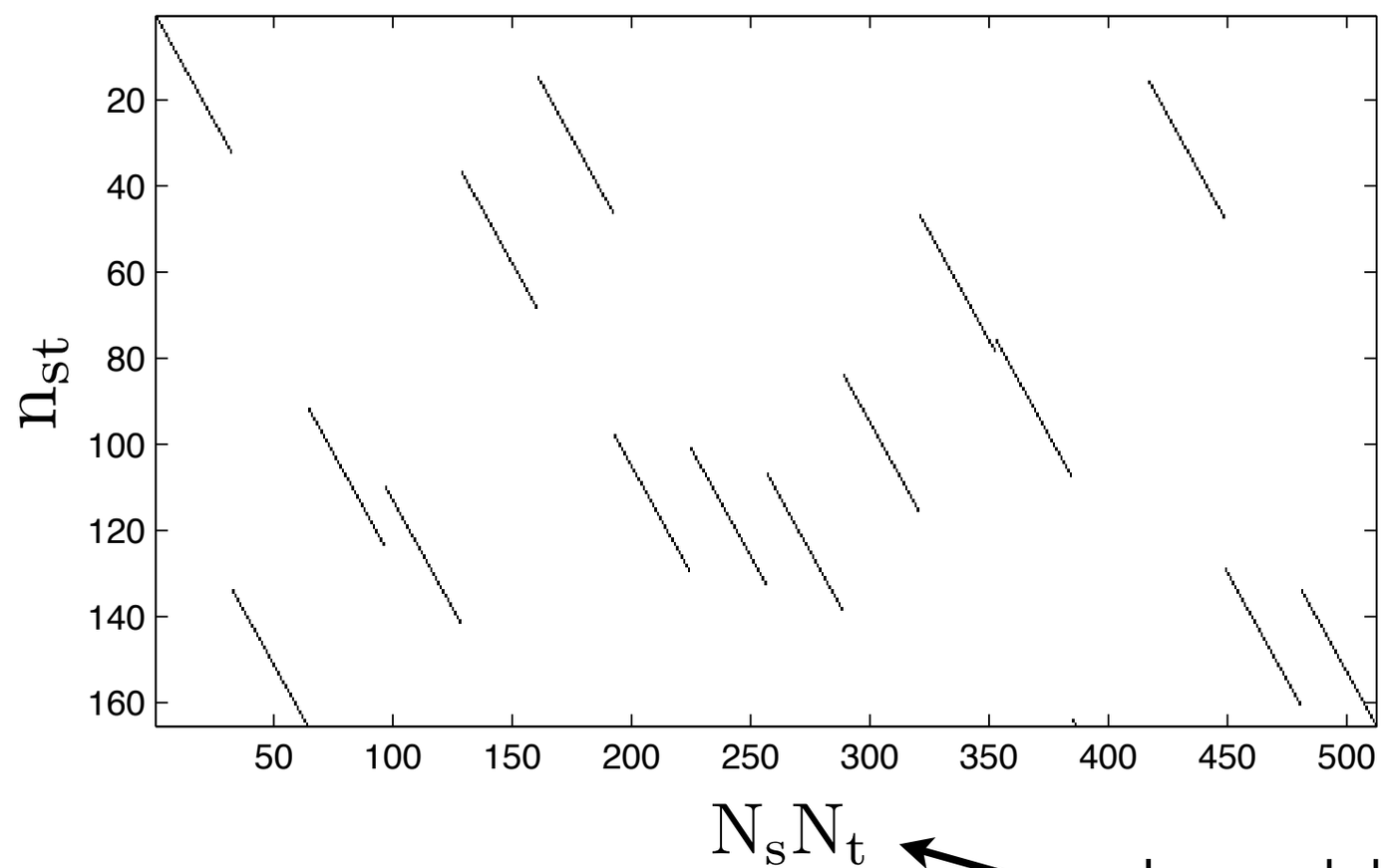
  - "without" simultaneous sources
  - with simultaneous sources

"Ideal" simultaneous acquisition matrix

For a seismic line with N_s sources, N_r receivers, and N_t time samples, the sampling matrix is

$$\mathbf{RM}$$



samples recorded at each receiver during simultaneous acquisition

samples recorded at each receiver during sequential acquisition

[Mansour et.al., 2011]

Framework

$$\mathbf{b} = \boxed{\mathbf{RM}} \times \mathbf{d}$$

$$\downarrow$$

$$\tilde{\mathbf{d}} \approx \mathbf{S}^{\mathbf{H}}\tilde{\mathbf{x}}$$

$$\downarrow$$

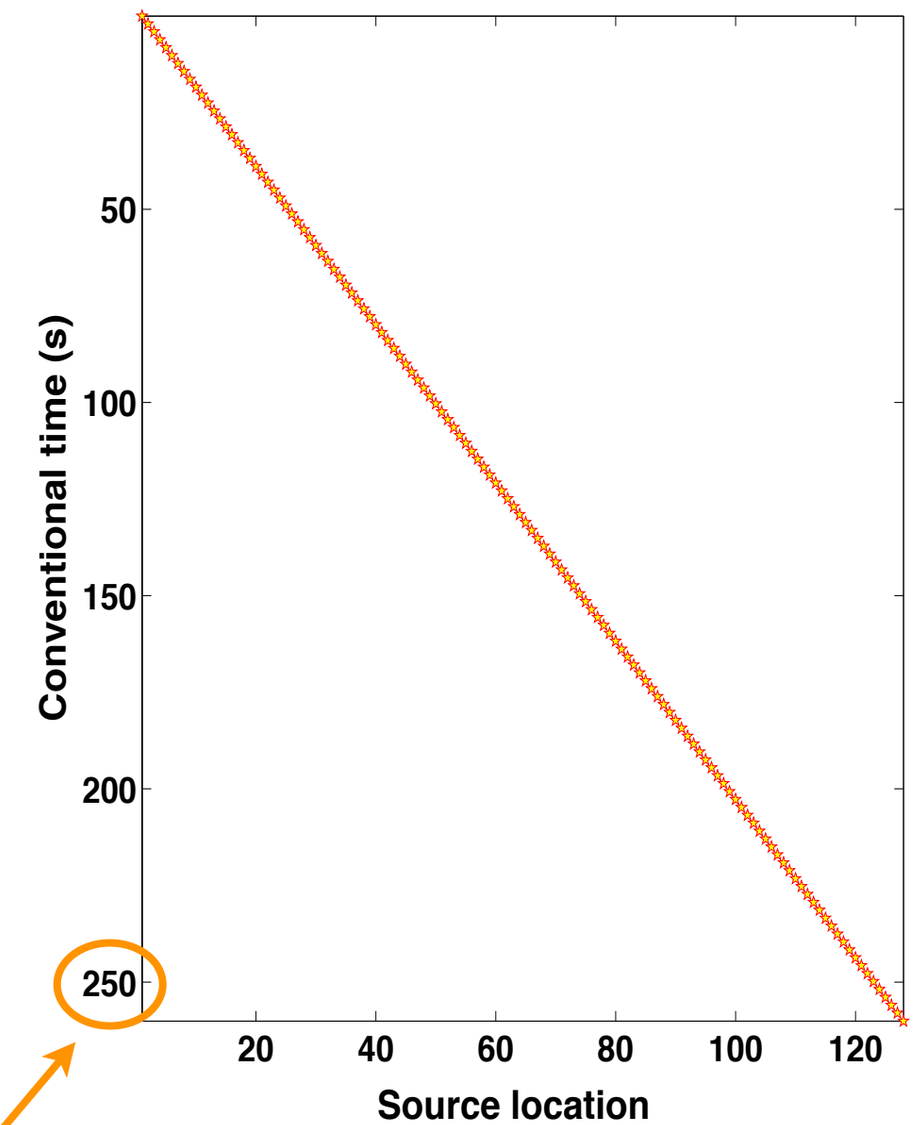
$$\underbrace{\boxed{\mathbf{RM}} \times \mathbf{S}^{\mathbf{H}}\tilde{\mathbf{x}}}$$

$$\boxed{\mathbf{A}} \quad \tilde{\mathbf{x}}$$

Compressive sampling matrix $\longleftarrow$ $\mathbf{A}$

Sequential vs. simultaneous sources

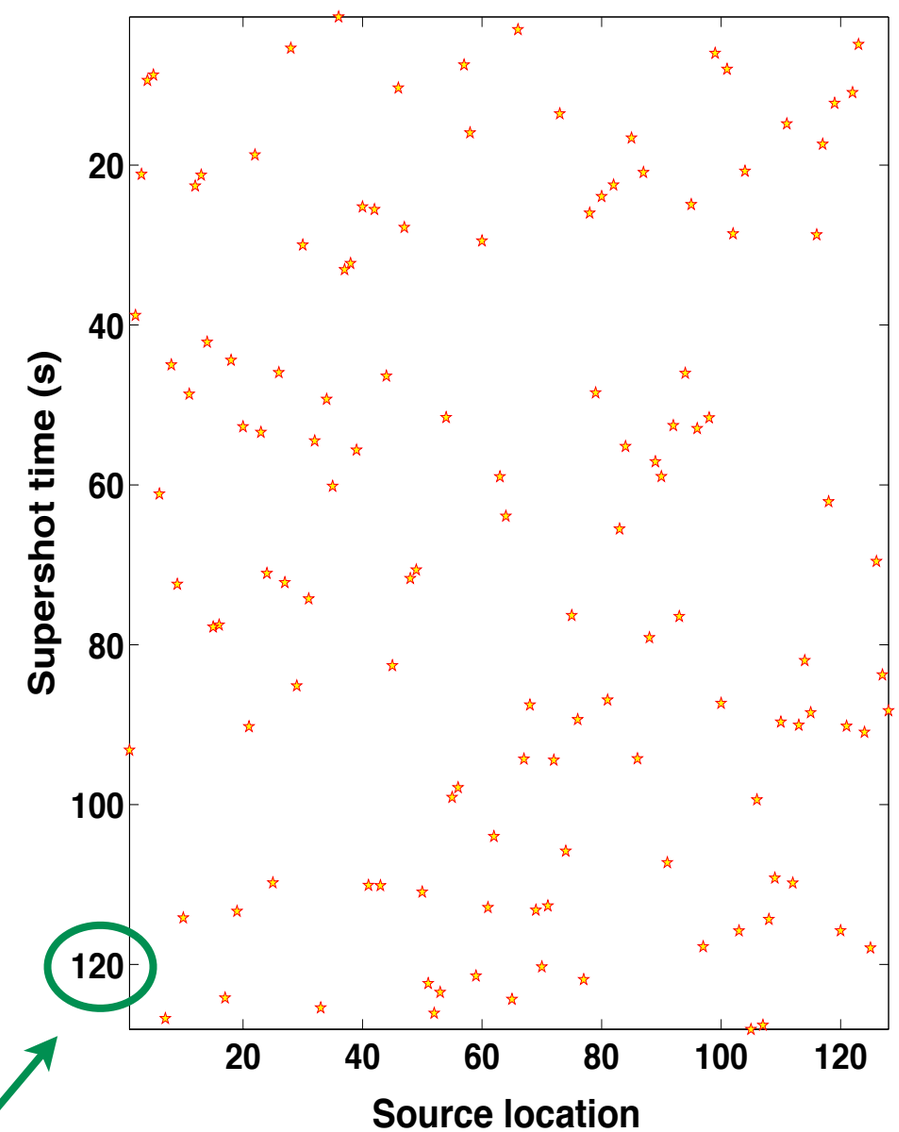
Conventional sequential acquisition



Conventional survey time:

$$t = N_s \times N_t$$

"Ideal" simultaneous acquisition

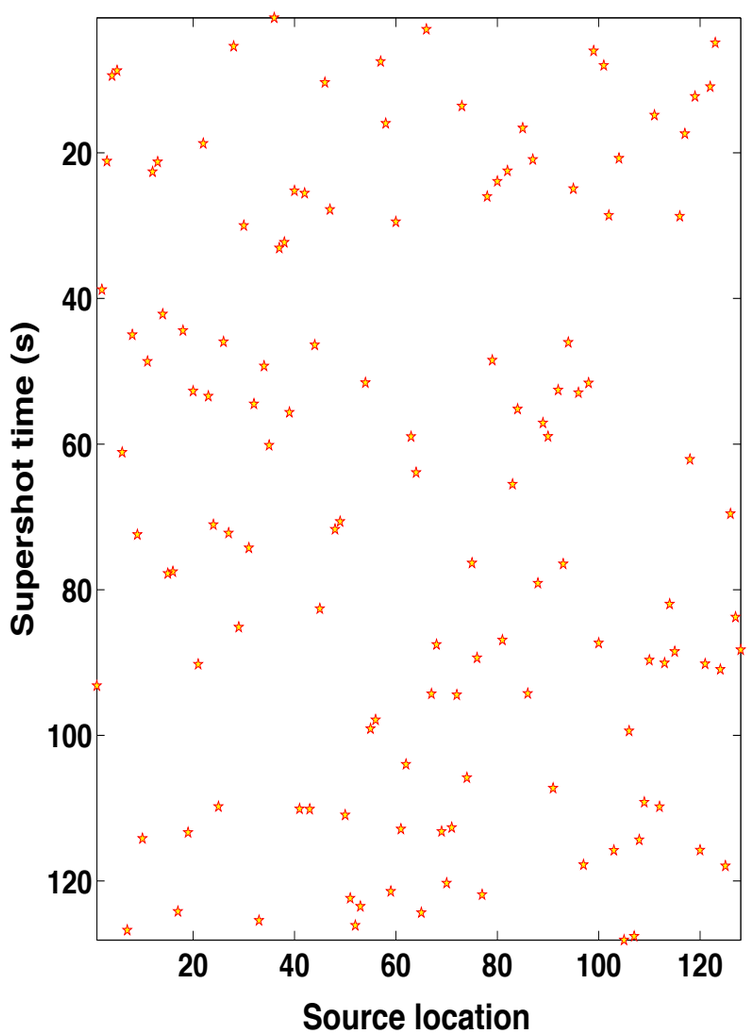


Theoretical survey time:

