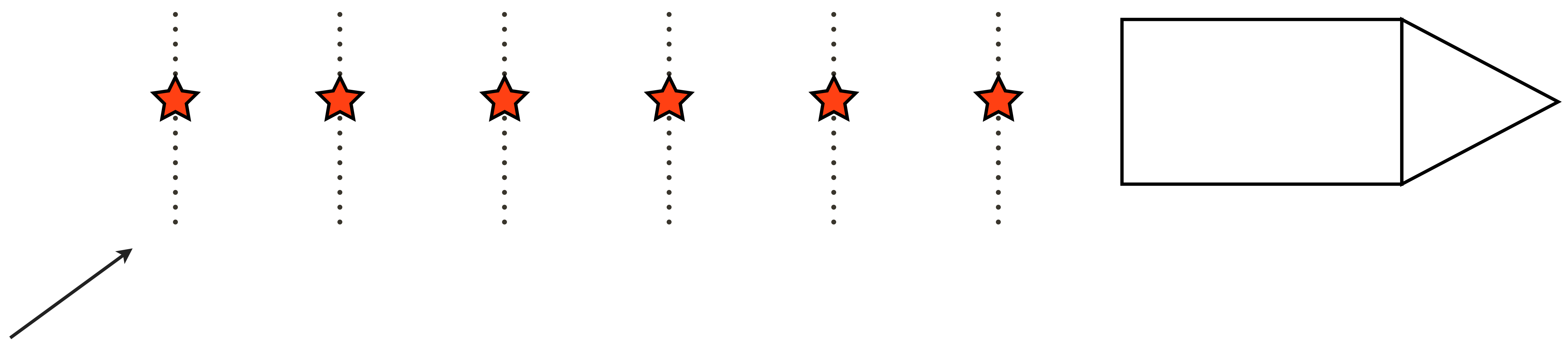
Time-*jittered* marine sources

Haneet Wason and Felix J. Herrmann

SLIM

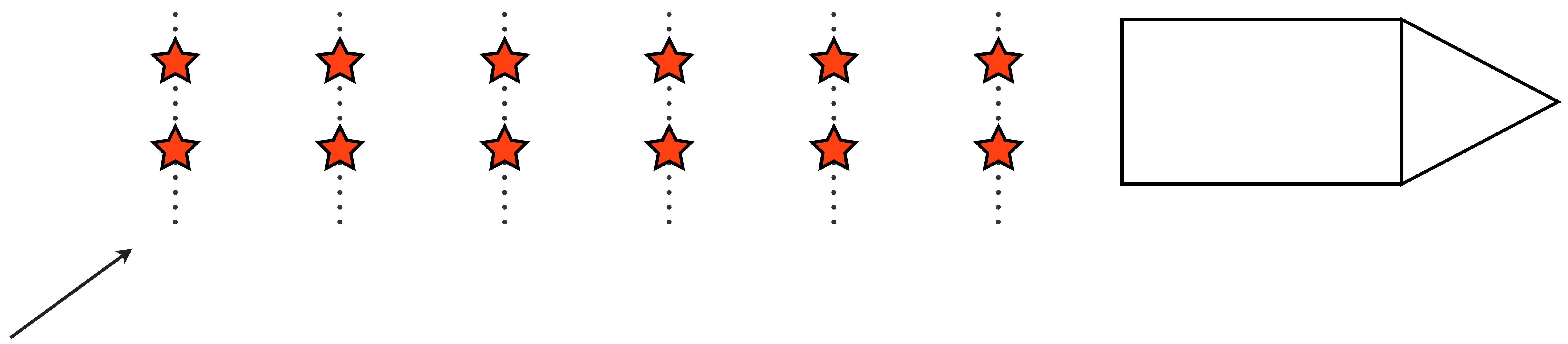
University of British Columbia

Marine acquisition - *PAST*



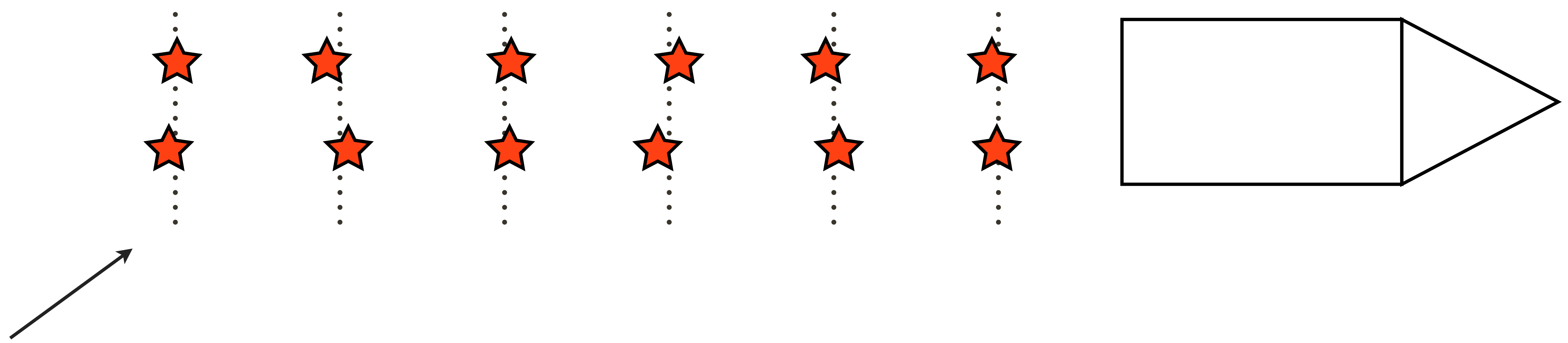
regularly sampled spatial grid

Marine acquisition - *PRESENT*



regularly sampled spatial grid

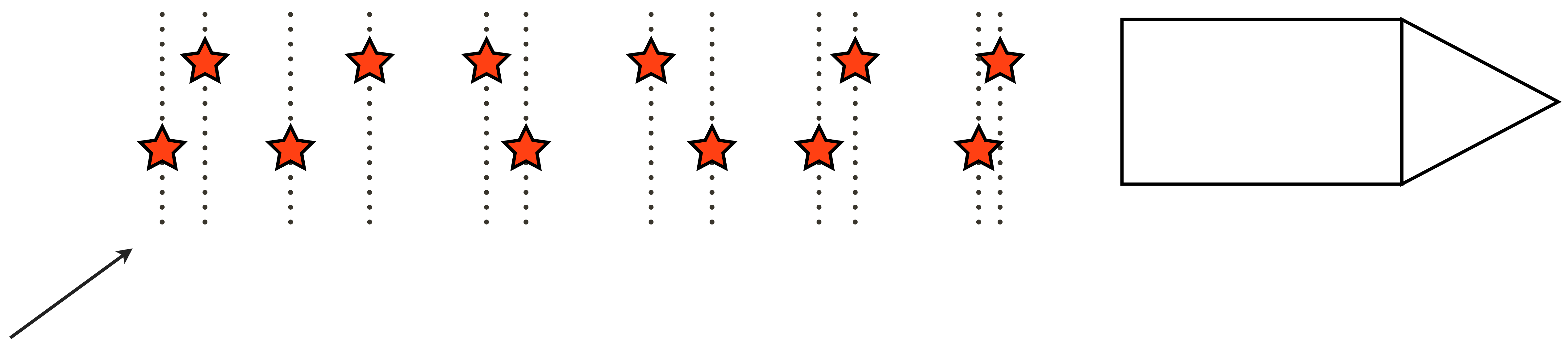
Simultaneous marine acquisition - *PRESENT*



regularly sampled spatial grid
(almost)

shot-time randomness - ***LOW***

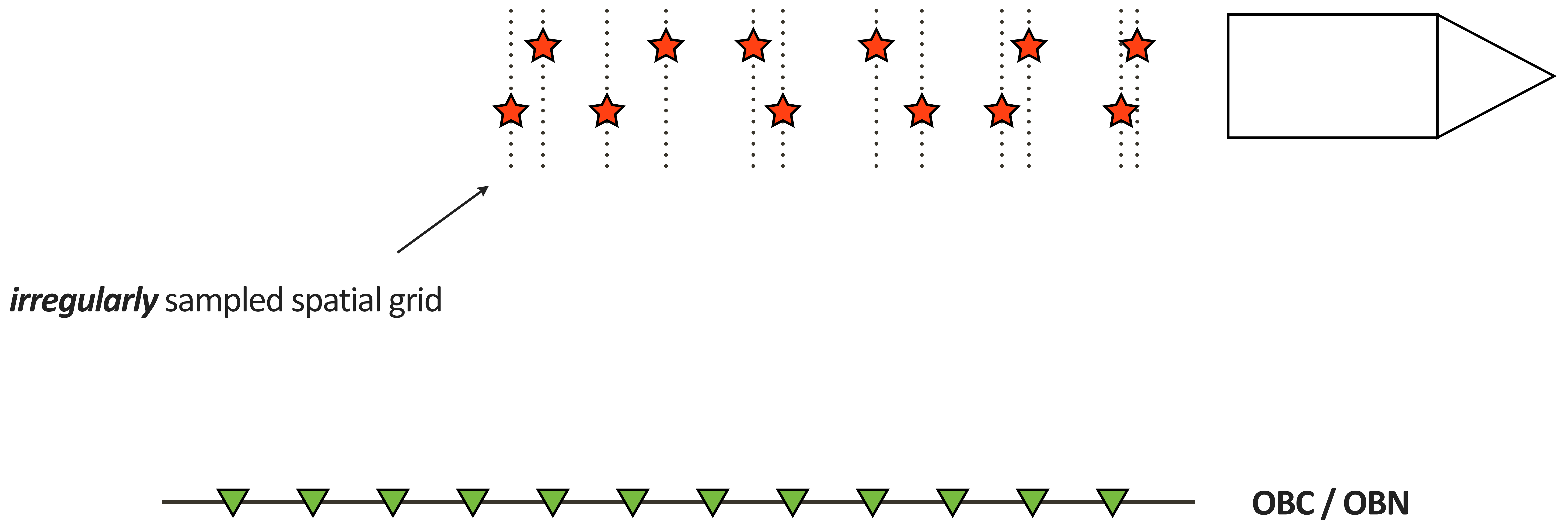
Simultaneous marine acquisition - *FUTURE ?*



irregularly sampled spatial grid

shot-time randomness - ***HIGH***

Simultaneous marine acquisition - *FUTURE ?*



Current challenges

- Need for full sampling
  - wave-equation based inversion (RTM & FWI)
  - AVO analysis, SRME/EPSI, etc.
- Full azimuthal coverage
  - multiple source vessels
  - simultaneous/blended acquisition
- Deblending or wavefield reconstruction
  - recover unblended data from blended data
  - challenging to recover weak late events

Motivation

Rethink marine acquisition

- sources (and receivers) at *random* locations
- as long as you know the locations afterwards... *it is fine!*

Want more for less ...

- *shorter* survey times
- *increased* spatial sampling

Motivation

Rethink marine acquisition

- sources (and receivers) at *random* locations
- as long as you know the locations afterwards... *it is fine!*

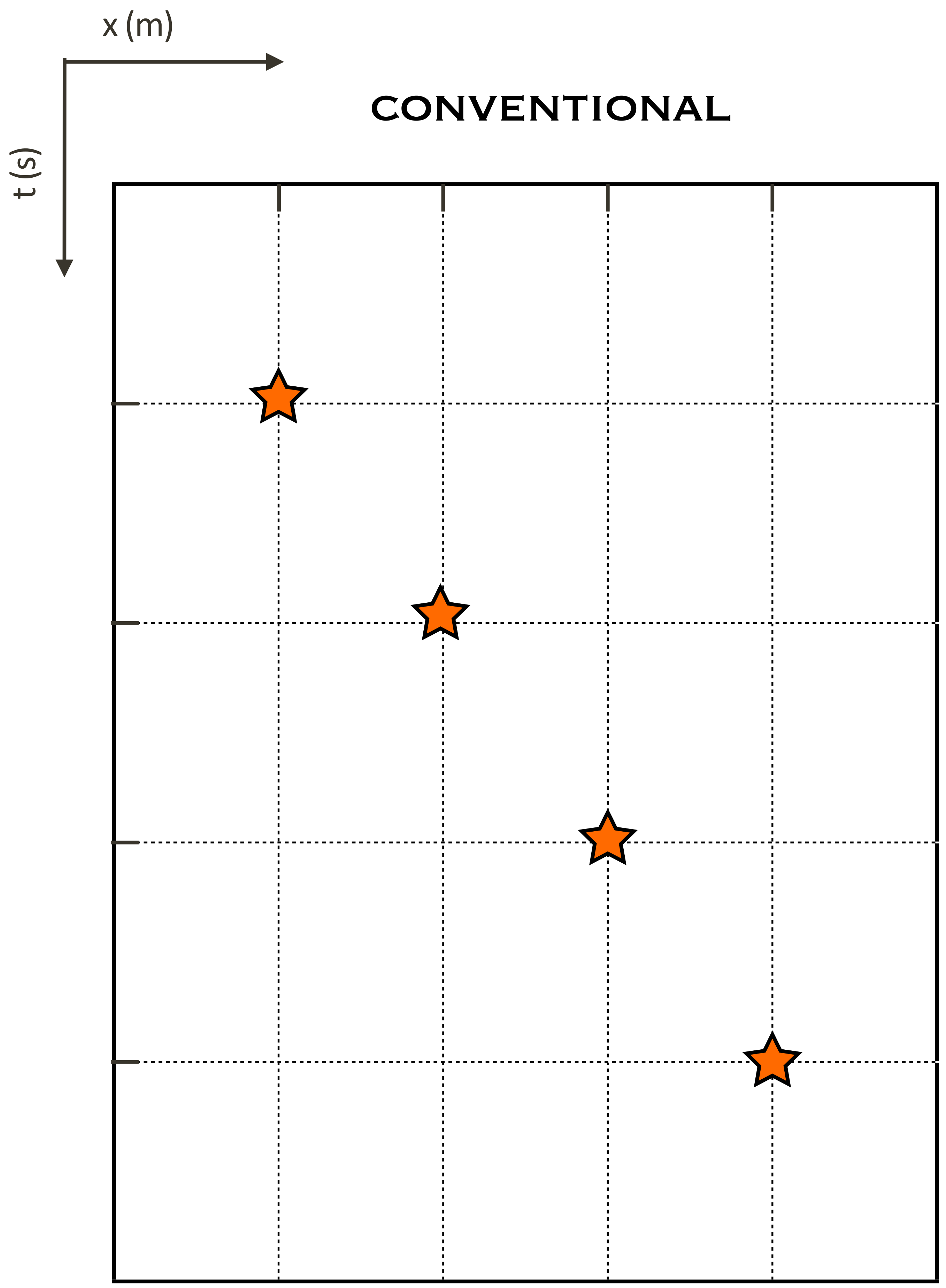
Want more for less ...