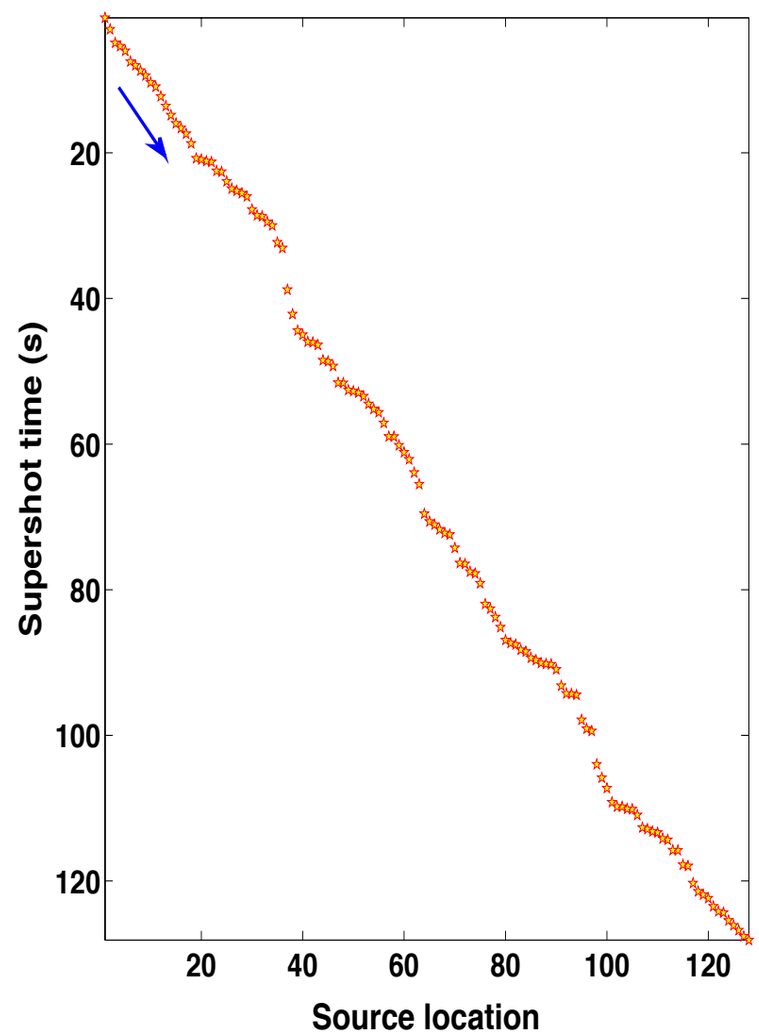
$$t = n_{st} \ll n_s \times N_t$$

Sampling schemes

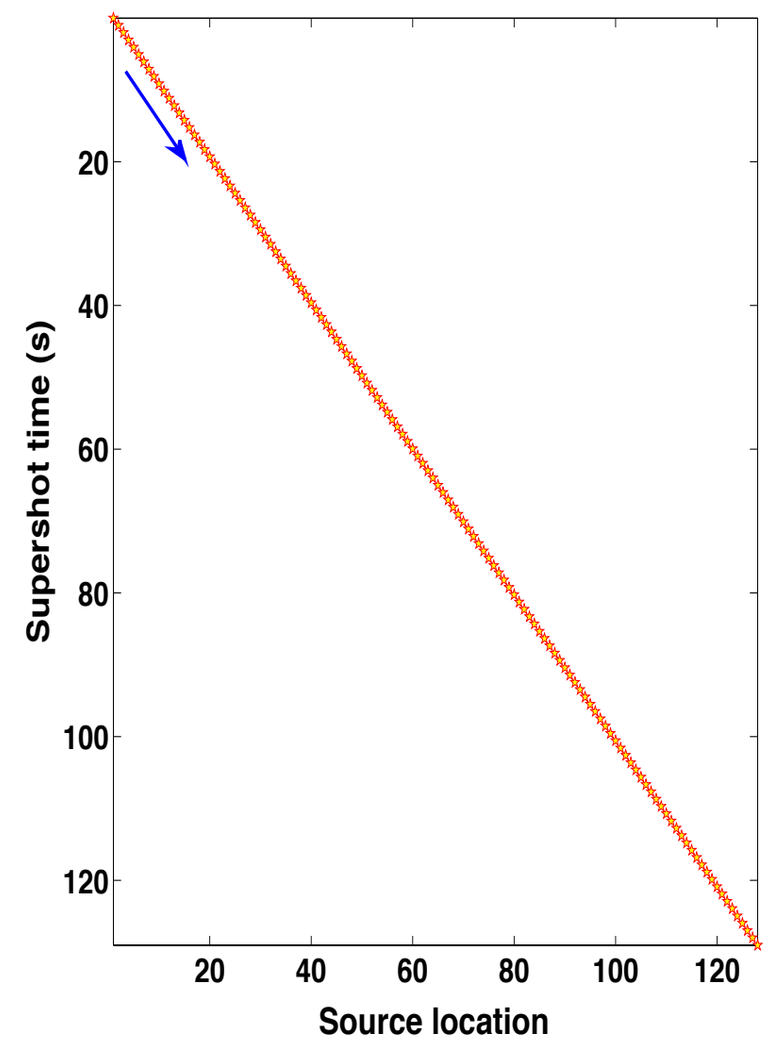
"Ideal" simultaneous acquisition



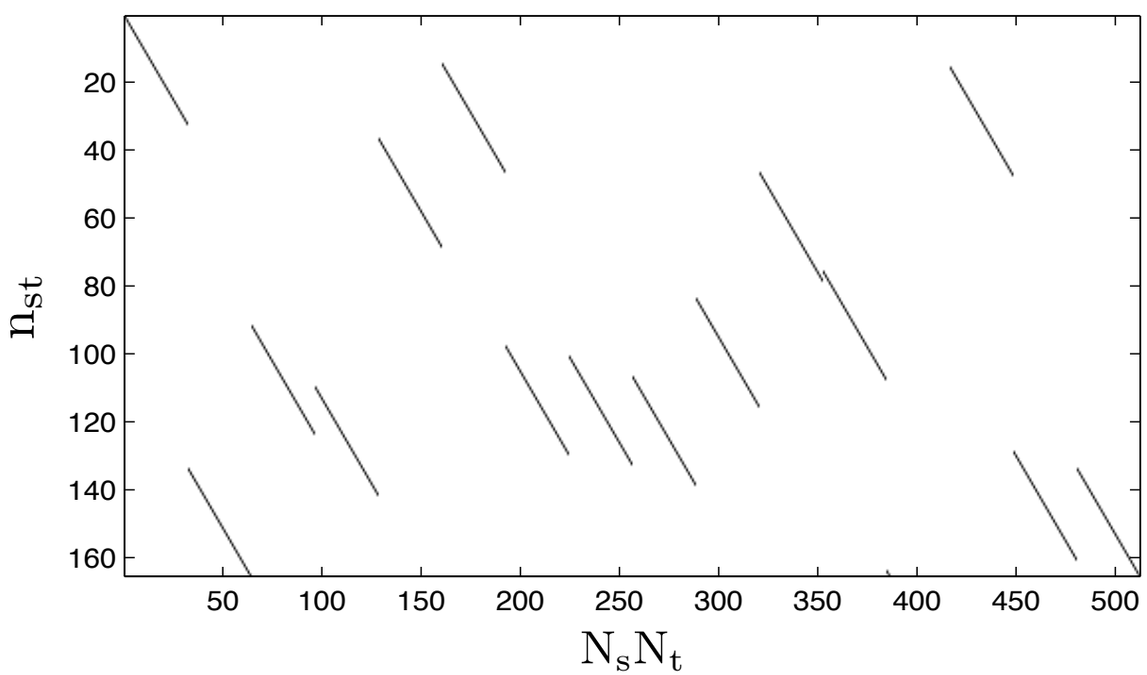
Random time-dithering



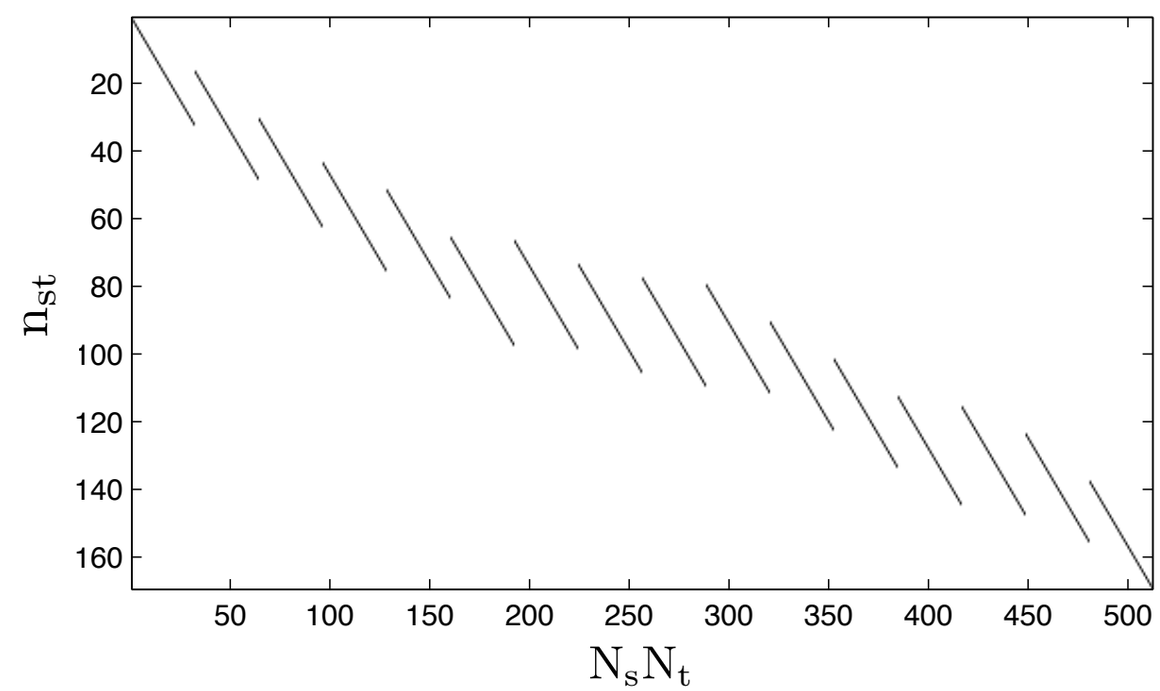
Periodic time-dithering



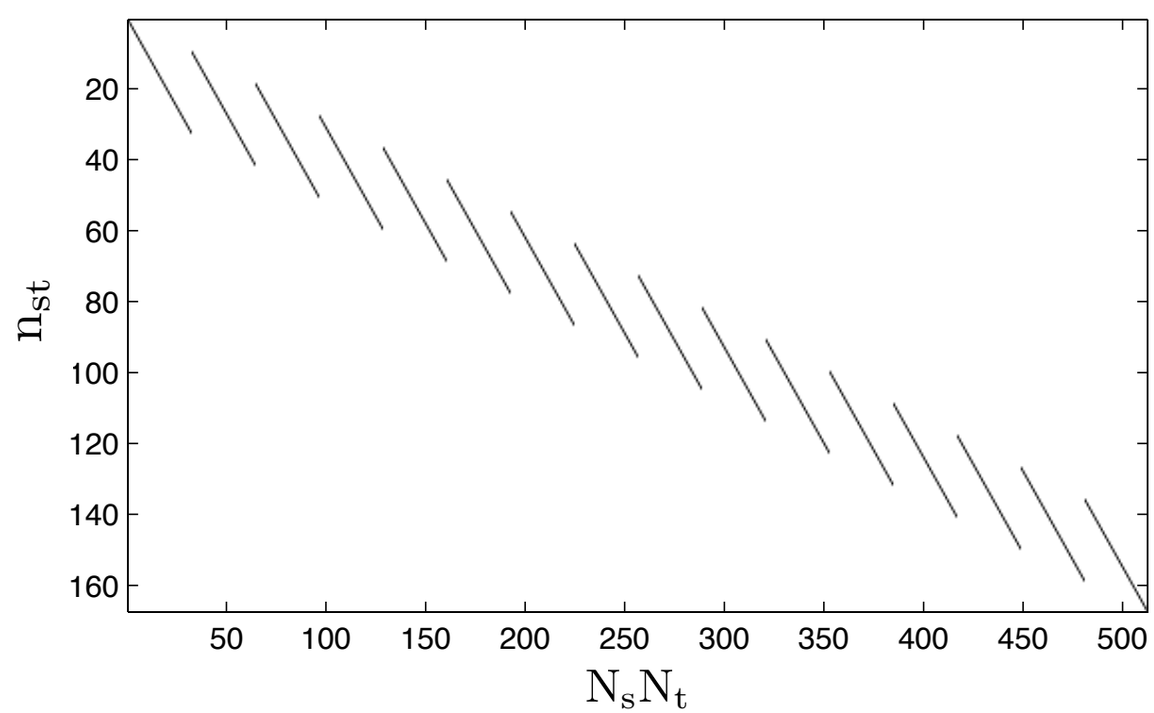
Sampling matrix (RM)



"Ideal" simultaneous acquisition

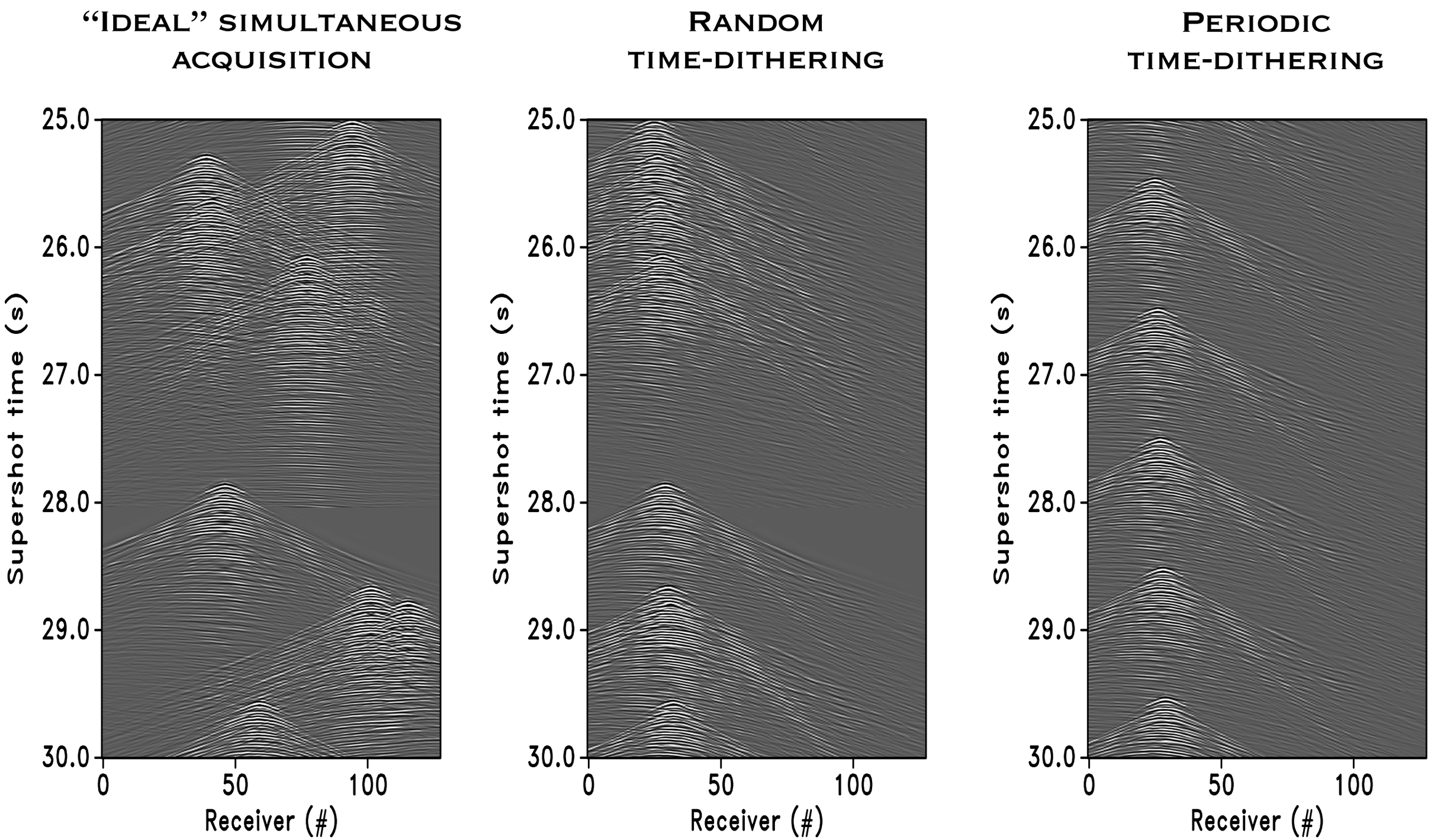


Random time-dithering



Periodic time-dithering

Measurements (b)



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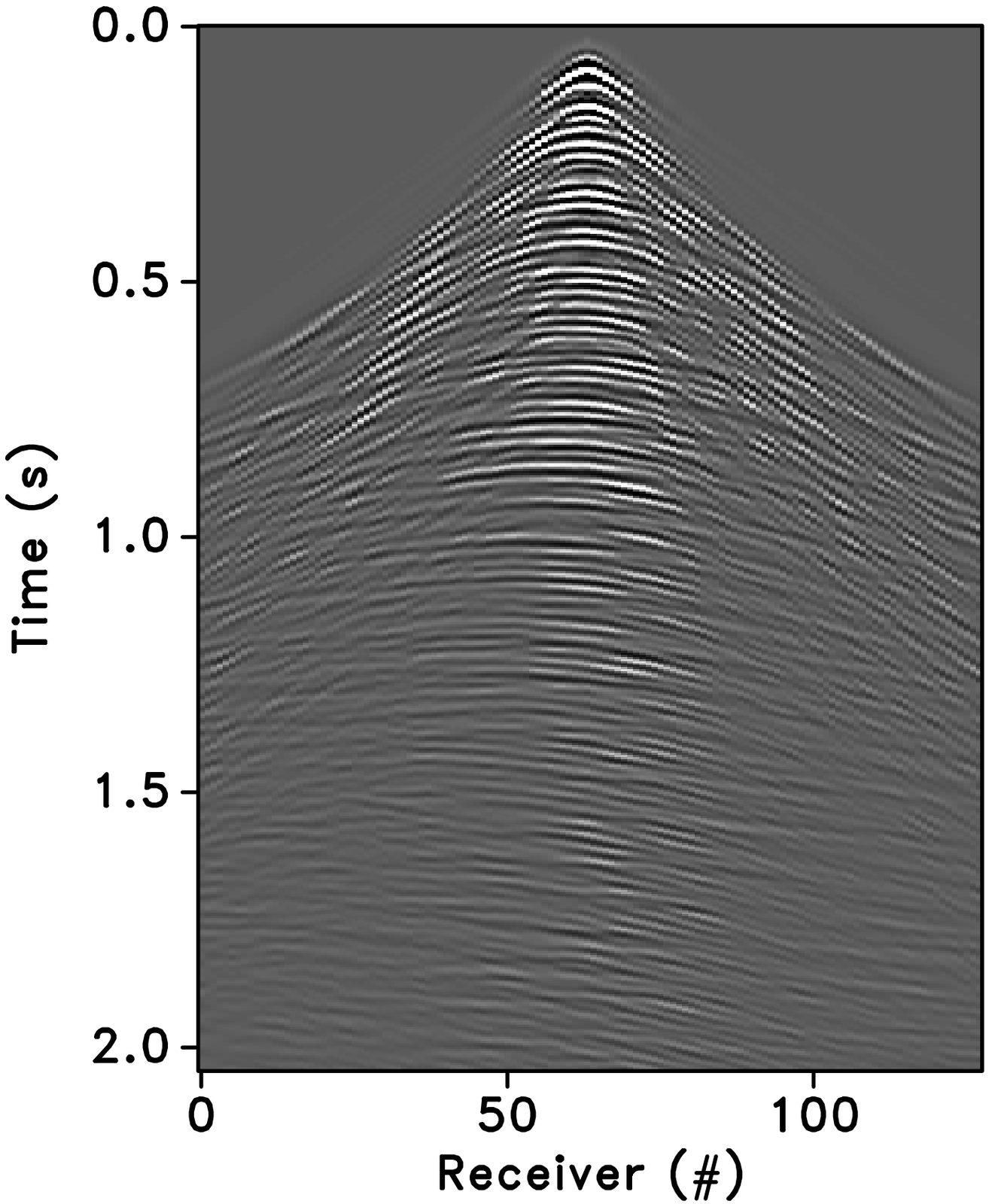
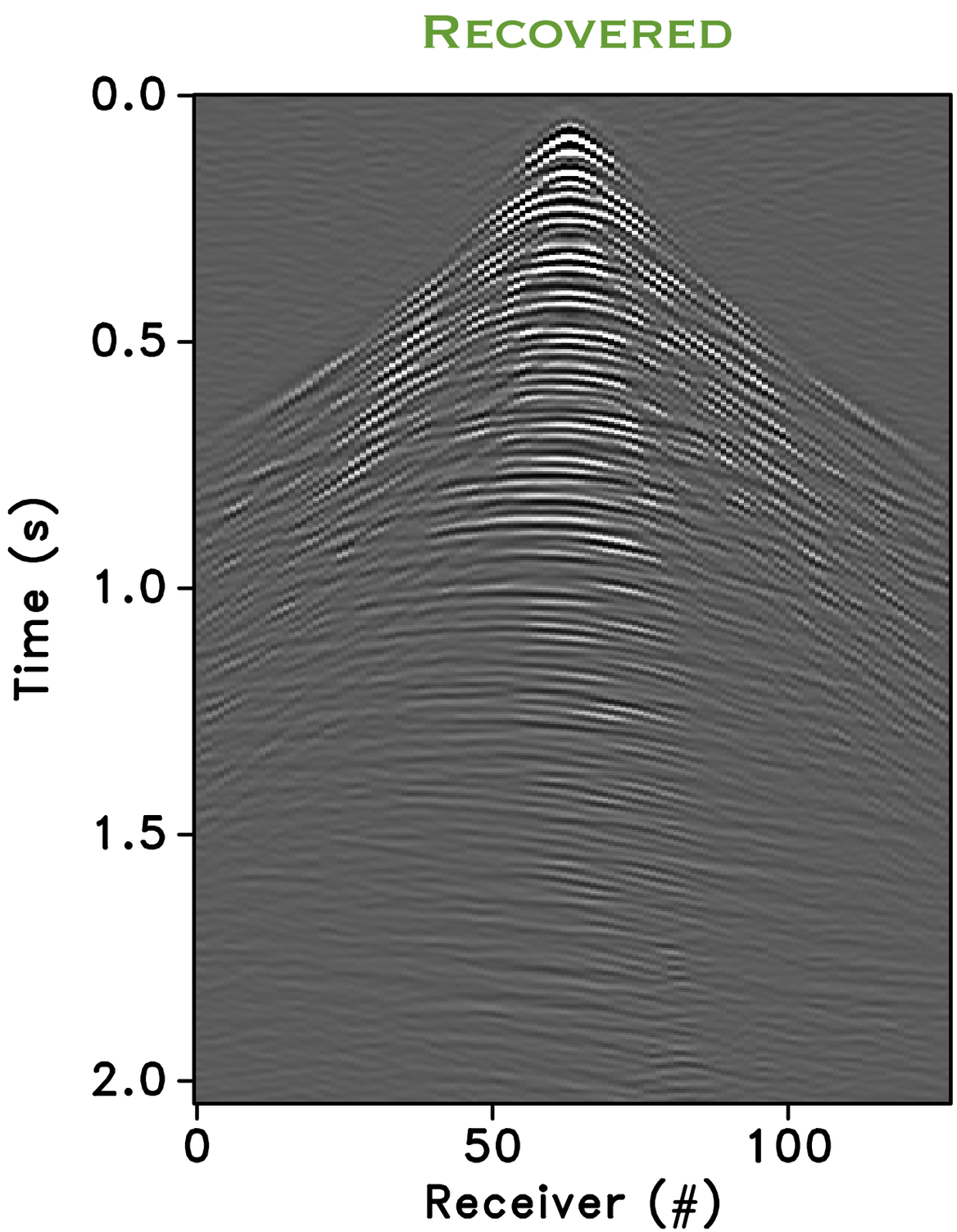
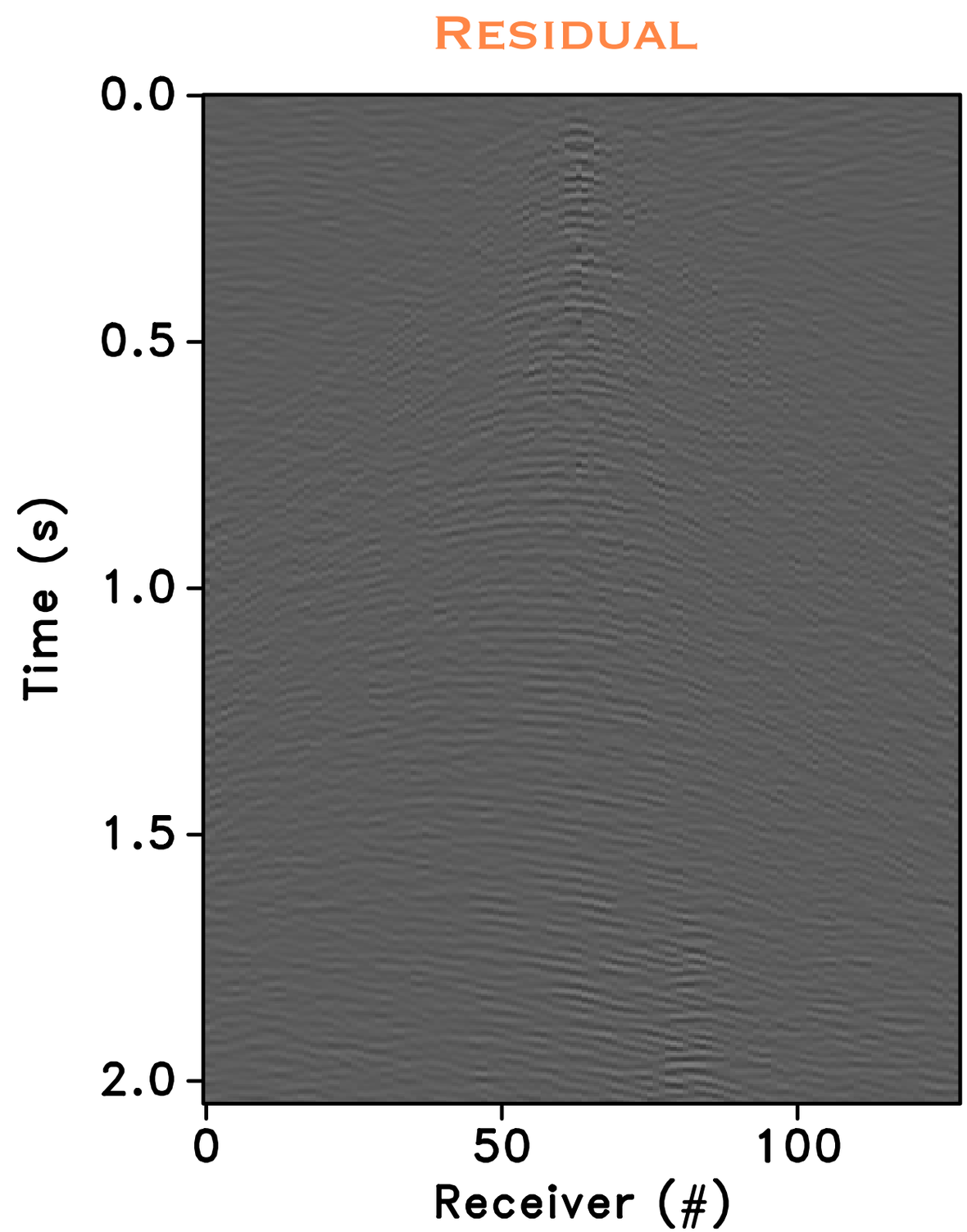


Gulf of Suez
(shot gather)