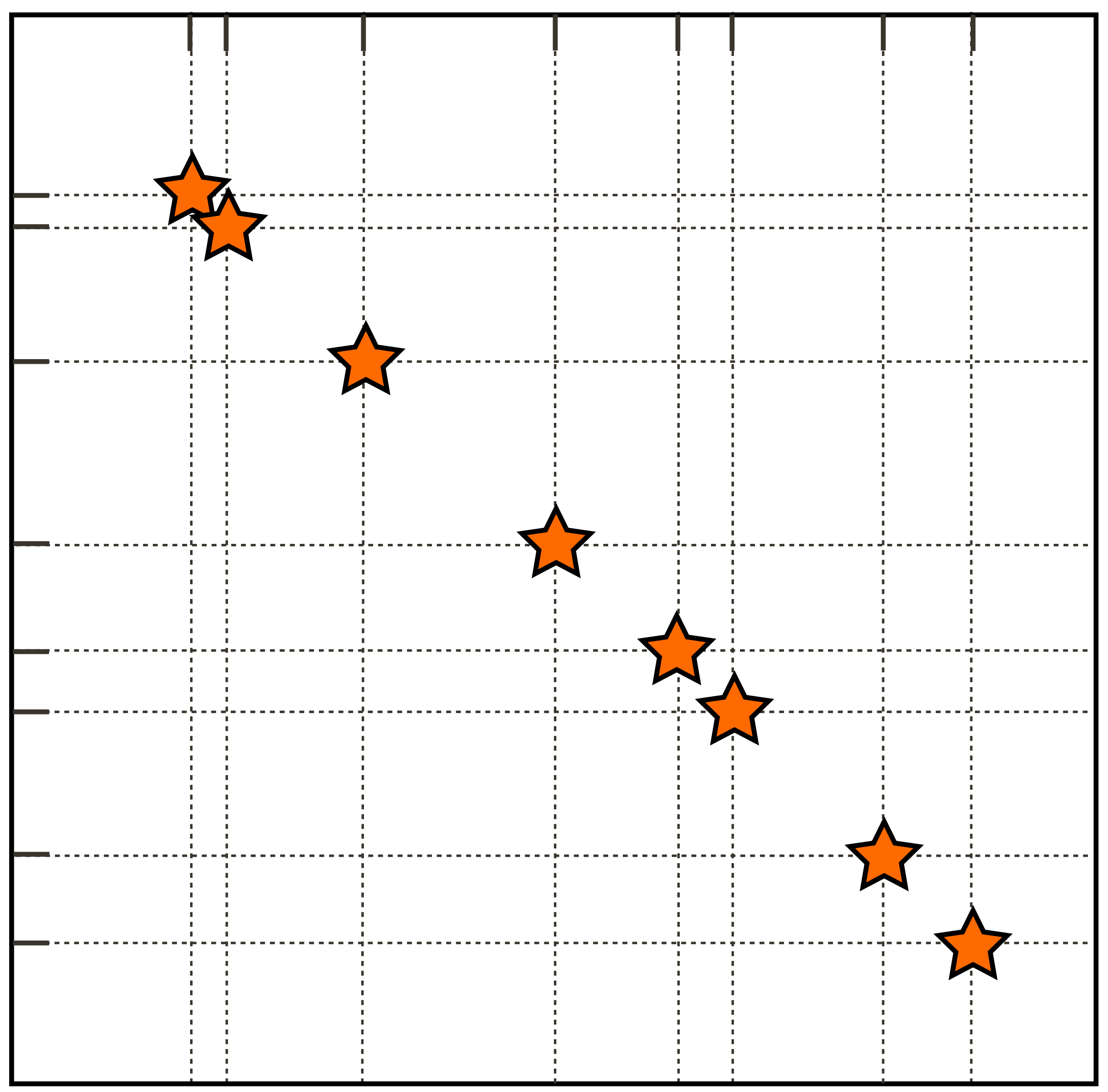
- *shorter* survey times
- *increased* spatial sampling

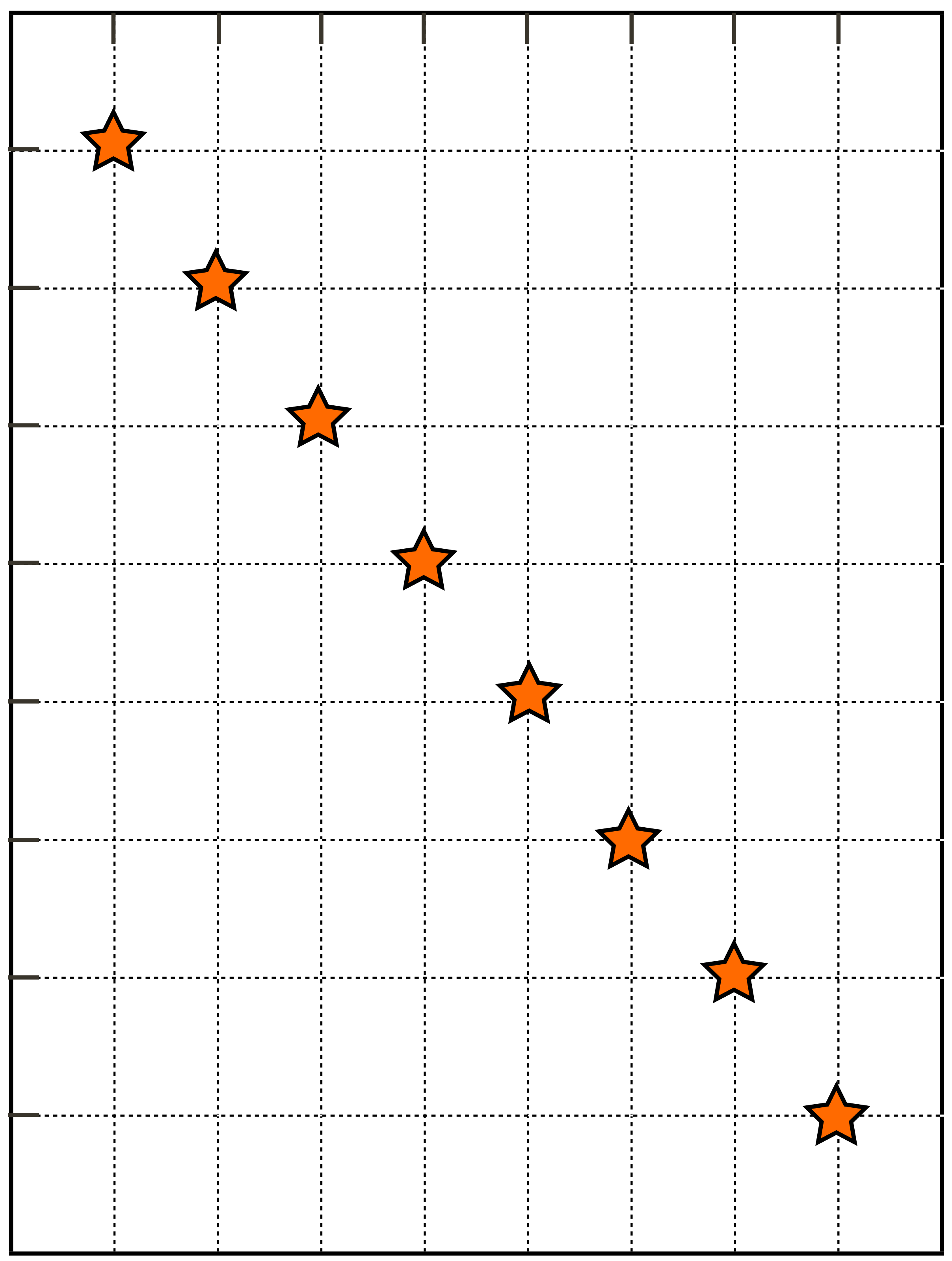
How is this possible?

- (multi-vessel) acquisition w/ *jittered* sampling & "blending" *via compressed randomized inter-shot* firing times
- *sparsity*-promoting recovery using ℓ_1 constraints ("deblending")

More for less



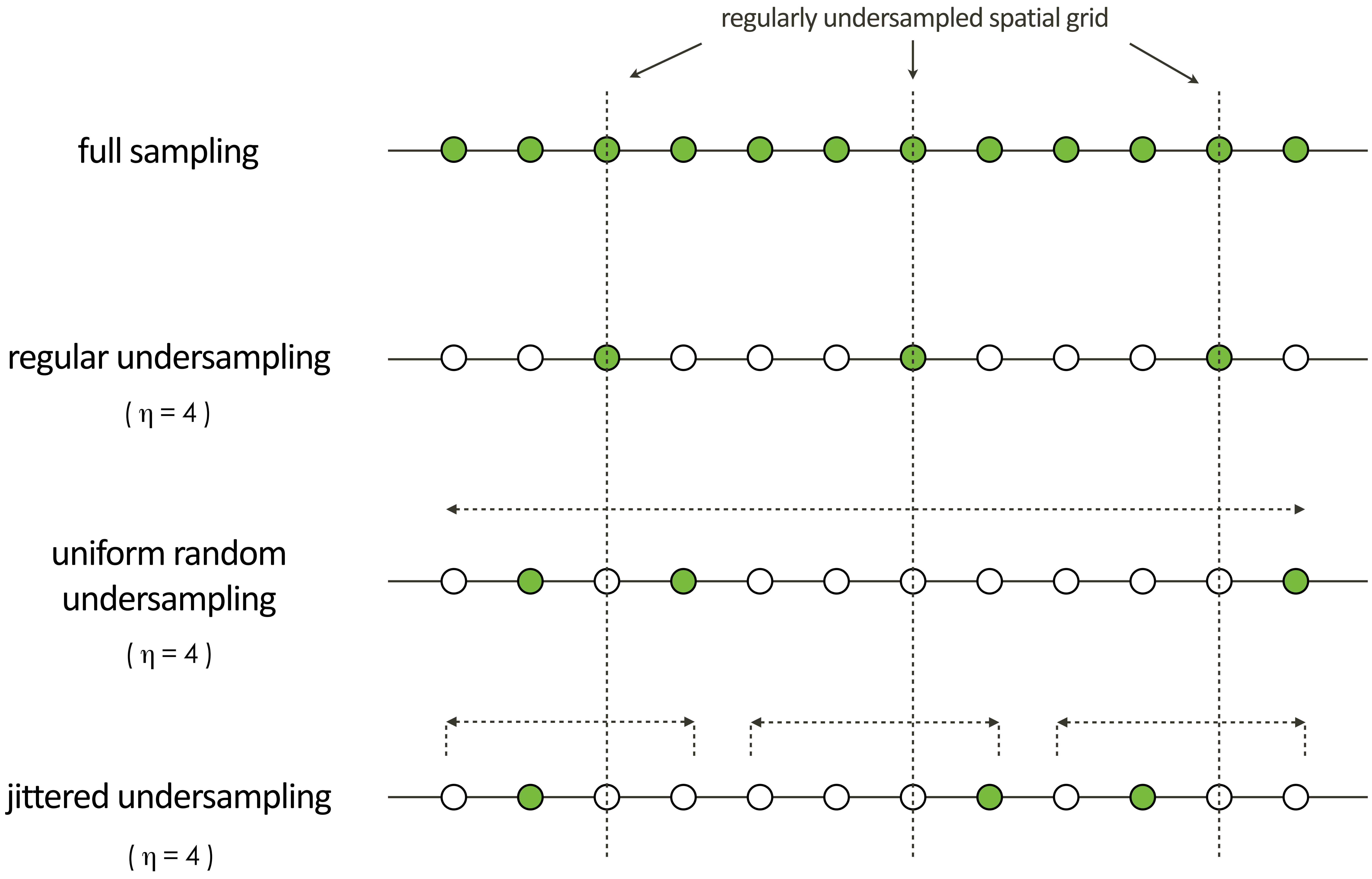




Outline

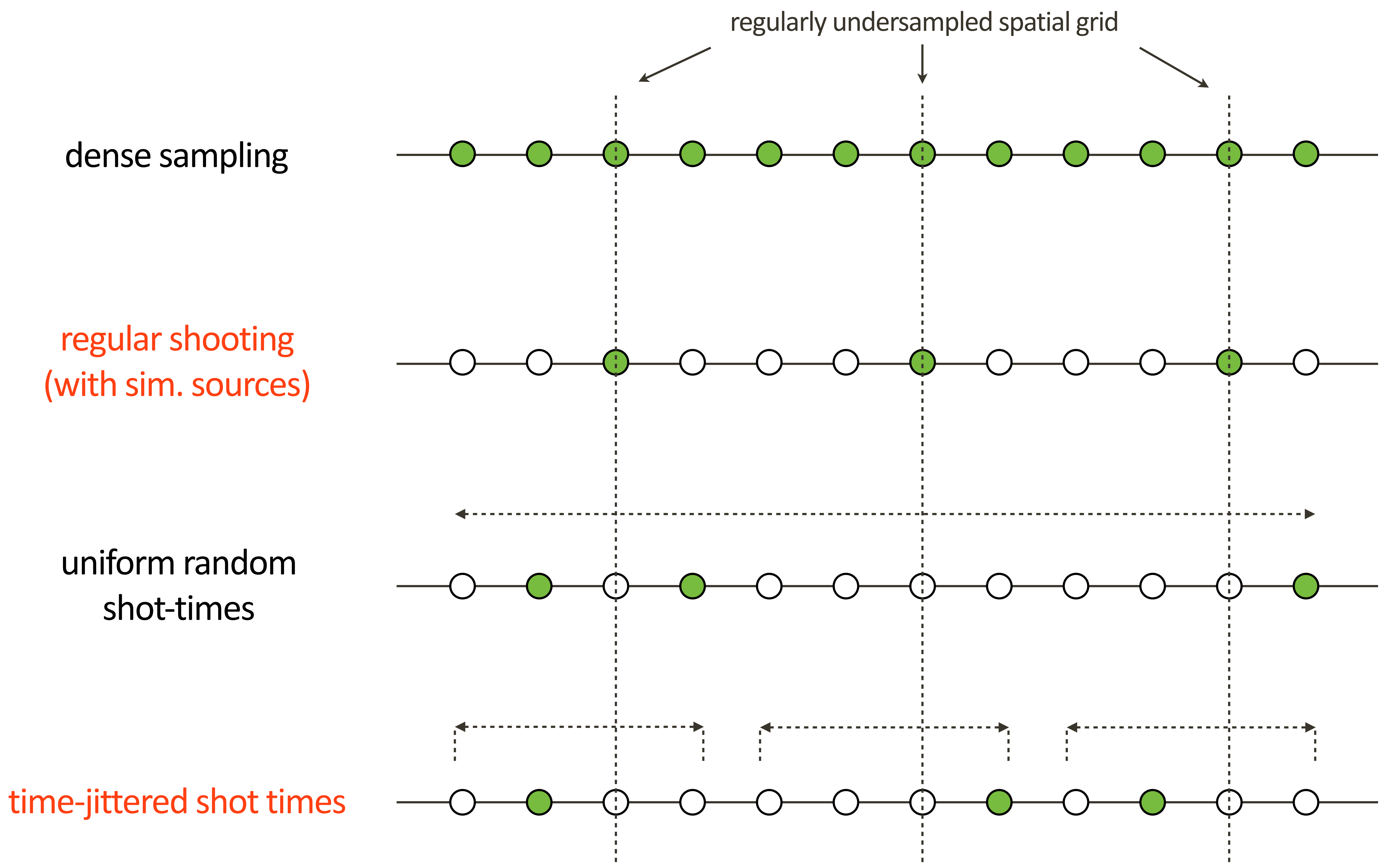
- Design of time-*jittered* acquisition
  - jitter in *time* ⇒ jittered in *space* (*shot* locations)
  - low vs. high shot-time jitter
- Recovery strategy
- Experimental results of *sparsity*-promoting processing
  - wavefield recovery via "*deblending*" & *interpolation* from (coarse) *jittered/irregular* to (fine) *regular* sampling grid

Sampling schemes



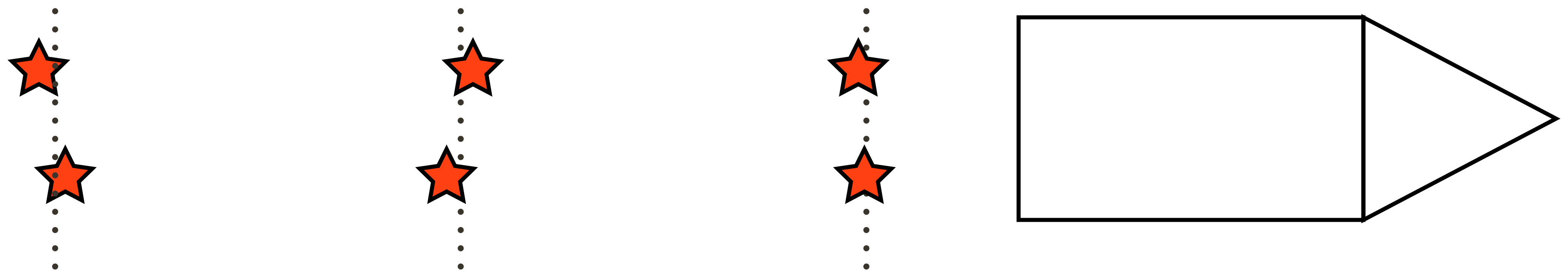
[Hennenfent et.al., 2008]

Sampling schemes

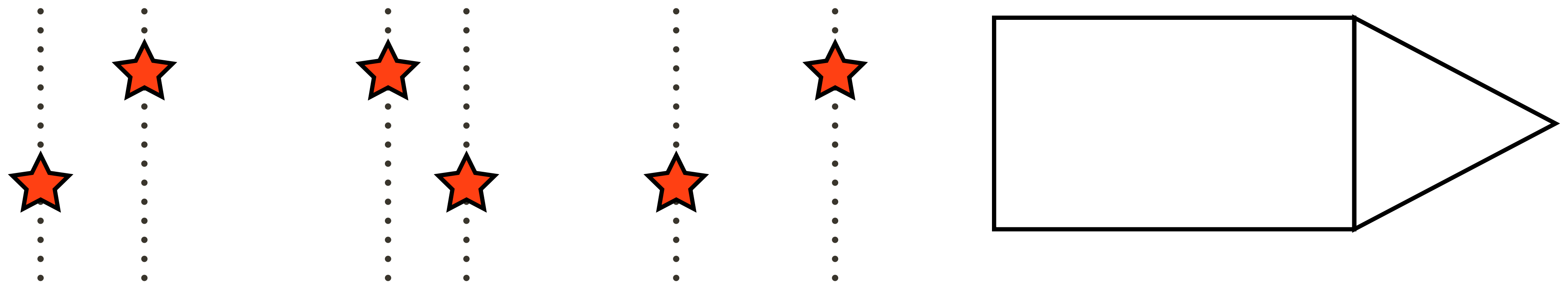


Regular vs. *jittered* locations

regularly sampled spatial grid
(almost)