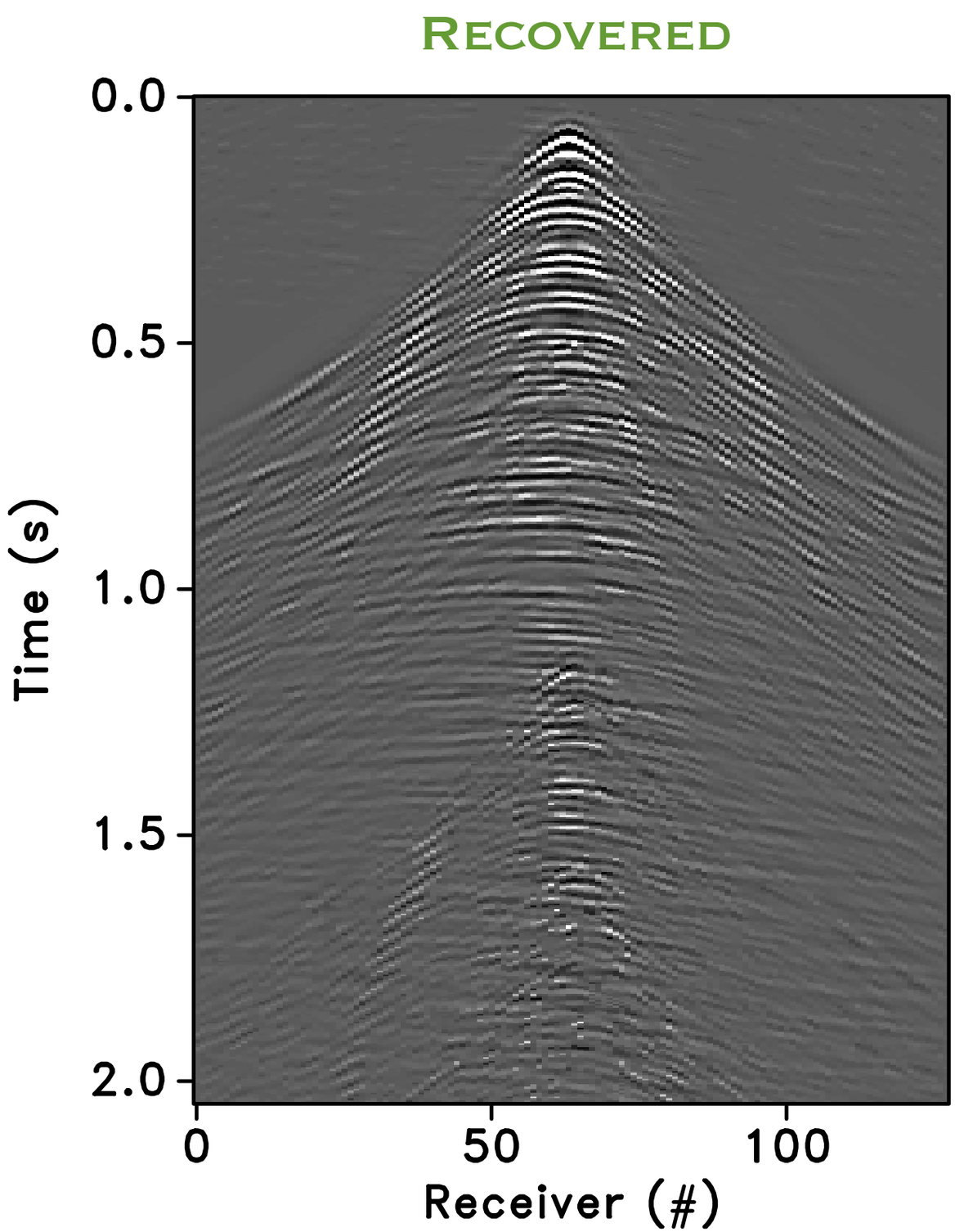
512 time samples
128 receivers
128 sources

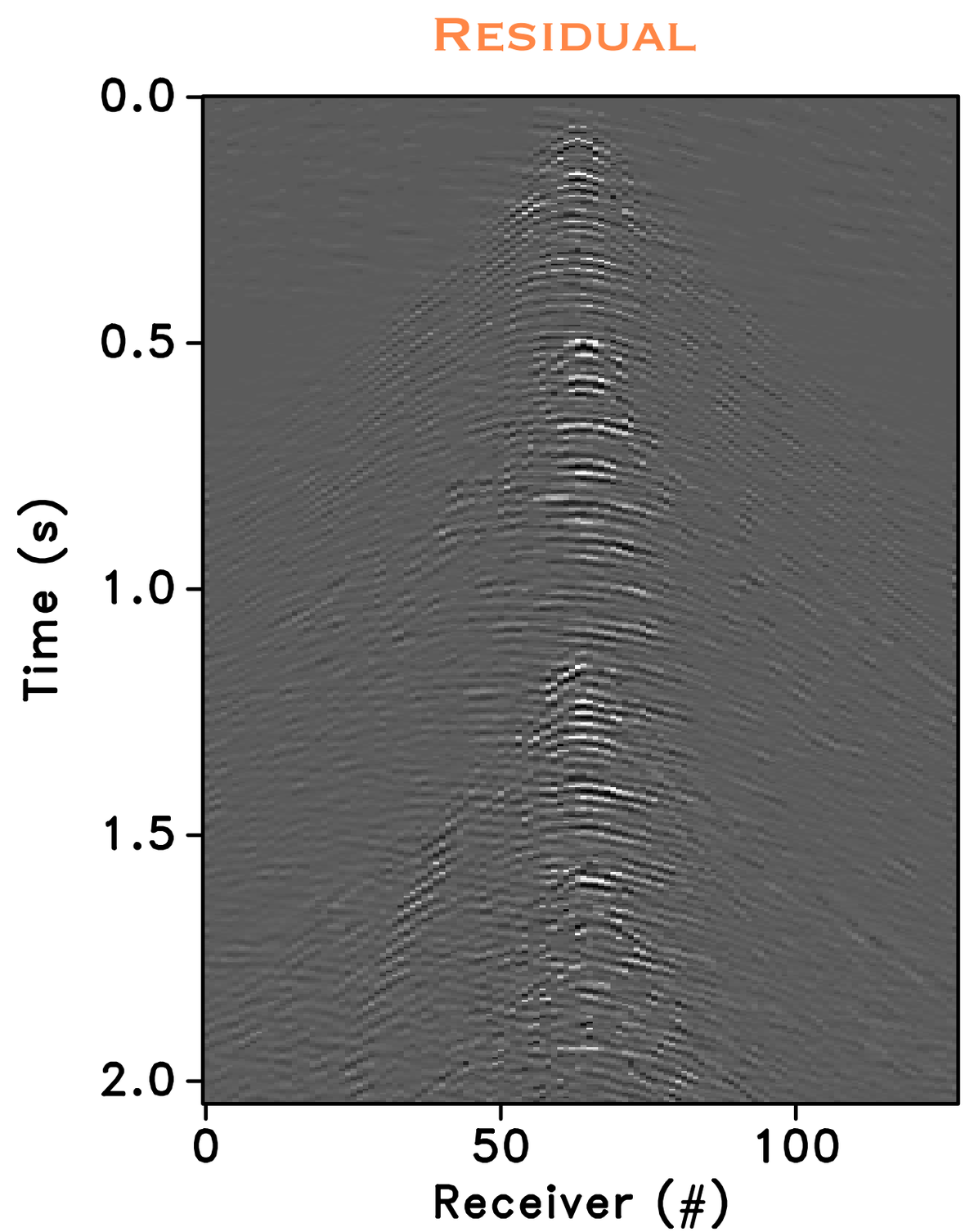
"Ideal" simultaneous acquisition
Sparsity-promoting recovery : 10.5 dB



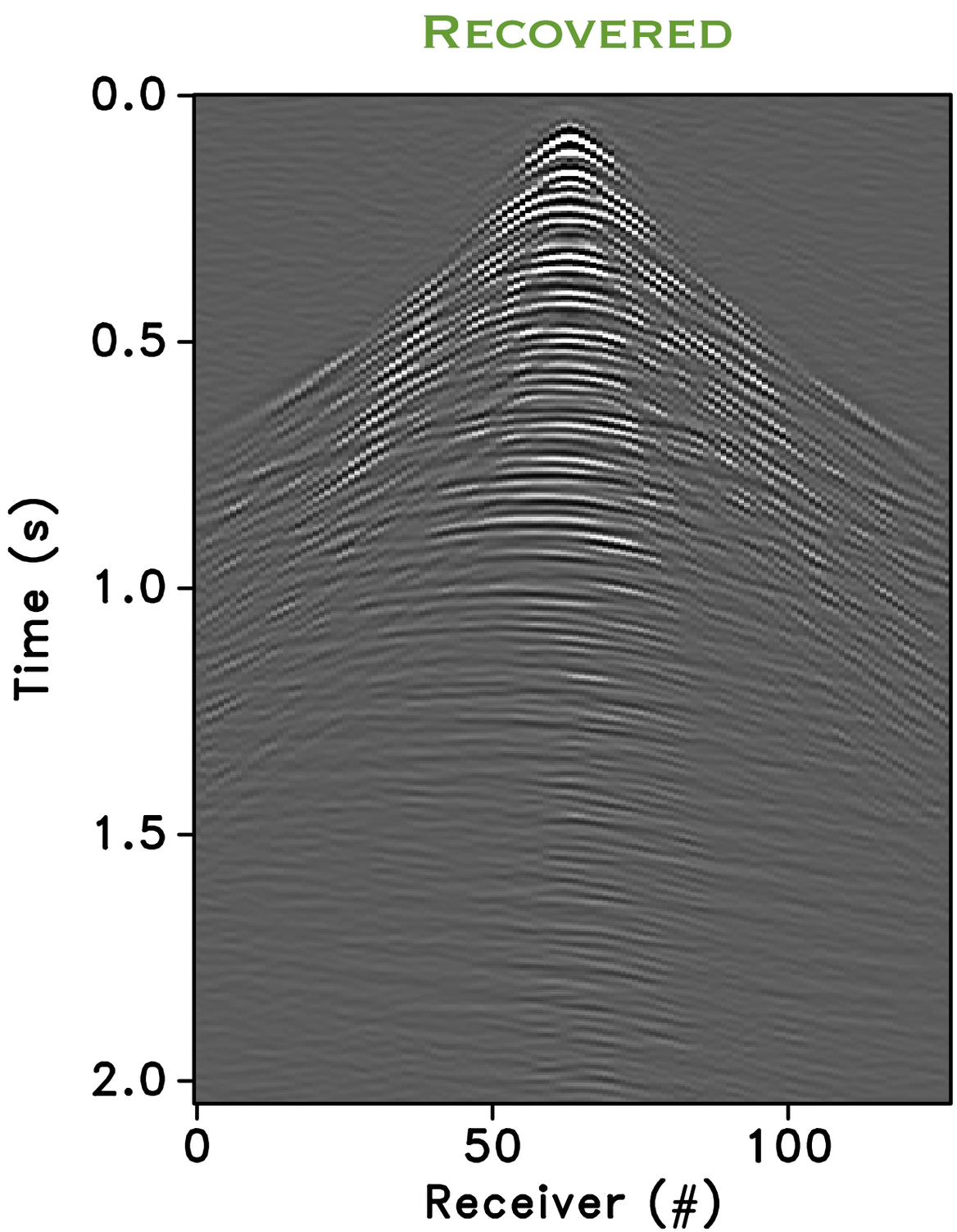


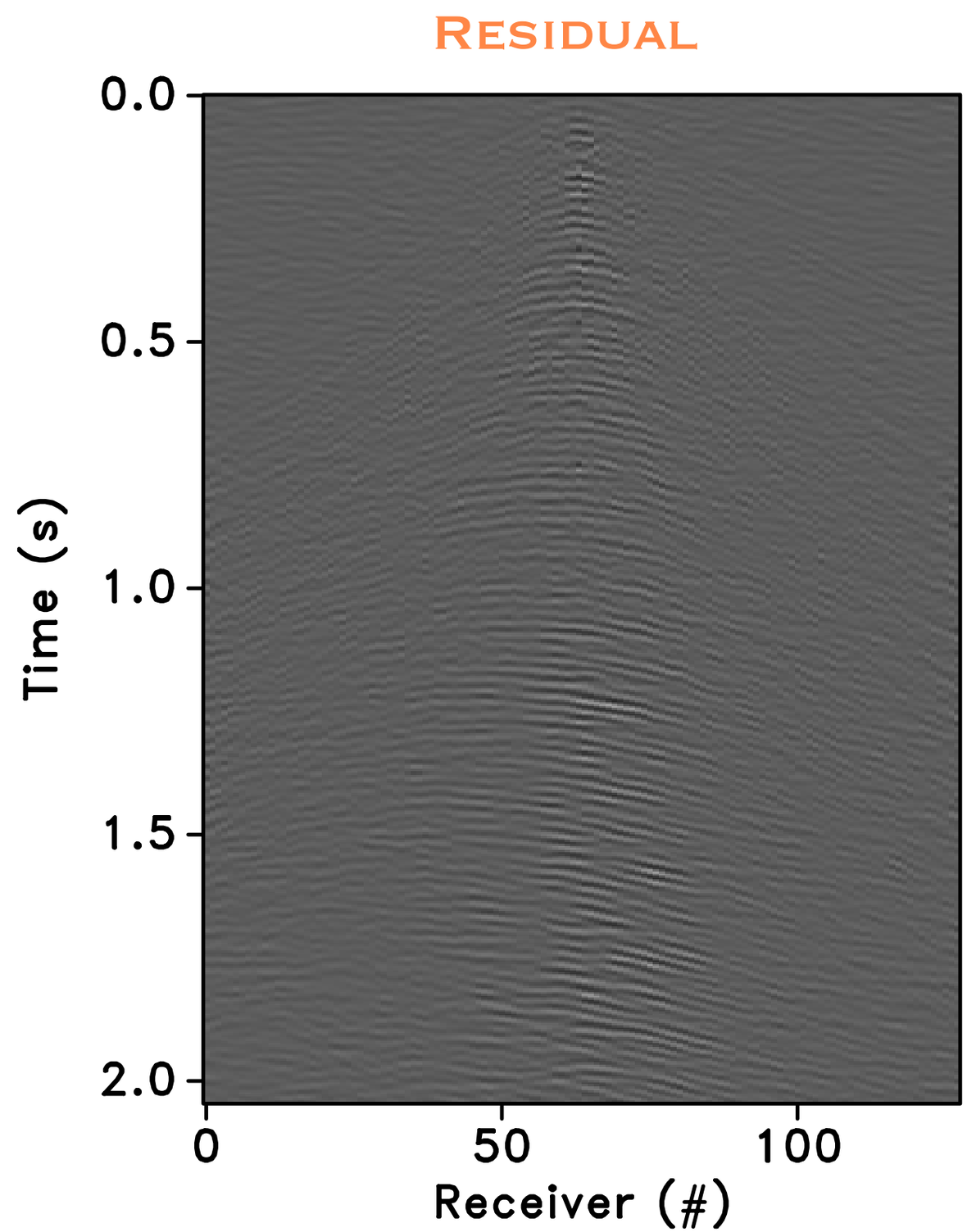
Random time-dithering
Conventional recovery : 3.92 dB