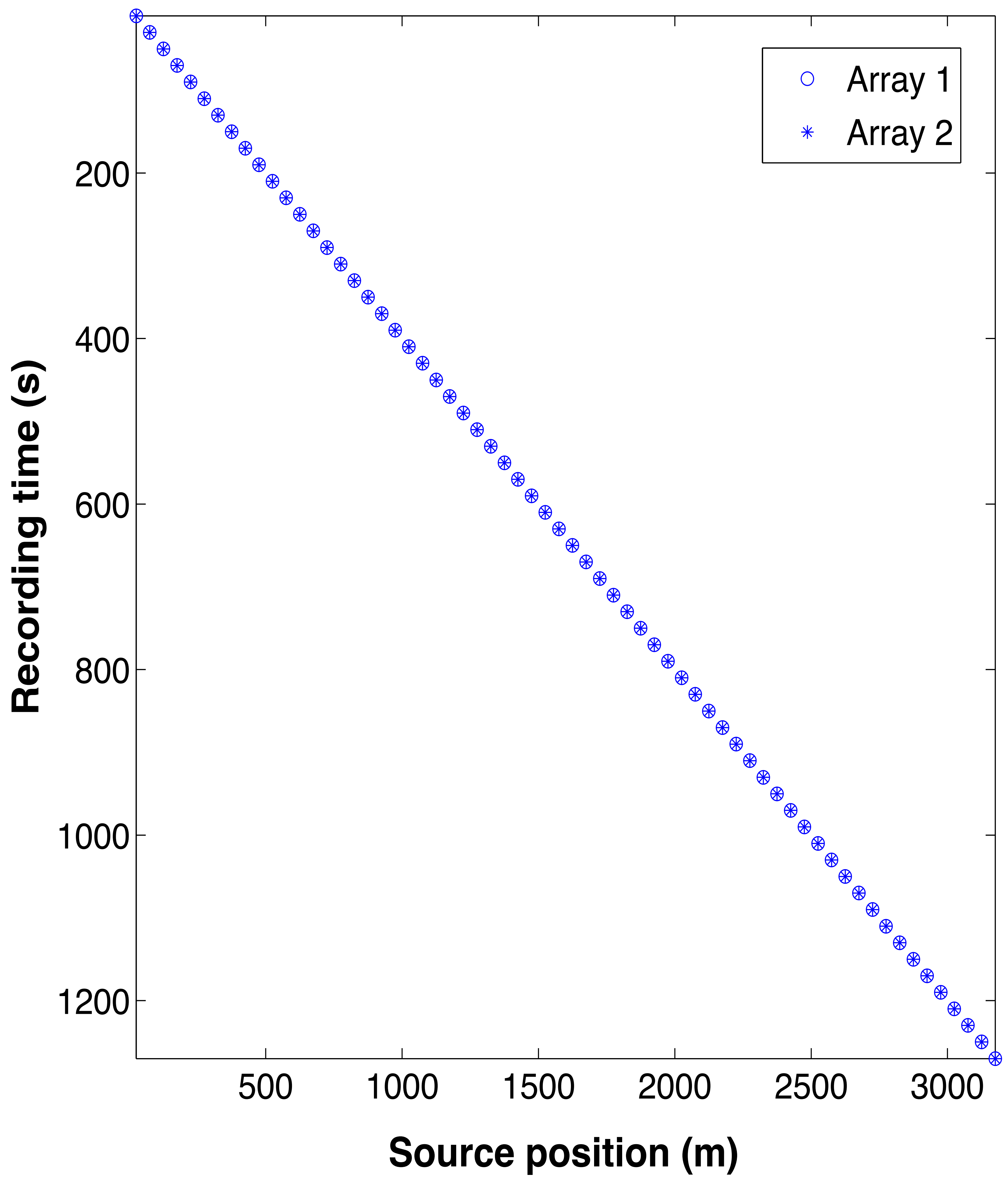


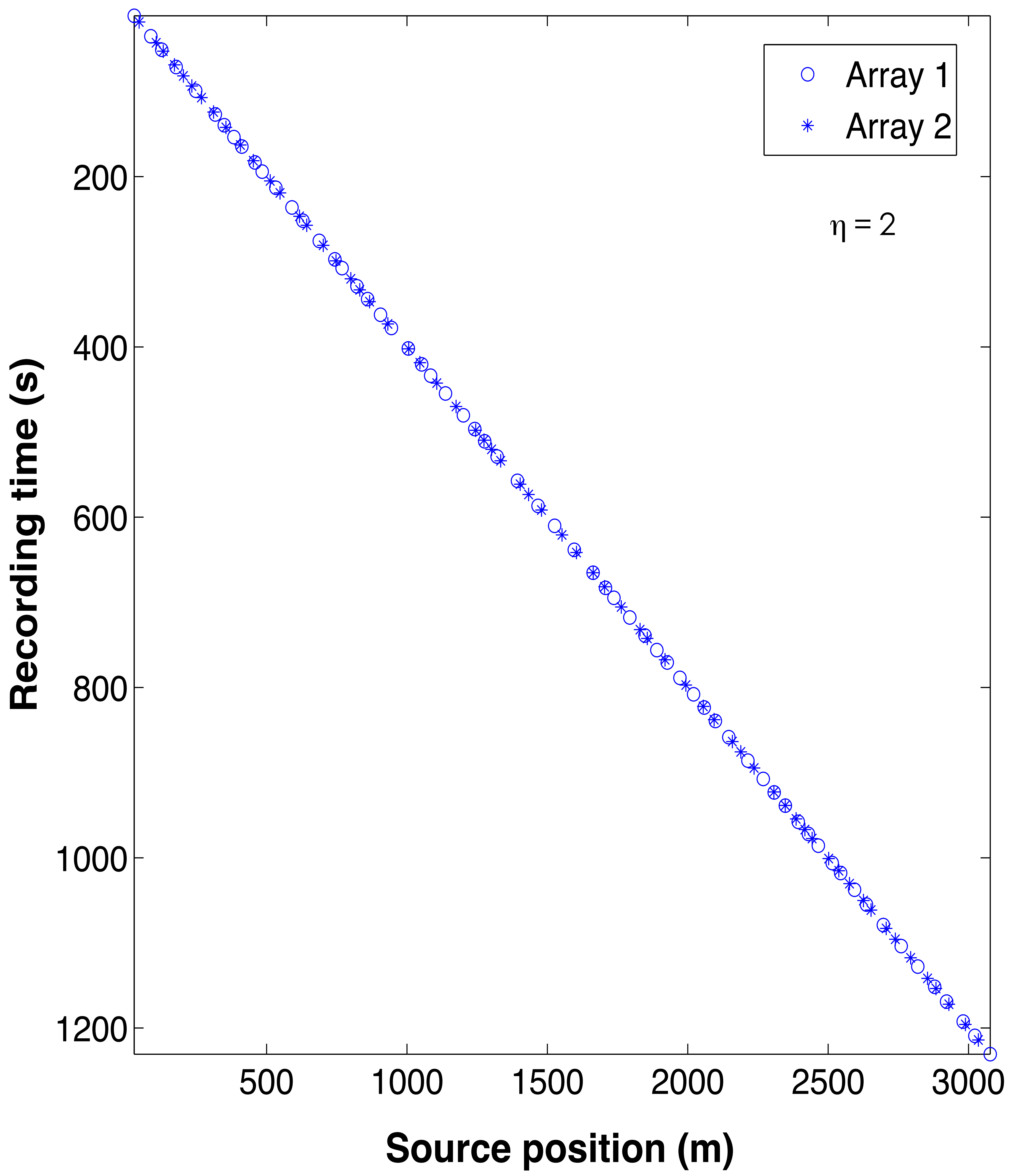
irregularly sampled spatial grid



Regular vs. *jittered* locations

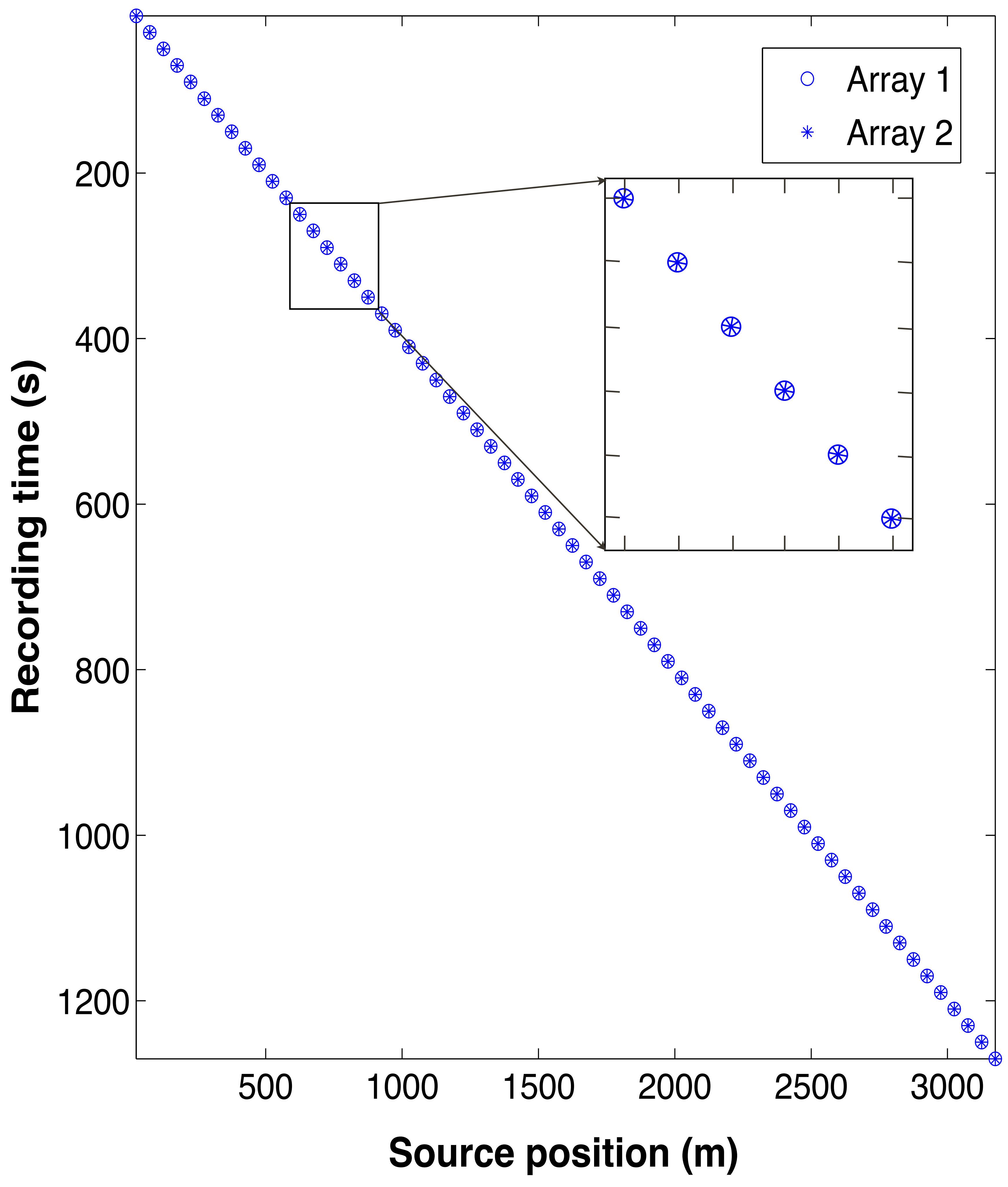
[Speed of source vessel = 5 knots ≈ 2.5 m/s]

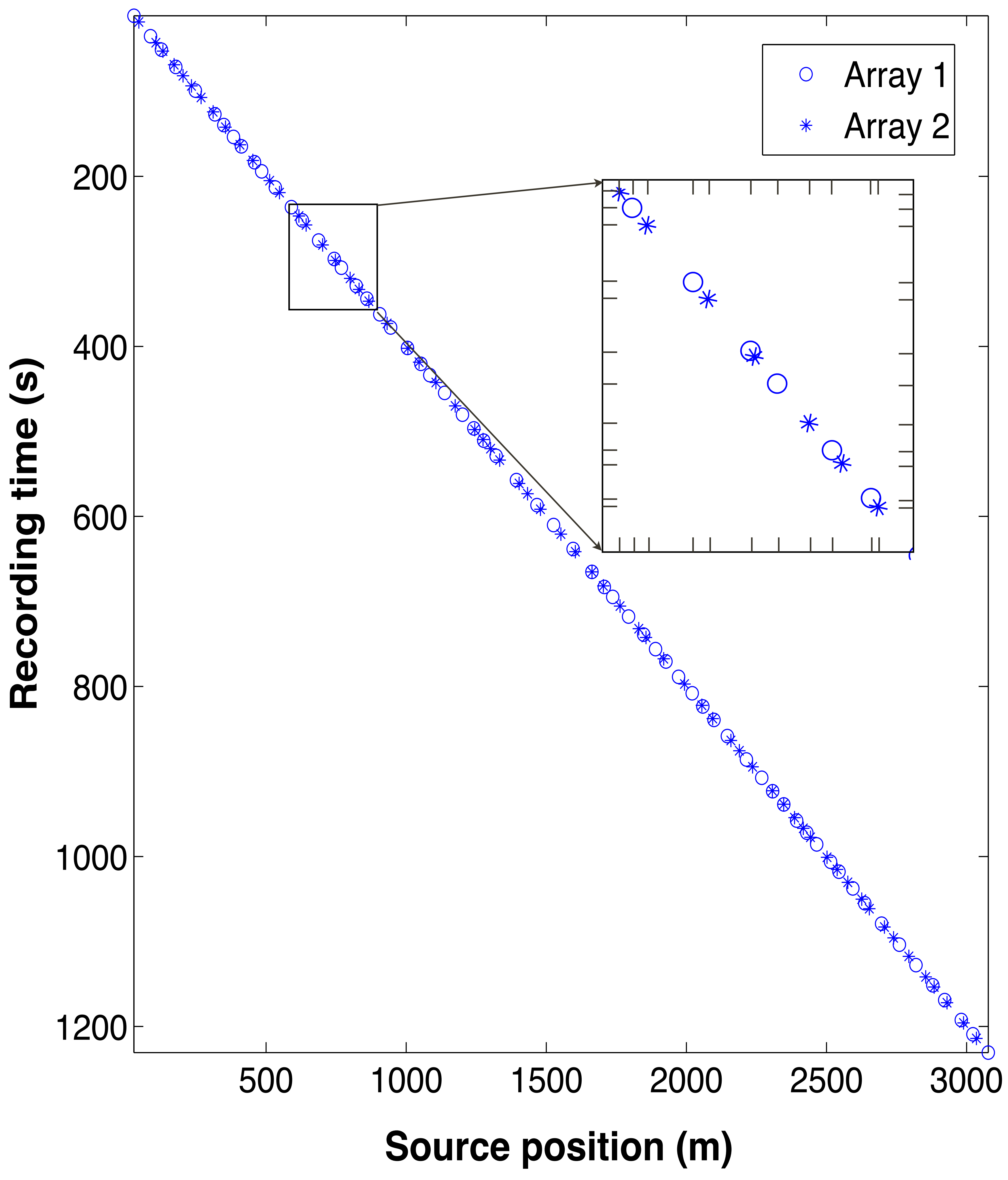




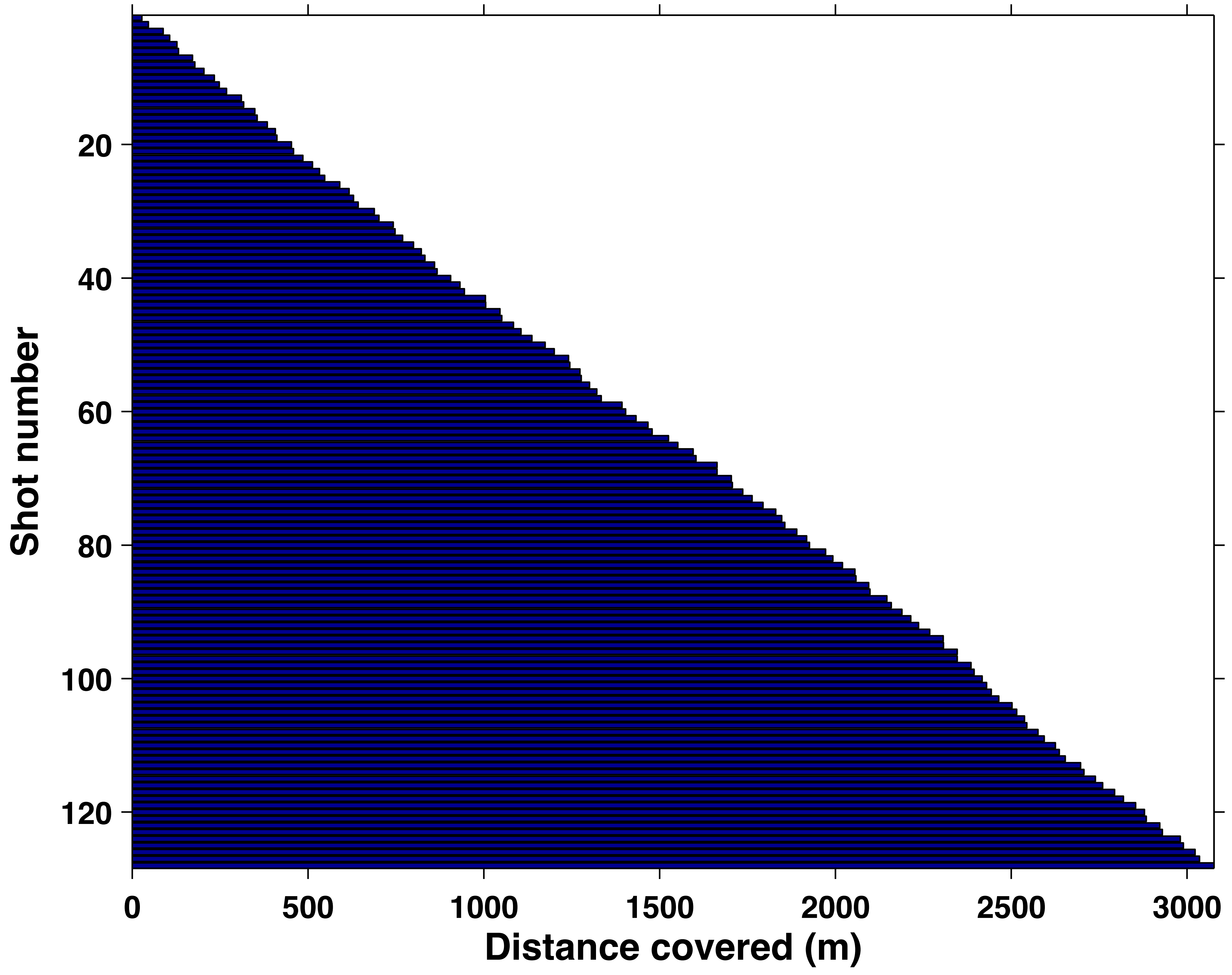
Regular vs. *jittered* locations

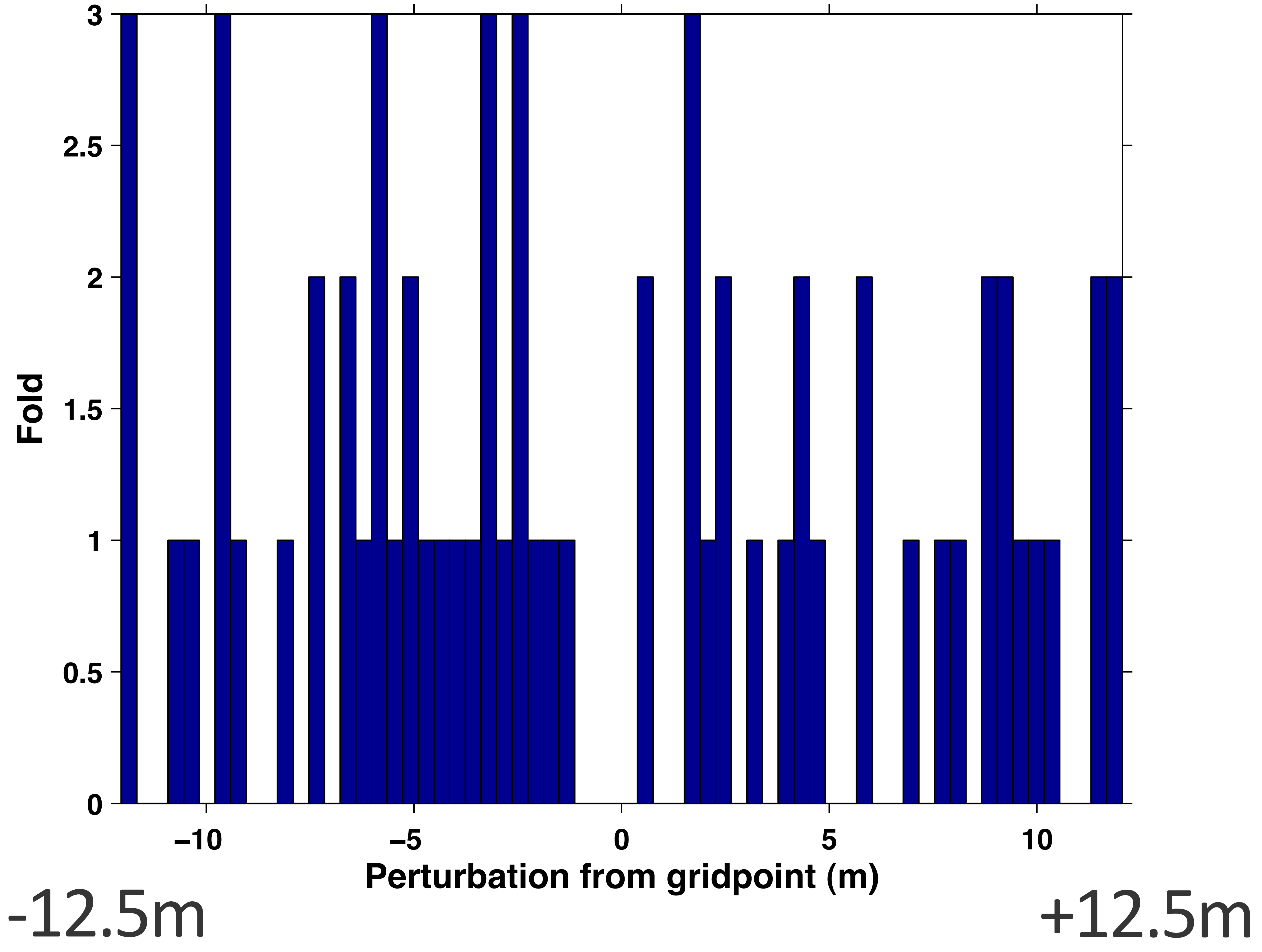
[Speed of source vessel = 5 knots ≈ 2.5 m/s]





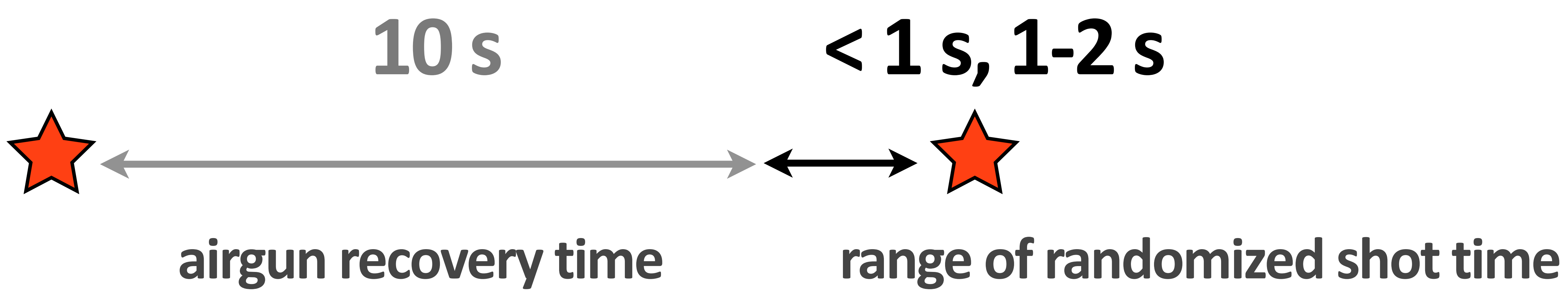
Significant spatial jittering





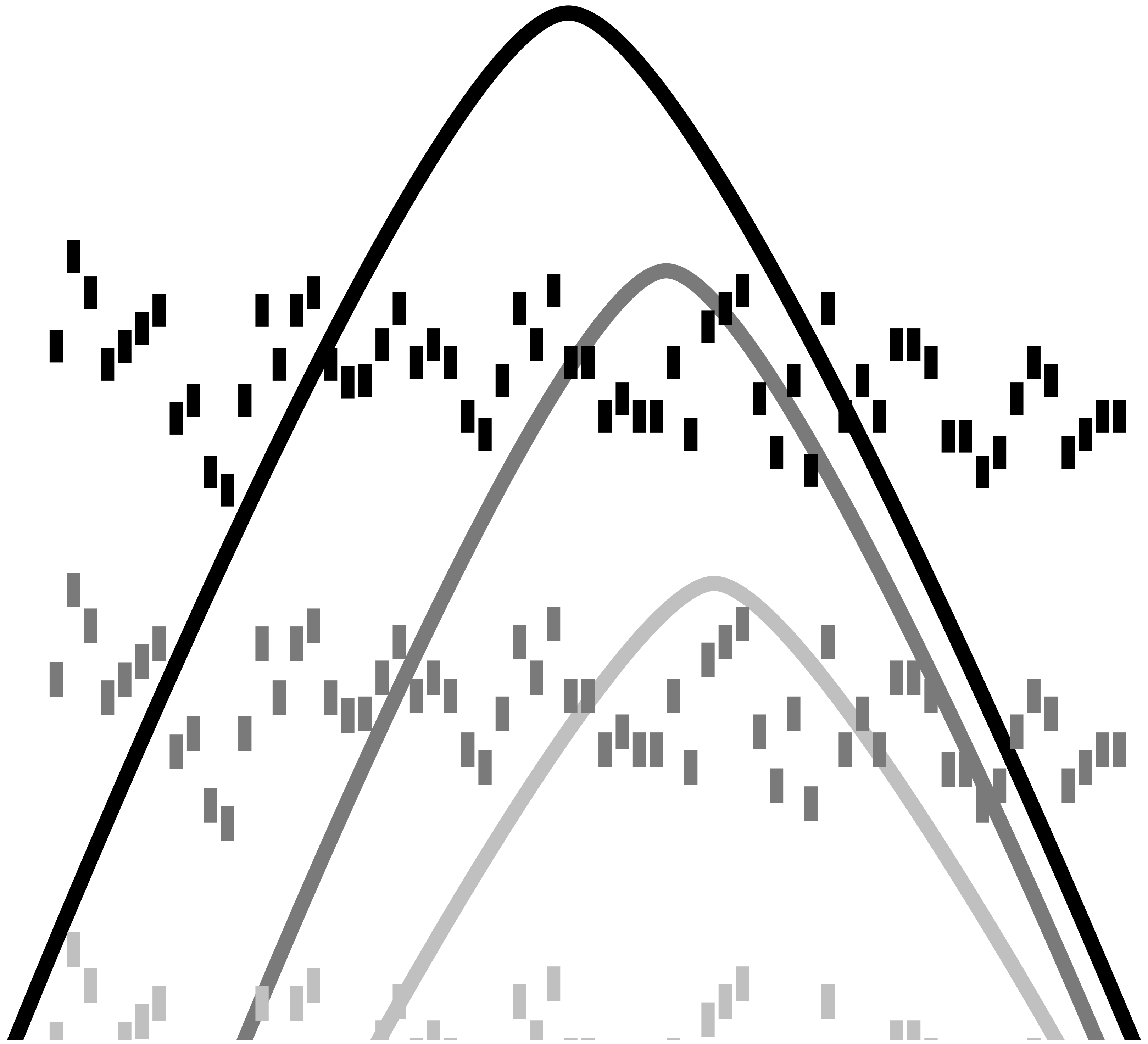
Design of time-jittered shots

Low variation



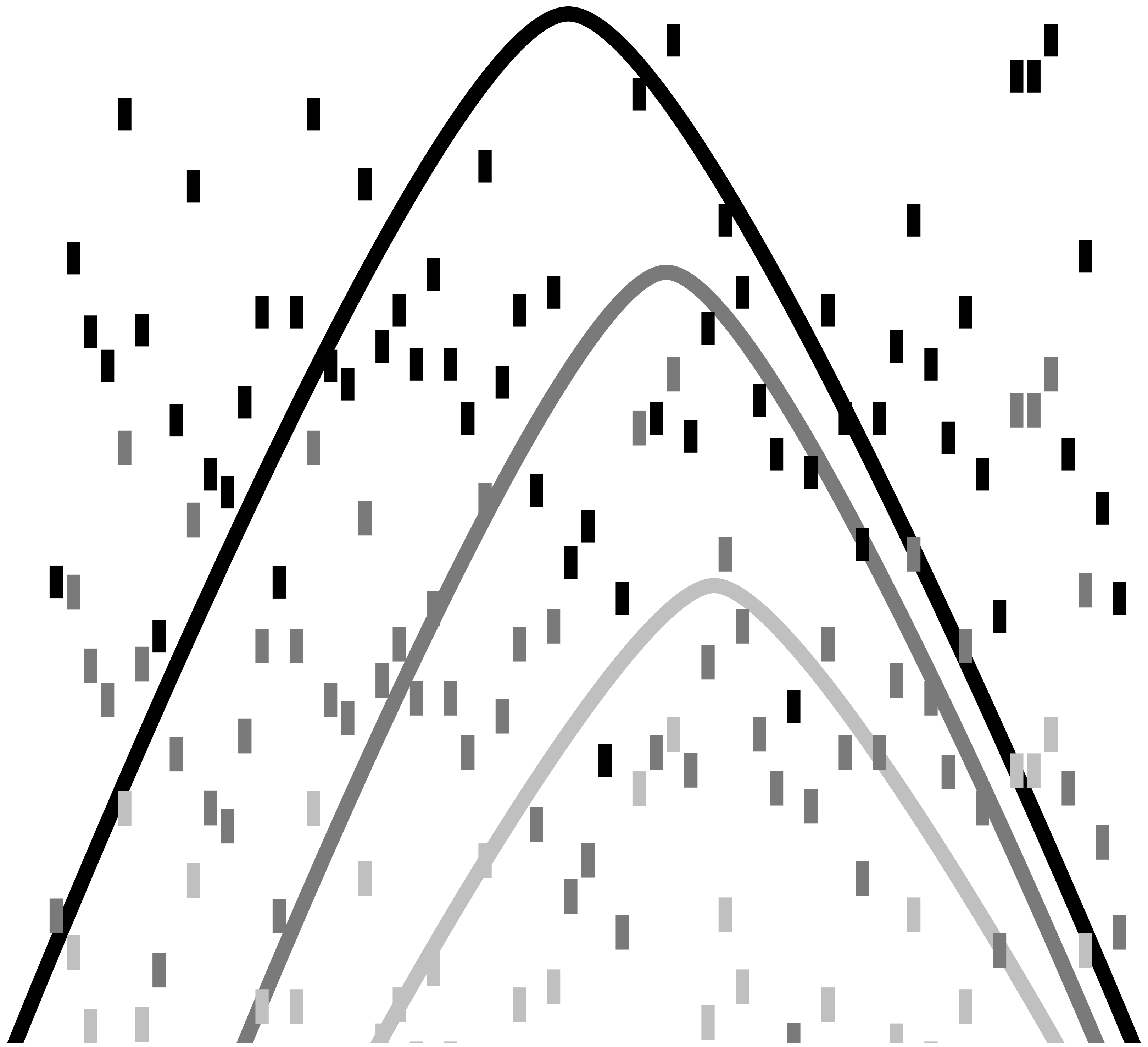
High variation

Shot-time randomness



low variability

Shot-time randomness



high variability,
easier to separate,
better low-frequency recovery(?)