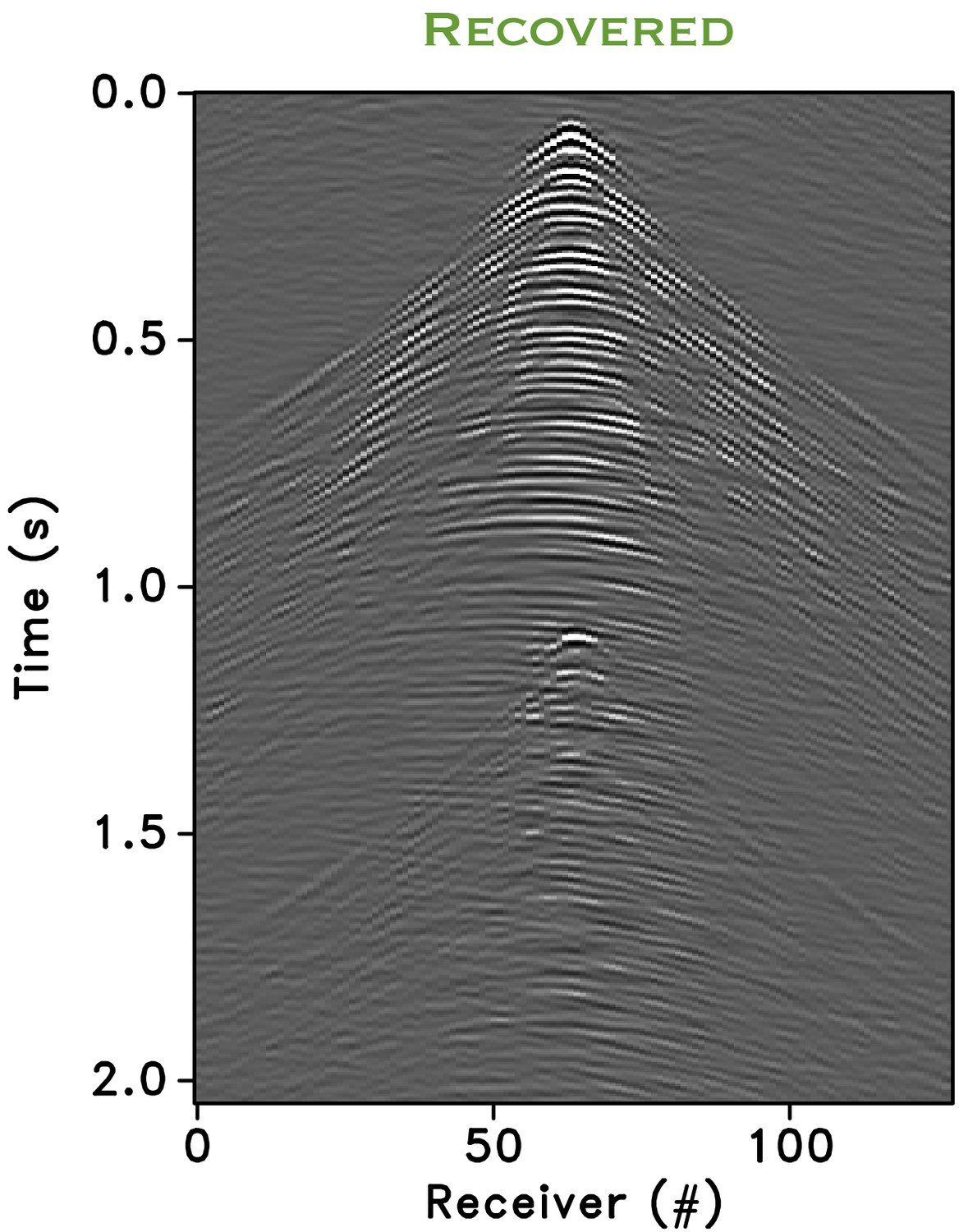


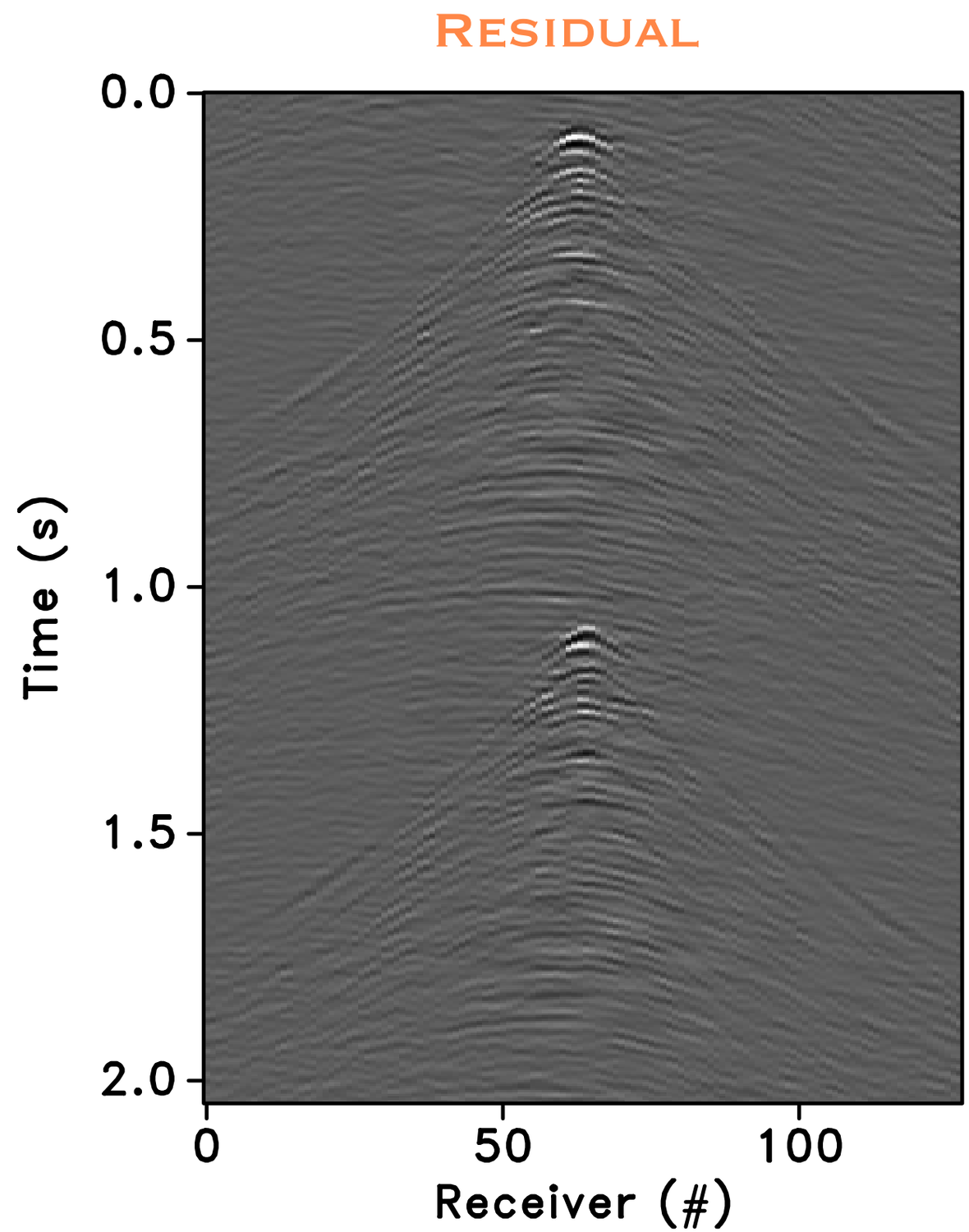
Random time-dithering
Sparsity-promoting recovery : 8.06 dB