Simultaneous source acquisition & deblending

- *A new look at simultaneous sources* by Beasley et. al., '98, '08
- *High quality separation of simultaneous sources by sparse inversion* by Abma et. al., '10
- *Continued development of simultaneous source acquisition for ocean bottom surveys* by Abma et. al., '13
- *Method and system for separating seismic sources in marine simultaneous shooting acquisition* by Baardman et. al., 13
- *Changing the mindset in seismic data acquisition* by Berkhout, '08
- *Utilizing dispersed source arrays in blended acquisition* by Berkhout et. al., '12
- *Random sampling: a new strategy for marine acquisition* by Moldoveanu, '10
- *Multi-vessel coil shooting acquisition* by Moldoveanu, '10
- *Simultaneous source separation by sparse radon transform* by Akerberg et. al., '08
- *Simultaneous source separation using dithered sources* by Moore et. al., '08
- *Simultaneous sources - processing and applications* by Moore, '10
- *Simultaneous source separation via multi-directional vector-median filter* by Huo et. al., '09
- *Separation of blended data by iterative estimation and subtraction of blending interference noise* by Mahdad et. al., '11

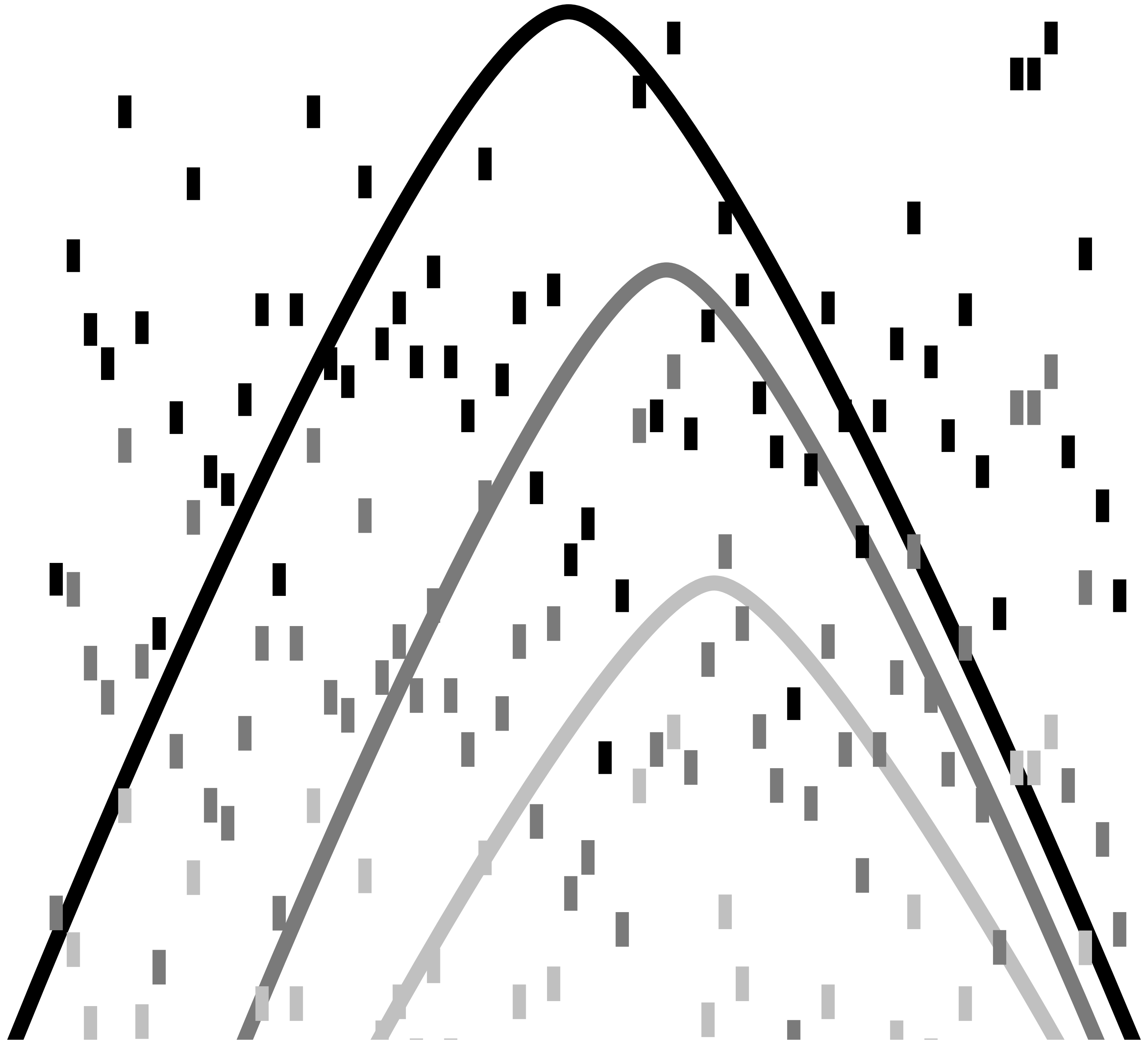
Our approach

Combination of

- multiple-source *time-jittered* acquisition
  - *random jitter* in time $\Longrightarrow$ *jitter* in *space* for a constant speed (*favours* recovery compared to *periodic* sampling)
  - shorter acquisition times
- *sparsity*-promoting processing
  - *data* is *sparse* in *curvelets*
  - *optimization*: use ℓ_1 *constraints*

Address two challenges - *overlap* and *jittered sampling* (*regularize* & *interpolate*)

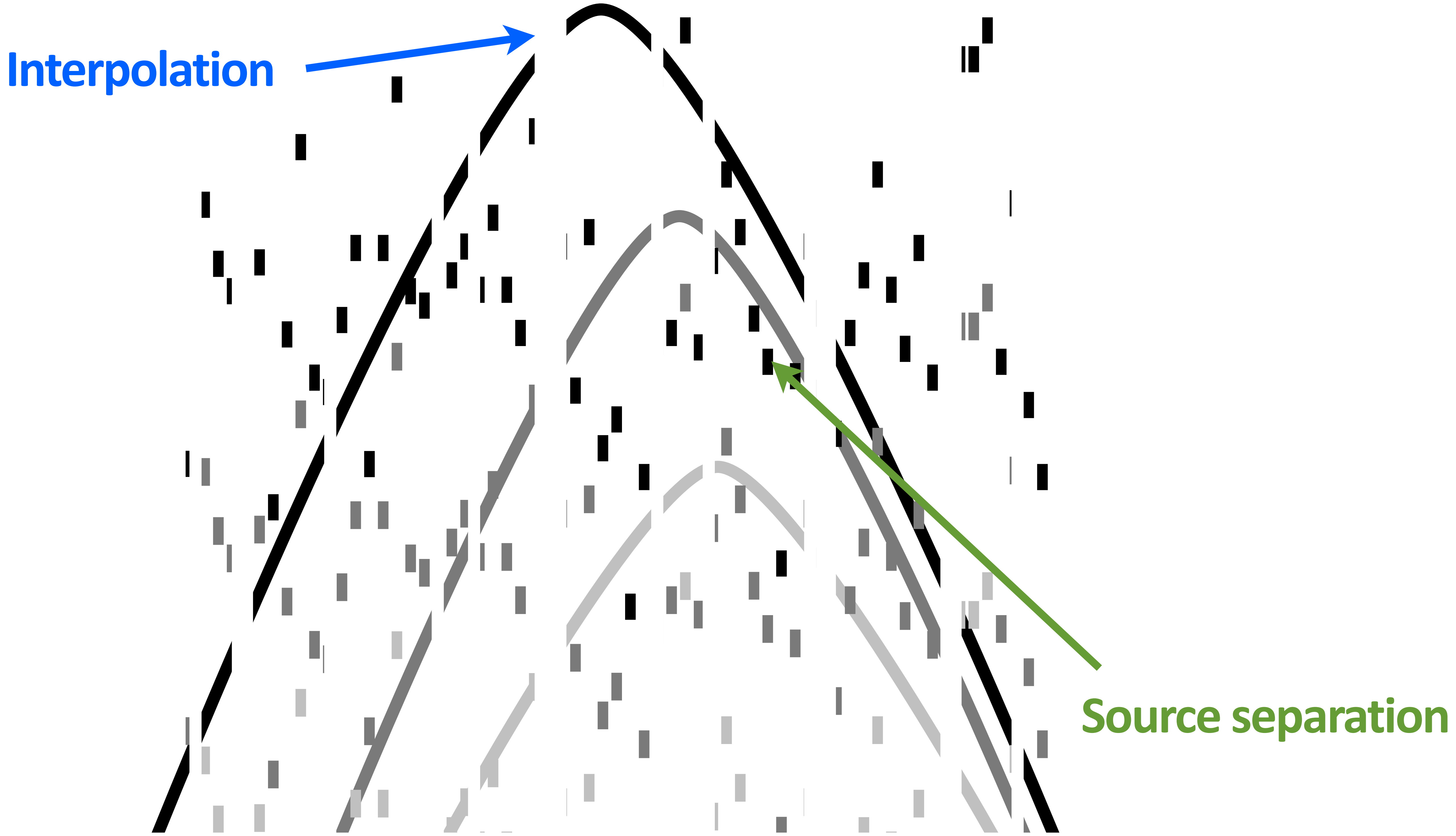
Shot-time randomness



high variability,
easier to separate,
better low-frequency recovery(?)

SLIM

Shot-time randomness



high variability
leads to
source separation
+
regularization
+
interpolation

Outline

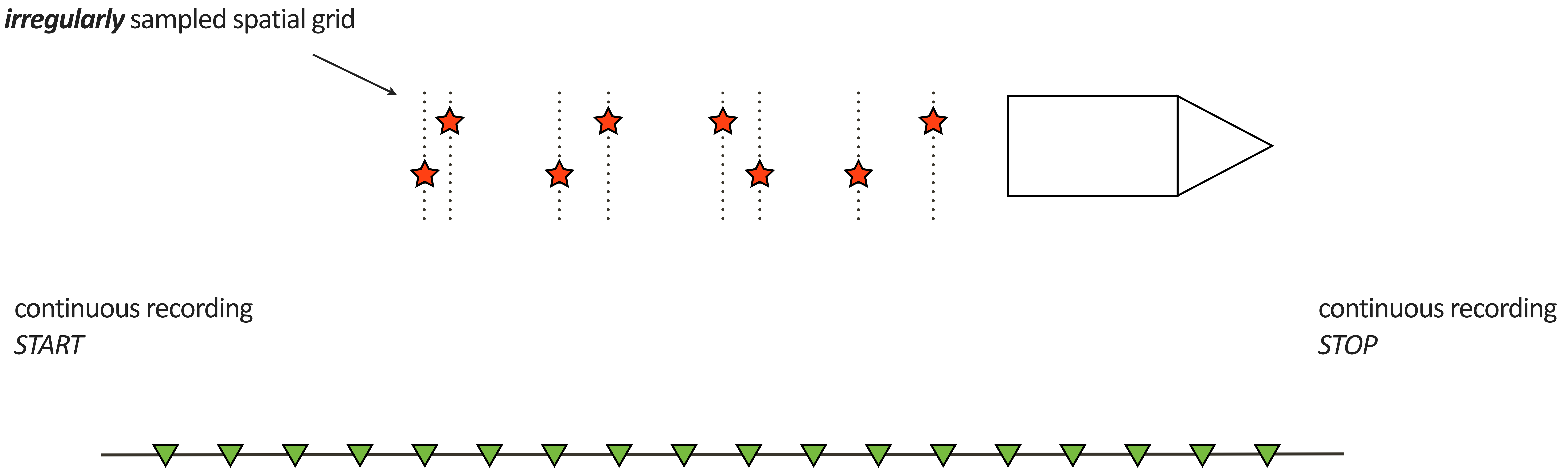
- Design of time-*jittered* acquisition
  - jitter in *time* ⇒ jittered in *space* (*shot* locations)
  - low vs. high shot-time jitter
- Recovery strategy
- Experimental results of *sparsity*-promoting processing
  - wavefield recovery via "*deblending*" & *interpolation* from (coarse) *jittered/irregular* to (fine) *regular* sampling grid

Compressed Sensing

Successful sampling & reconstruction scheme

- exploit *structure* via *sparsifying* transform
- *subsampling* – decreases sparsity
- large scale *optimization* – look for *sparsest* solution

Time-jittered acquisition

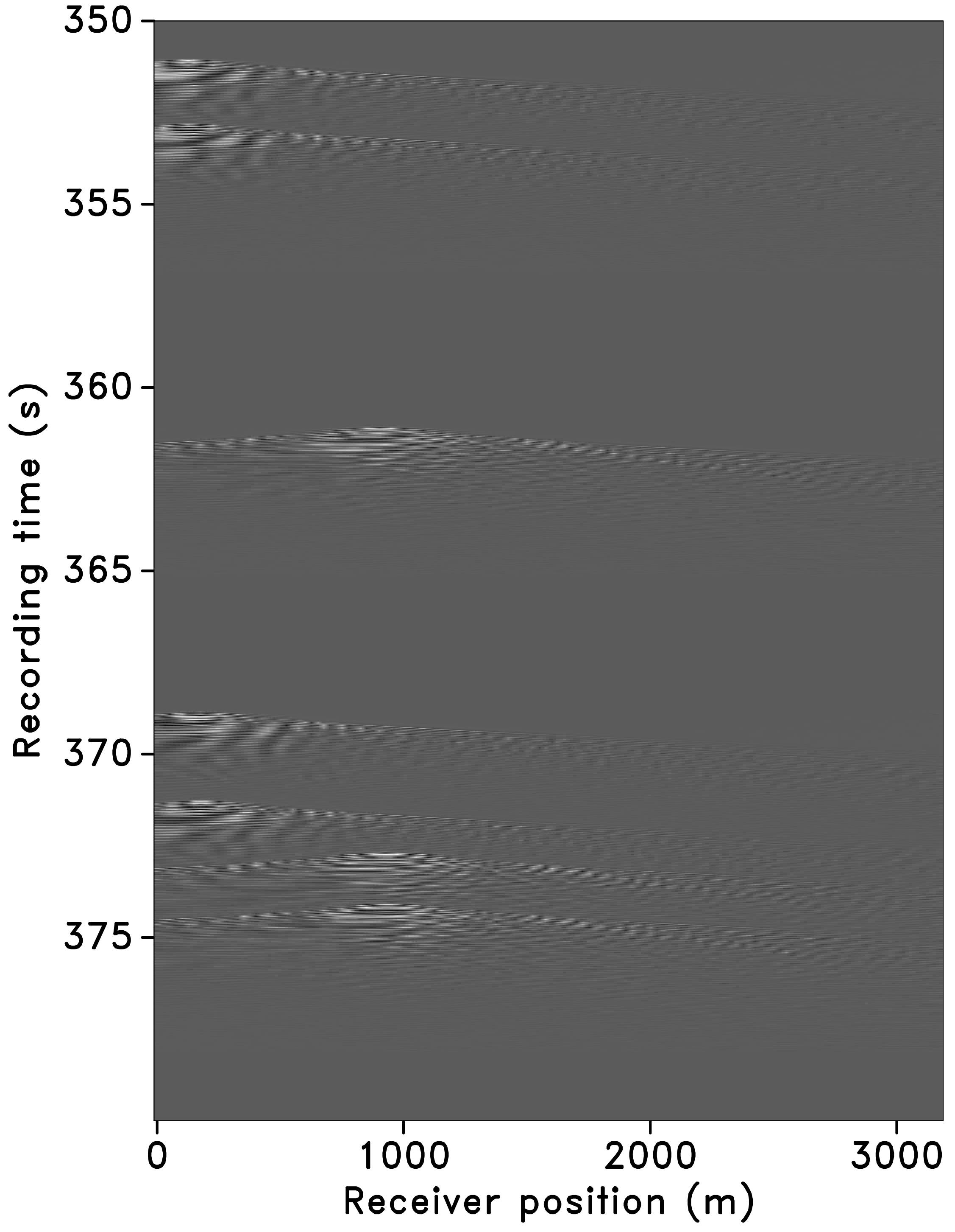


acquire in the field on *irregular* grid (*subsampled* shots *w/ overlap* between shot records)

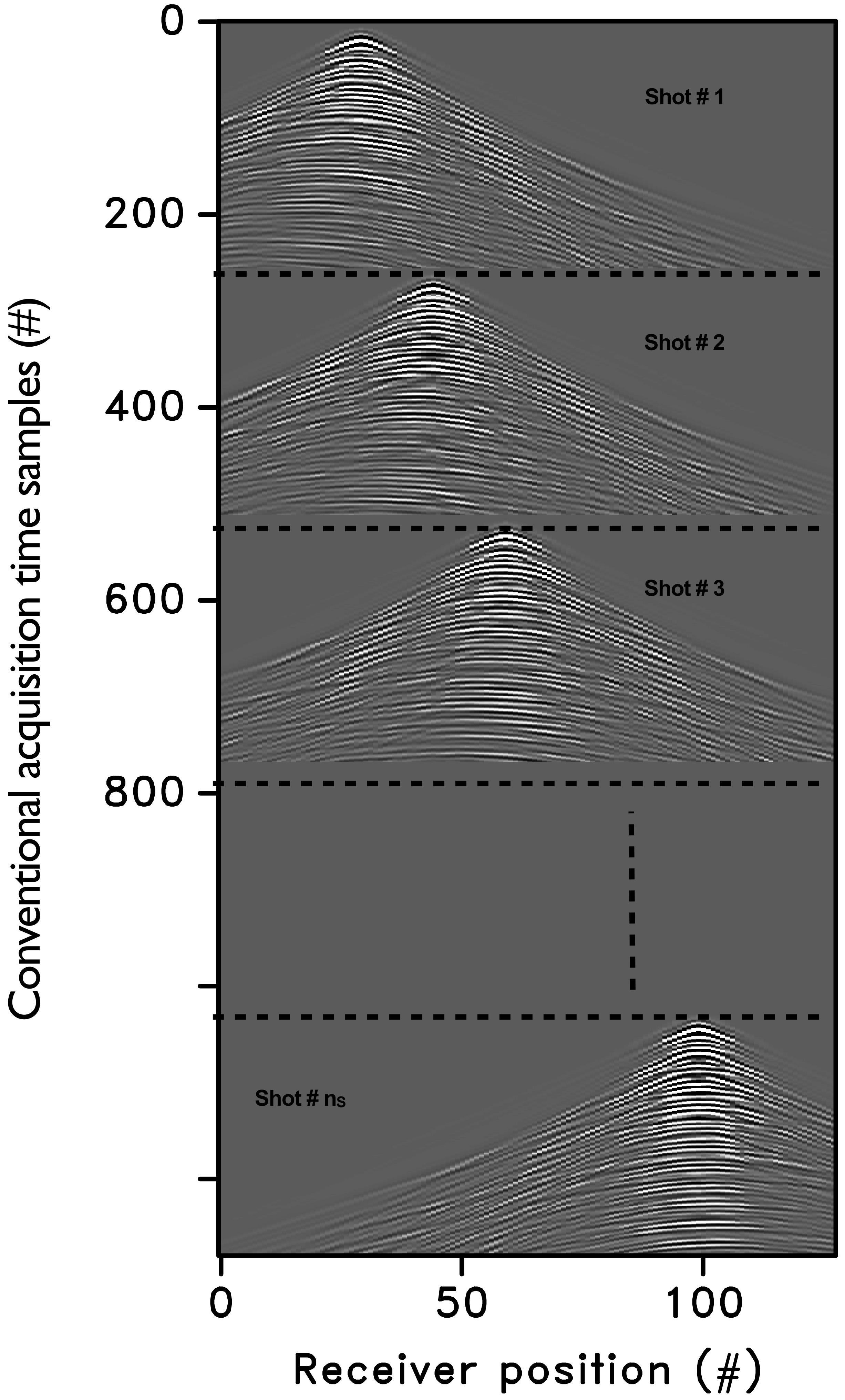
would like to have on *regular* grid (*all* shots *w/o overlaps* between shot records)

$$\mathbf{b} = \mathbf{\Gamma R} \, \mathbf{d}$$

b



d



SLIM

Sparsity-promoting recovery

$$\mathbf{d} = \mathbf{S^H x}$$

$$\tilde{\mathbf{x}} = \arg\min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{subject to} \quad \mathbf{Ax} = \mathbf{b}$$

$\mathbf{x}$	*a* choice of curvelet coefficients for $\mathbf{d}$
$\mathbf{S^H}$	a transform domain synthesis
$\mathbf{A}$	measurement operator : $\mathbf{\Gamma R S^H}$
	$\mathbf{\Gamma}$ is blending operator, $\mathbf{R}$ is regularization operator
$\mathbf{b}$	blended data
$\tilde{\mathbf{x}}$	estimated curvelet coefficients for source separated wavefield
$\tilde{\mathbf{d}}$	$(= \mathbf{S^H}\tilde{\mathbf{x}})$ estimated source separated wavefield

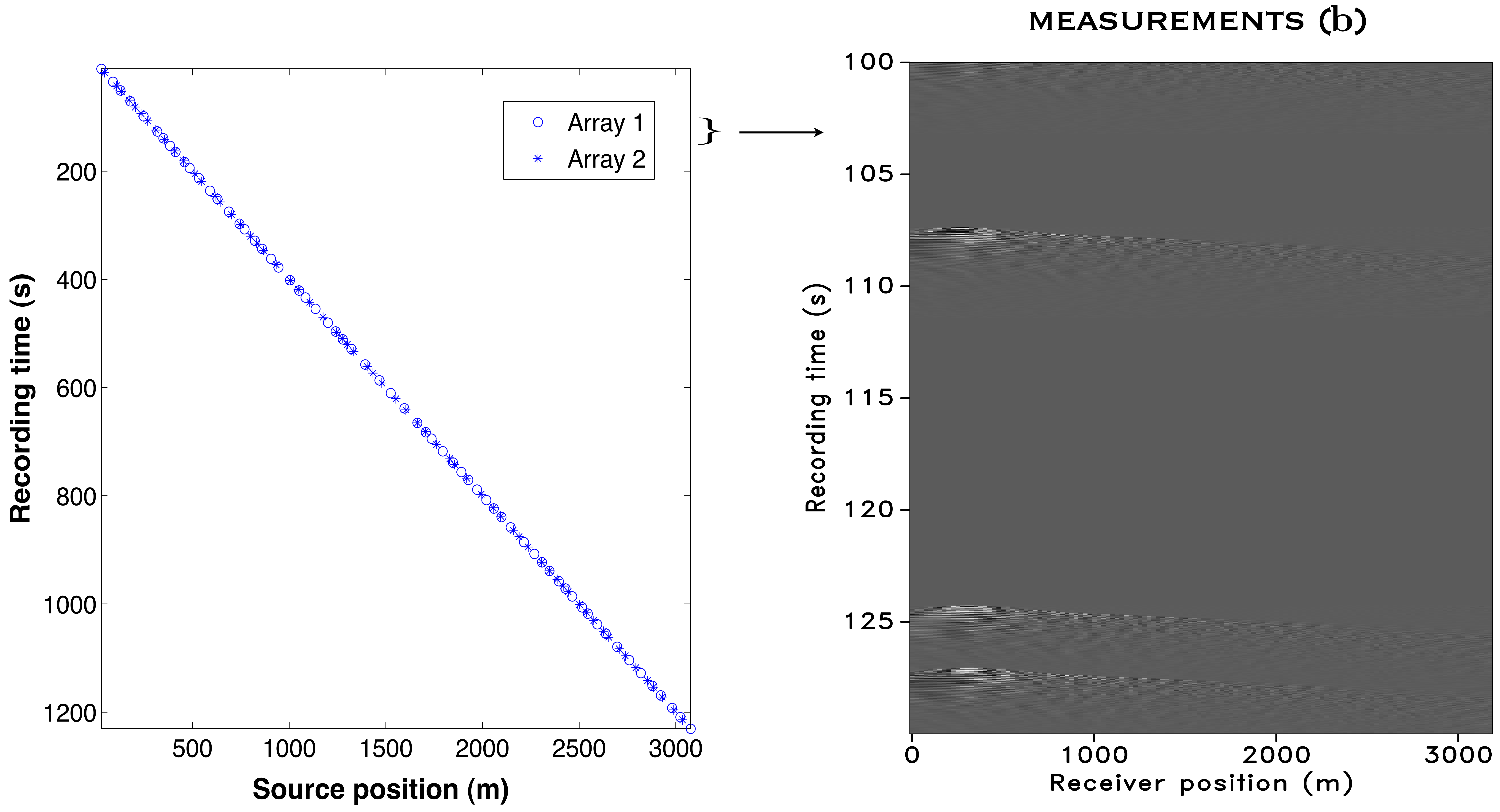
Outline

- Design of time-*jittered* acquisition
  - jitter in *time* ⇒ jittered in *space* (*shot* locations)
  - low vs. high shot-time jitter
- Recovery strategy
- Experimental results of *sparsity*-promoting processing
  - wavefield recovery via "*deblending*" & *interpolation* from (coarse) *jittered/irregular* to (fine) *regular* sampling grid