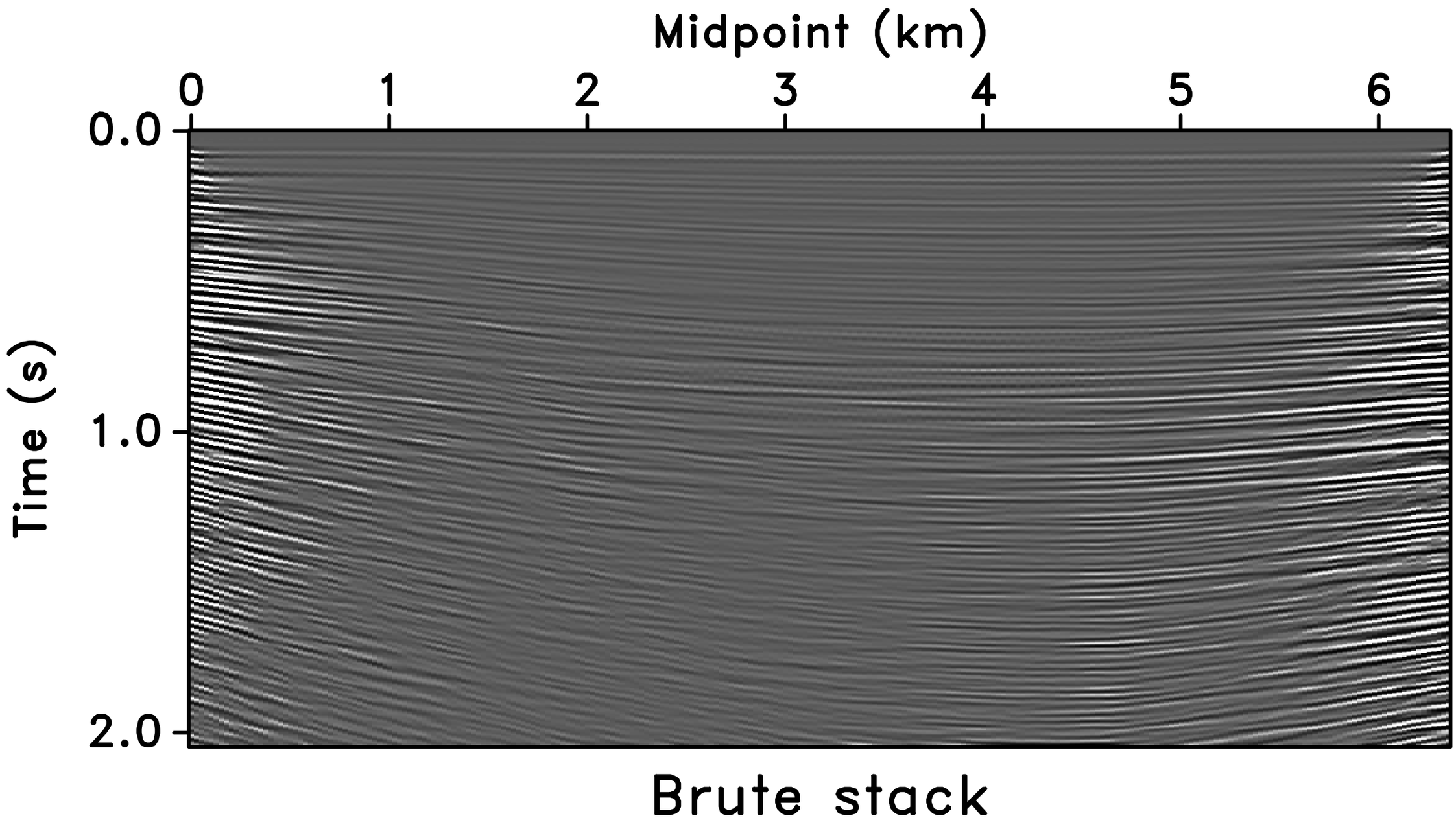


Periodic time-dithering
Sparsity-promoting recovery : 4.80 dB

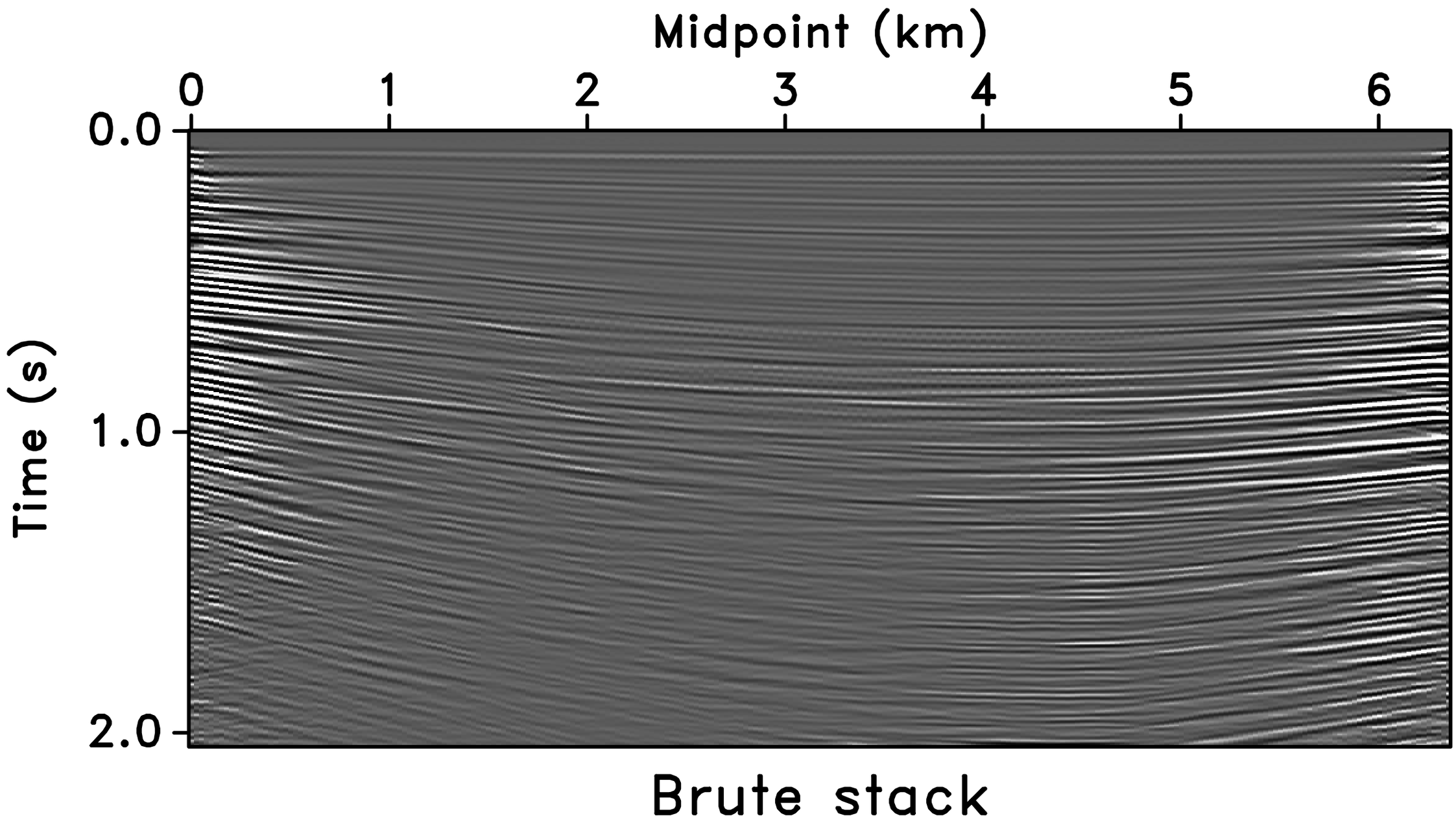




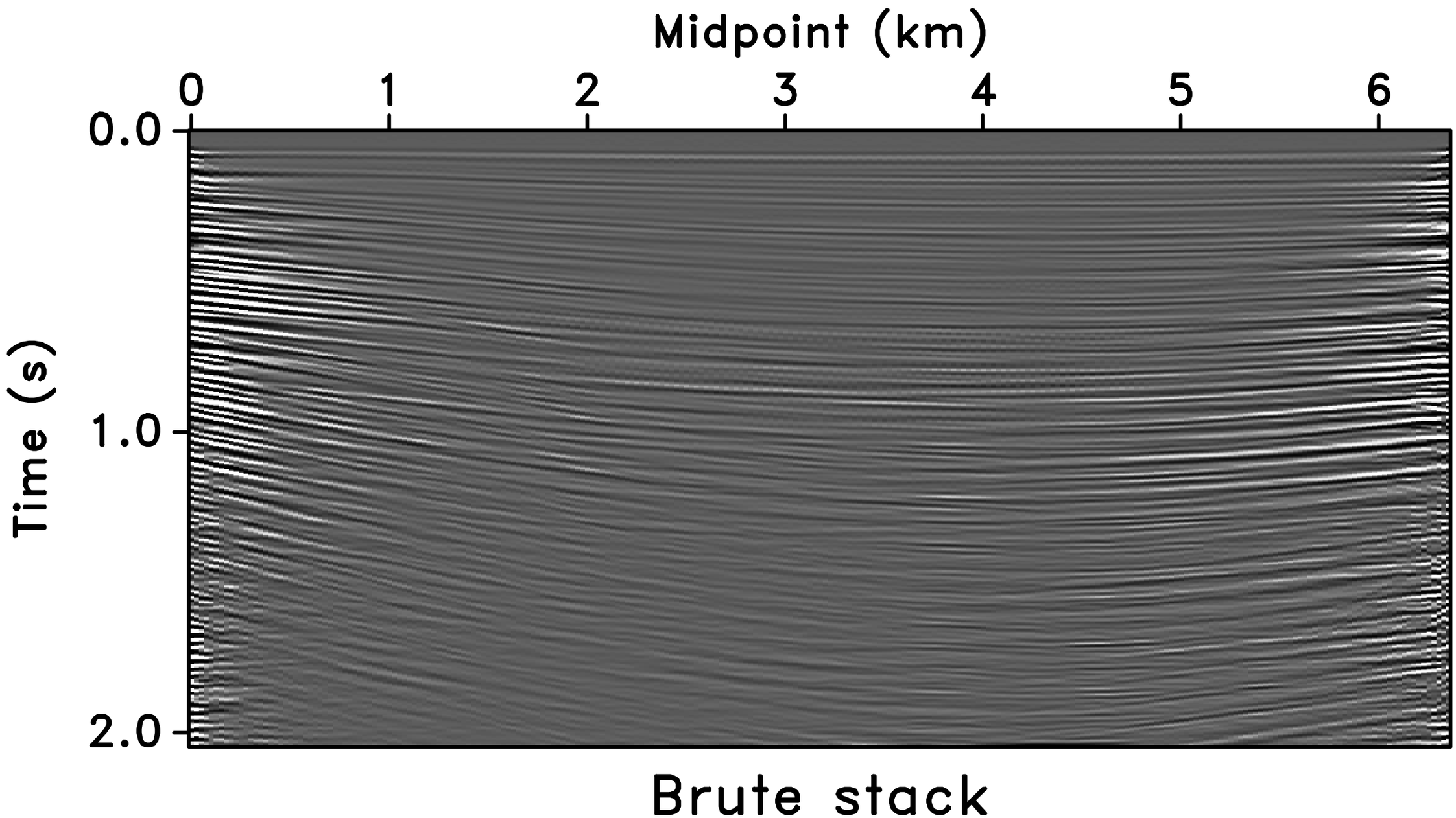
True data



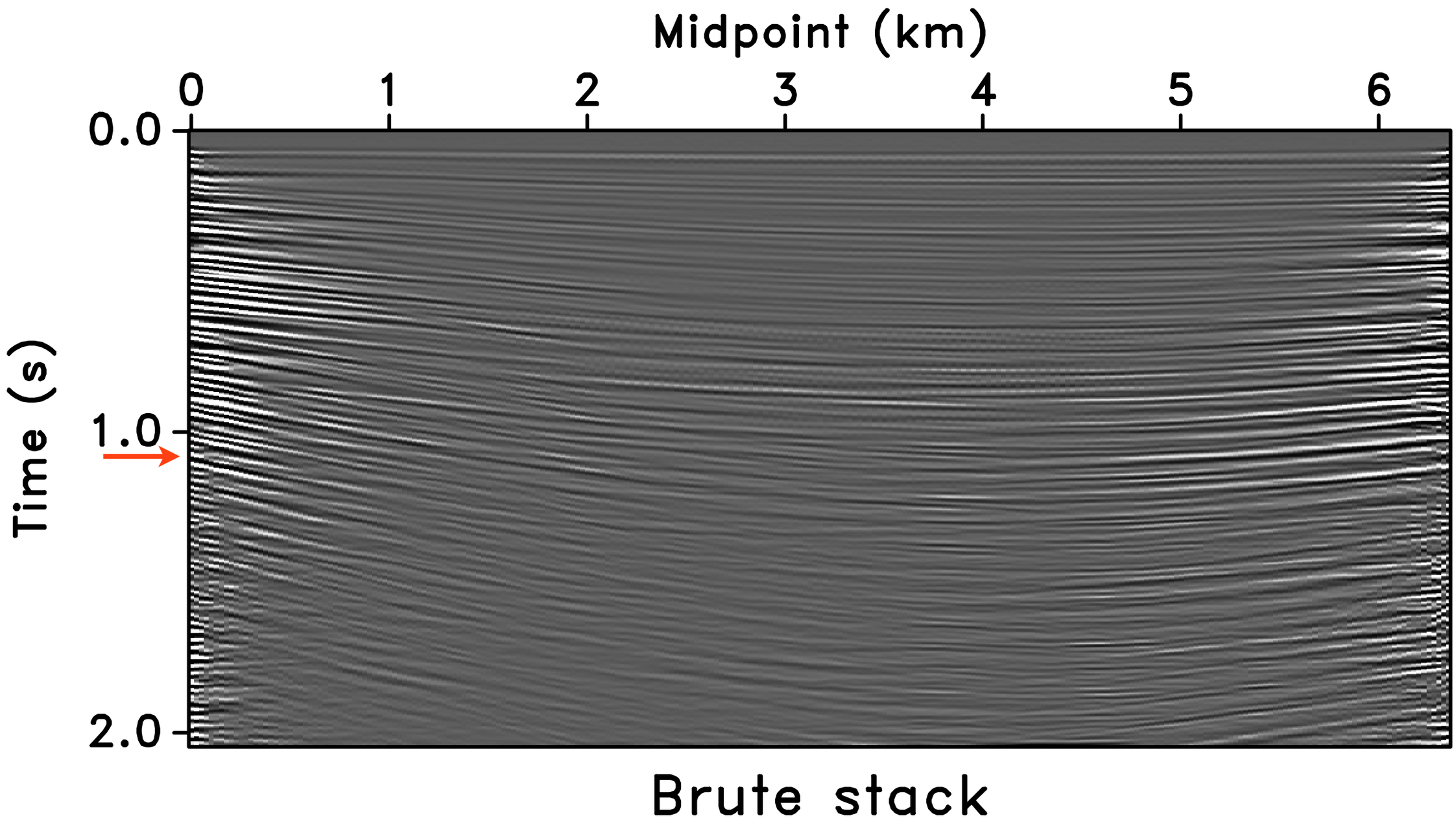
“Ideal” simultaneous acquisition



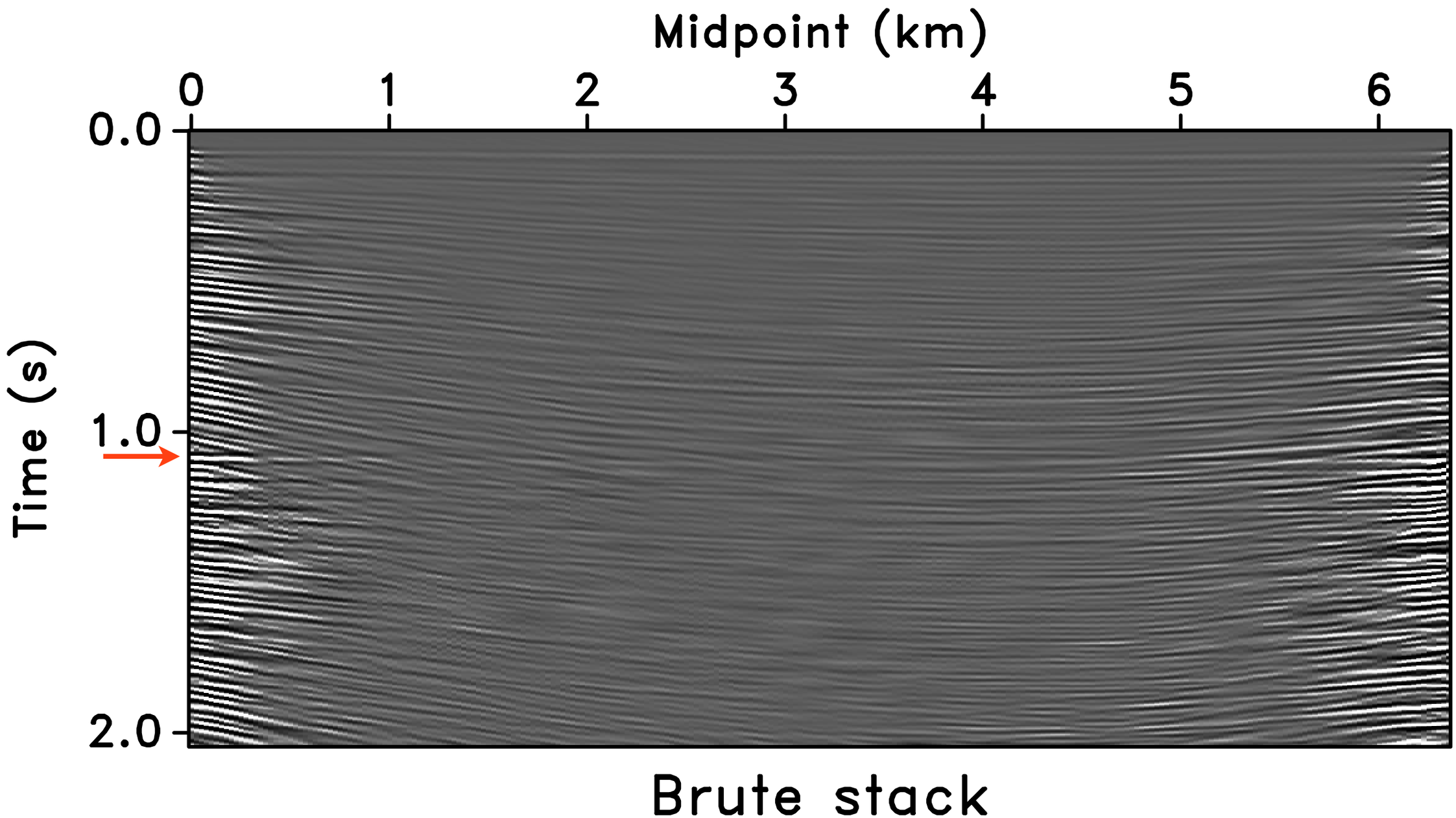
Random time-dithering



Random time-dithering



Periodic time-dithering



SNR (dB)

Subsampling ratio	Simultaneous acquisition	Random time-dithering	Periodic time-dithering
0.75	13.0	11.2	6.93
0.50	10.5	8.06	4.80
0.33	8.31	5.33	*7.32
0.25	6.55	4.35	2.85
0.10	2.82	1.14	1.60

[Mansour et.al., 2011]

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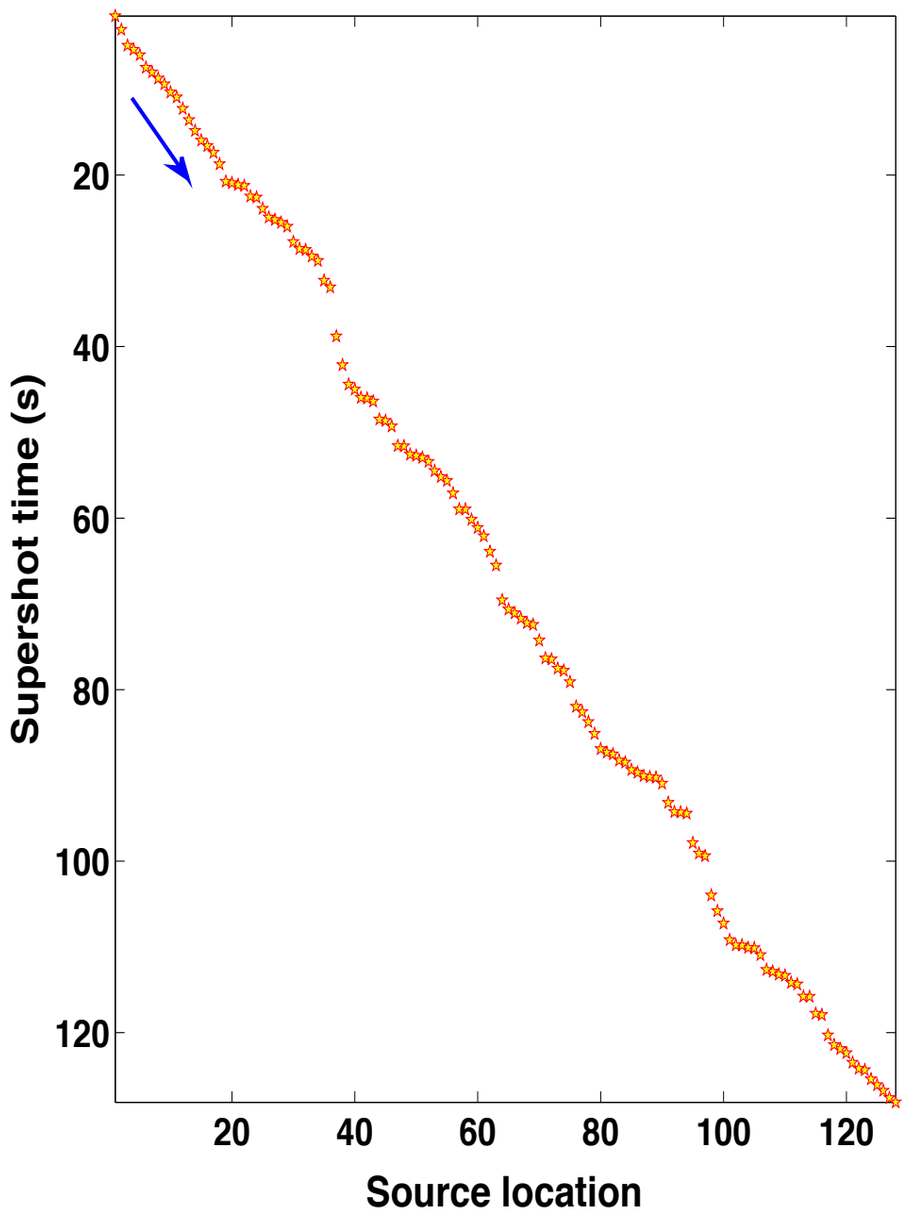
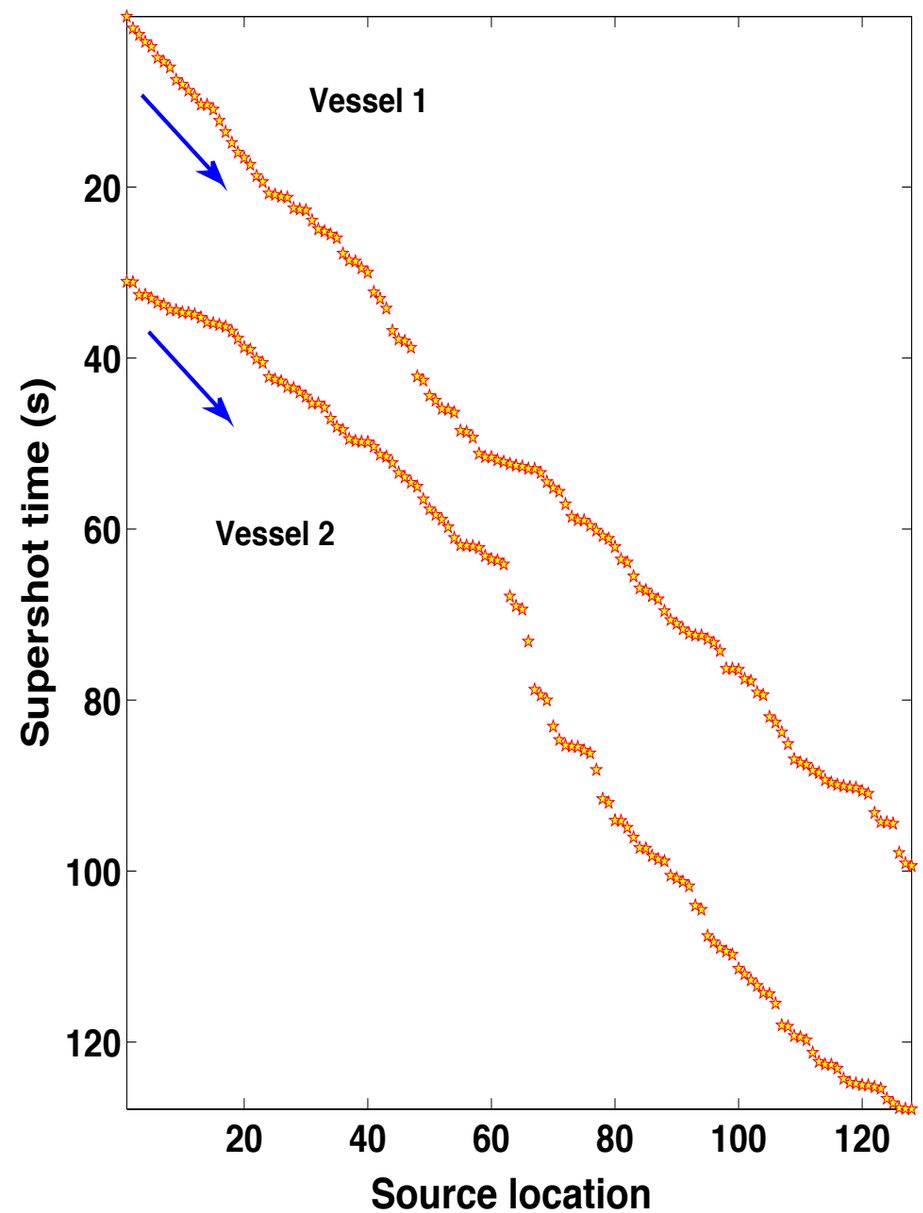
Random time-dithering

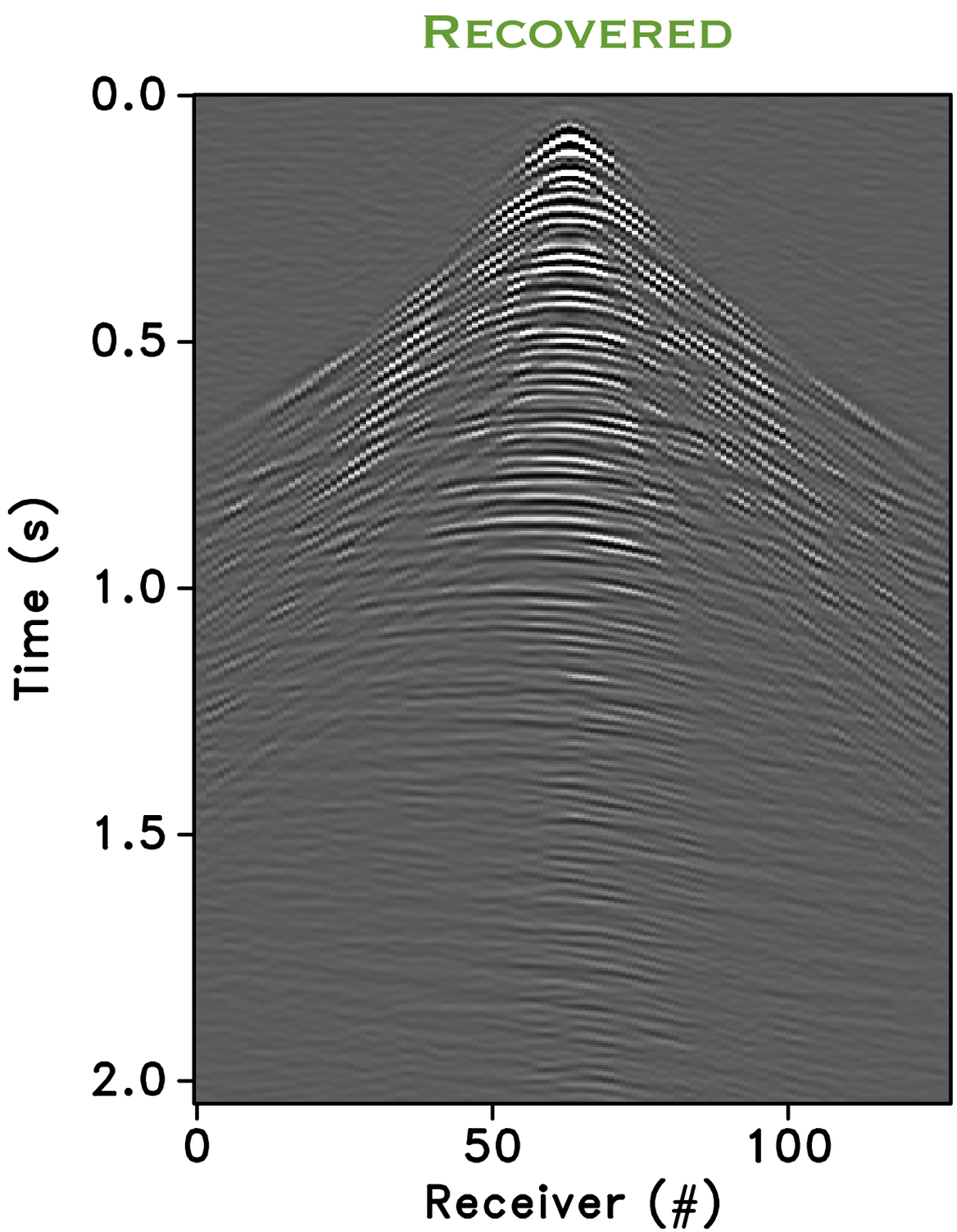
1 source vessel

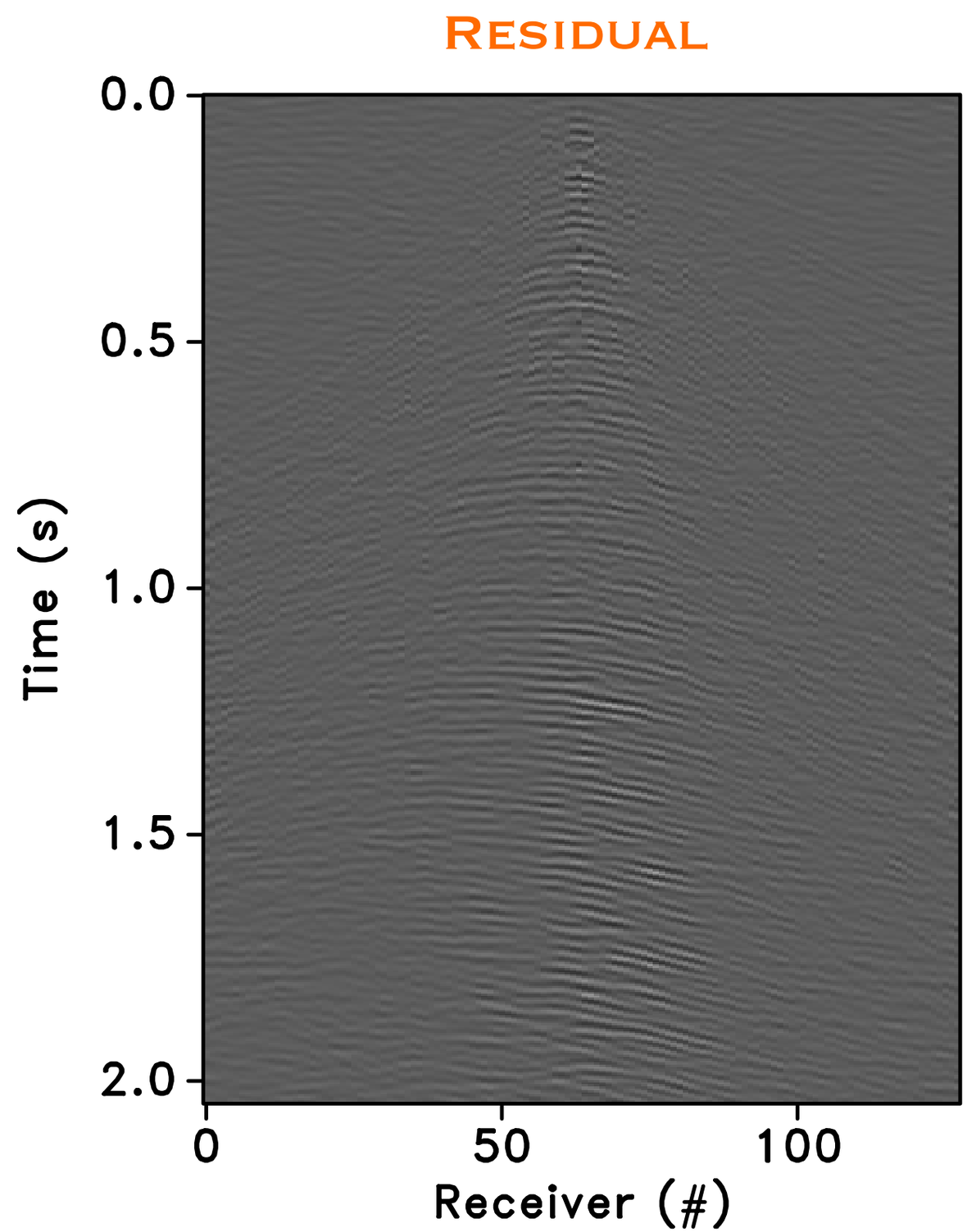


2 source vessels

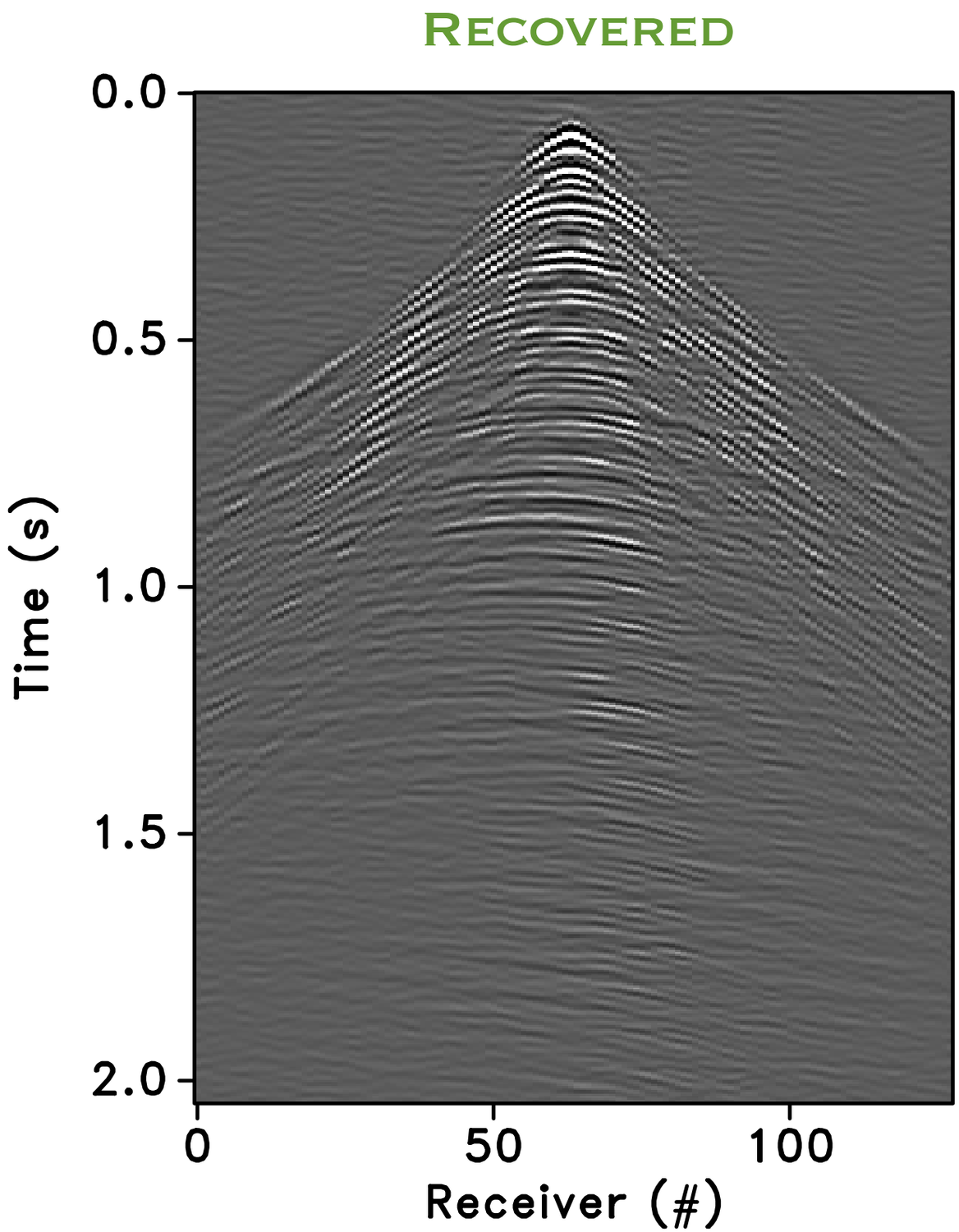


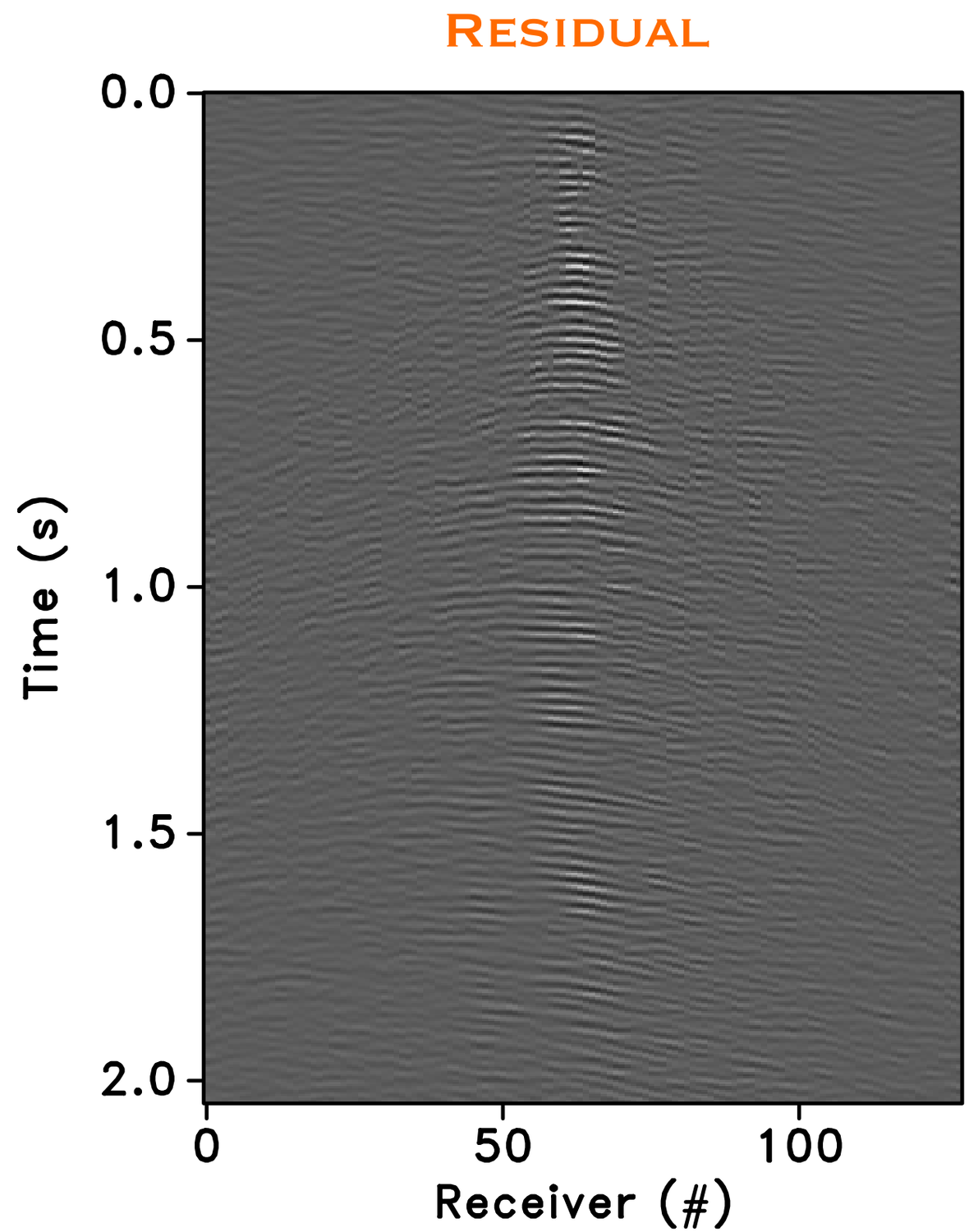
Random time-dithering with 1 source vessel
Recovery : 8.06 dB



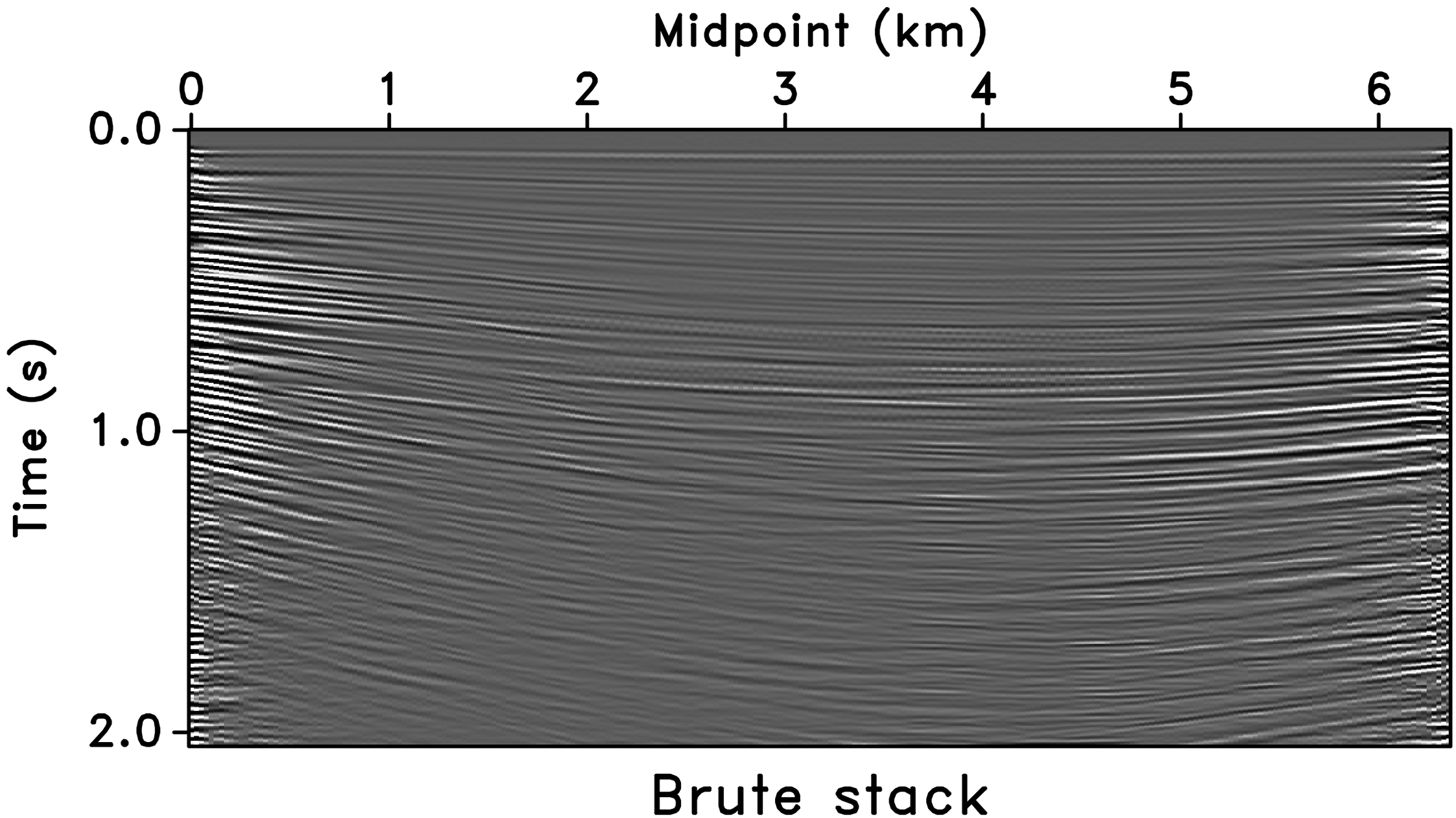


Random time-dithering with 2 source vessels
Recovery : 10.3 dB

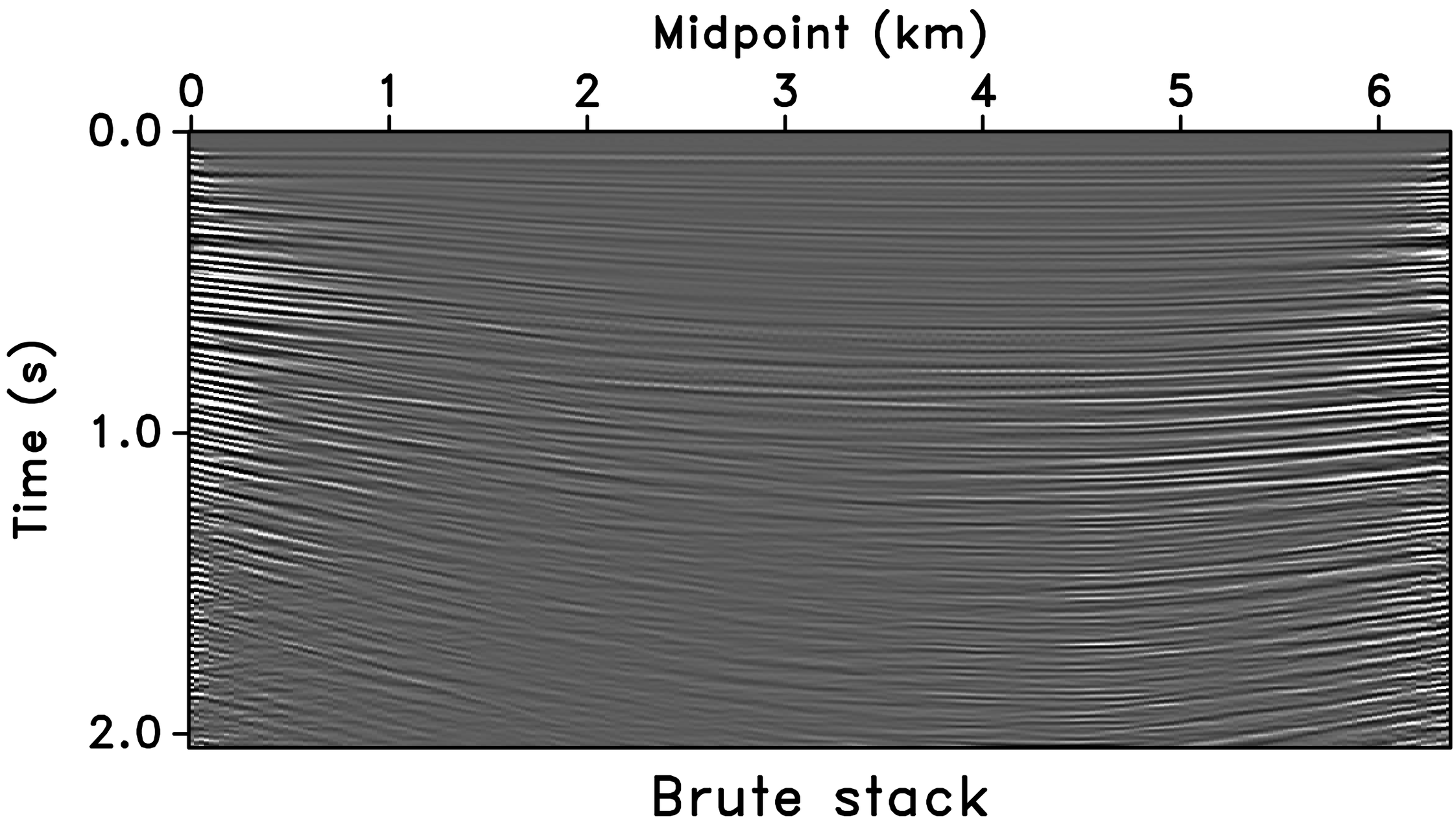




Random time-dithering with *1 source vessel*



Random time-dithering with 2 *source vessels*



Conclusions

Randomized simultaneous marine acquisition is an instance of *compressive sensing*

Critical for reconstruction quality:

- *design* of sampling schemes
- appropriate *sparsifying* transform
- *sparsity*-promoting *solver*

Only dither: efficient marine acquisition - improves with simultaneous sources

Future work

Design *physically realizable* acquisition schemes

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SINBAD

NSERC CRSNG

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