Time-jittered OBC acquisition

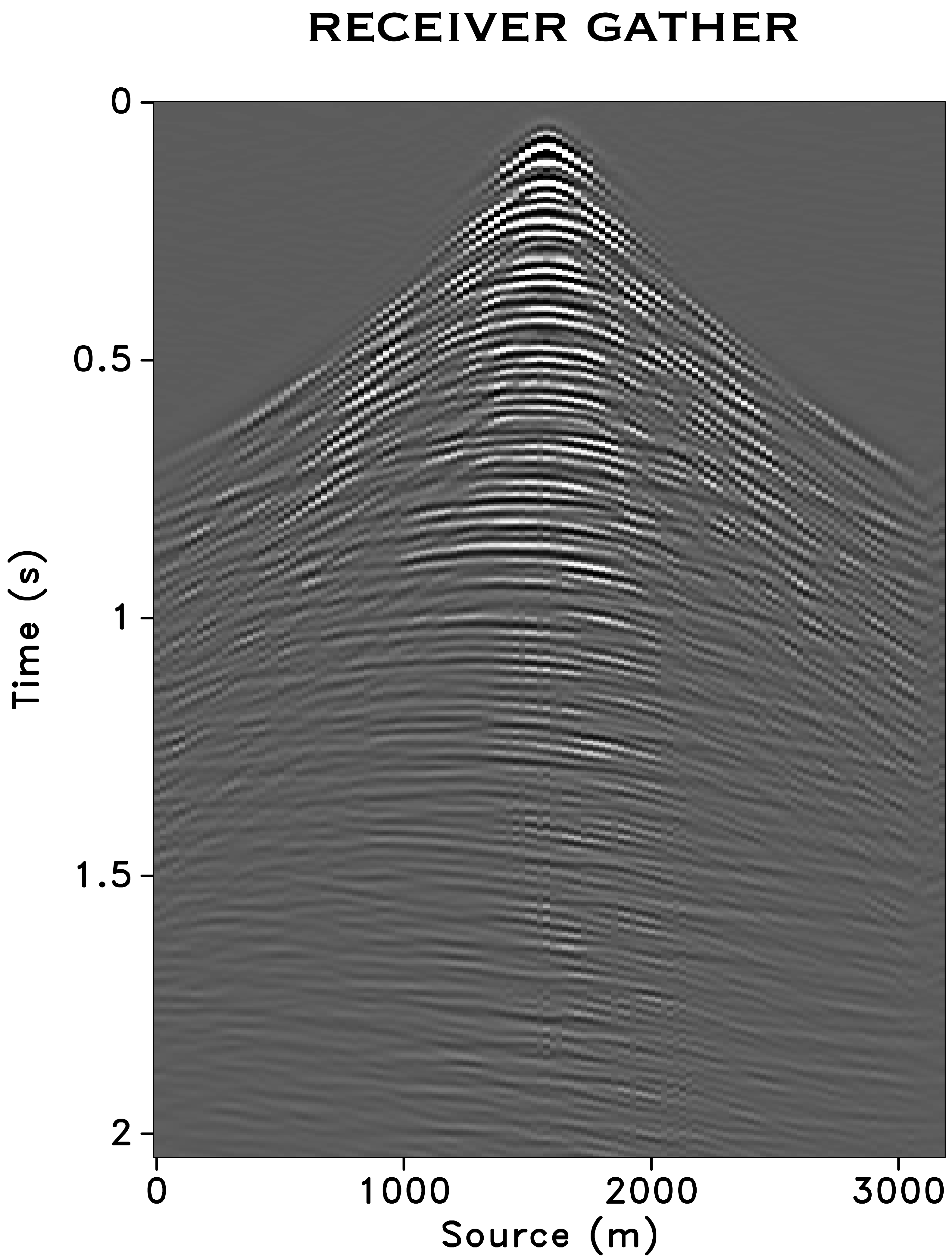
[1 source vessel, speed = 5 knots, underlying grid: 25 m]

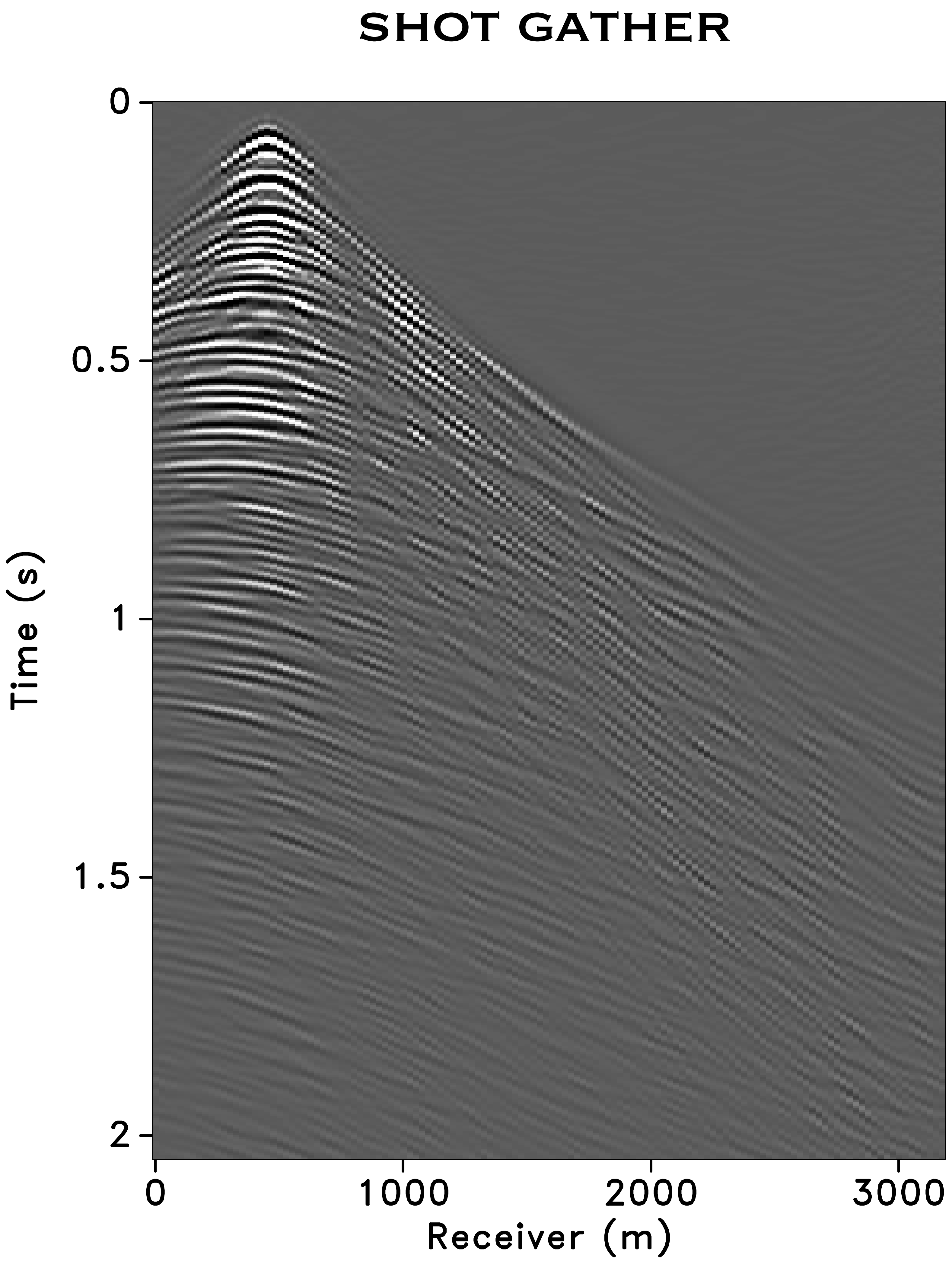
[no. of *jittered* source locations is *half* the number of sources (per array) in *ideal* periodic survey w/o overlap]



Sparsity-promoting recovery *on the grid* (14.2 dB)

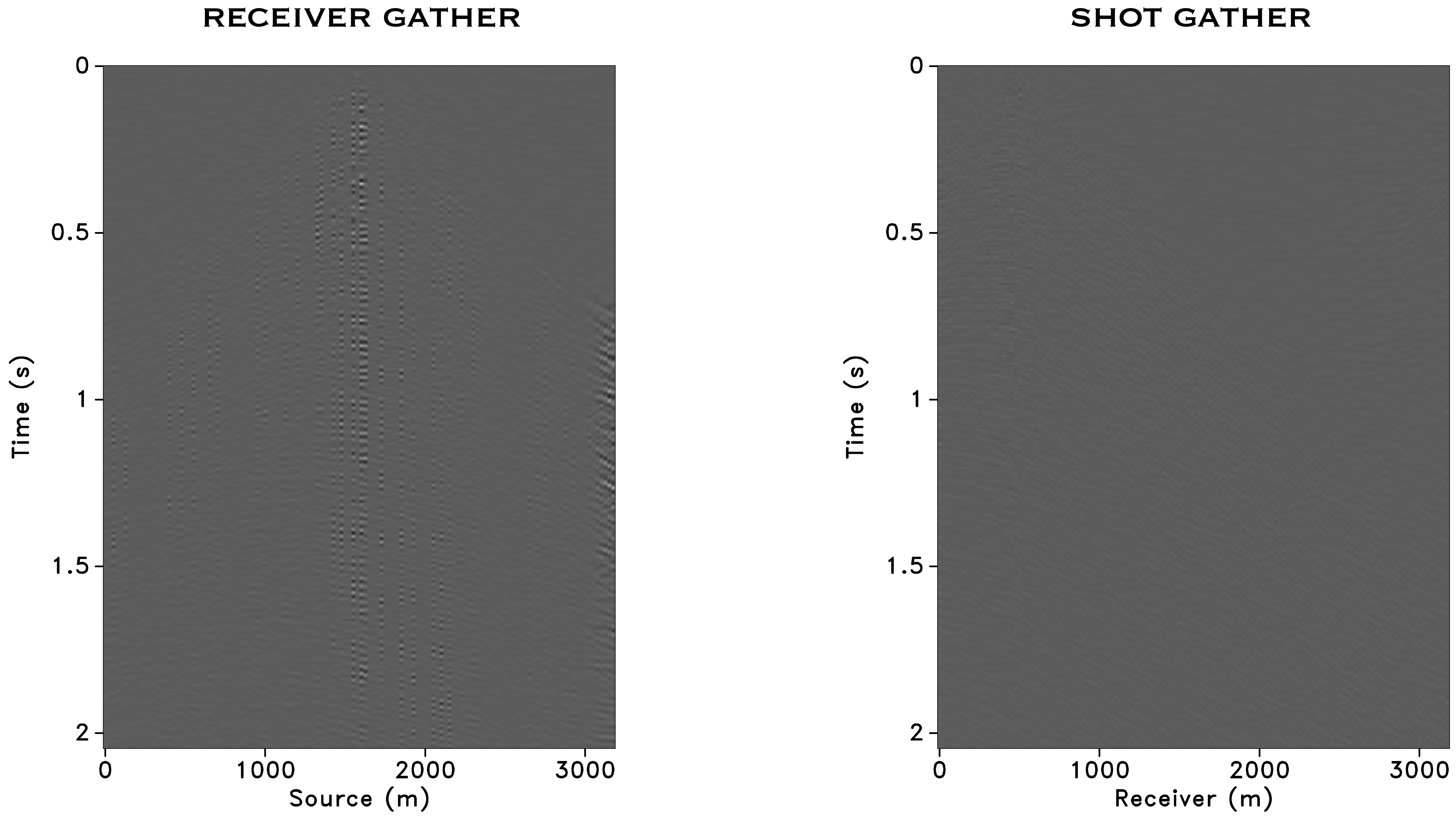
[“deblending” from *jittered* 50m grid to *regular* 25m grid]





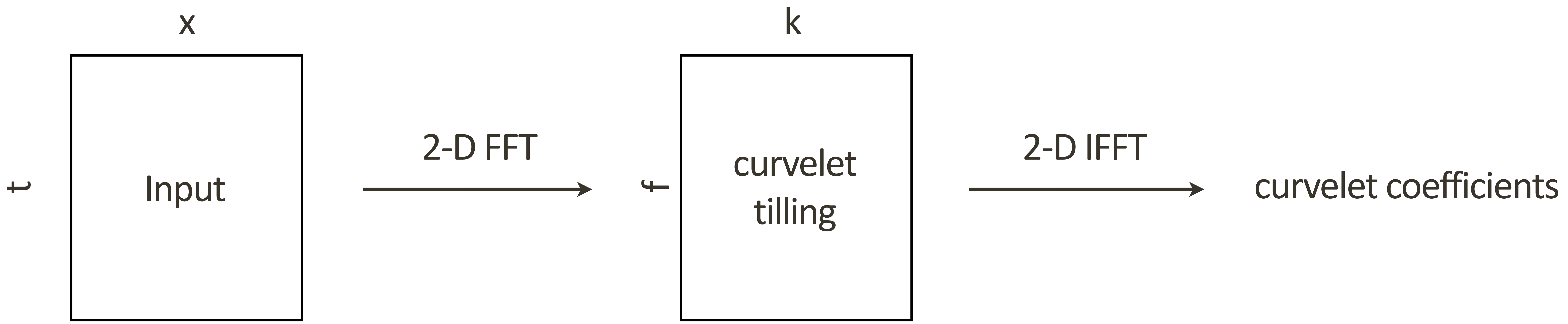
Sparsity-promoting recovery *on the grid* (14.2 dB)

["deblending" from *jittered* 50m grid to *regular* 25m grid] (difference)

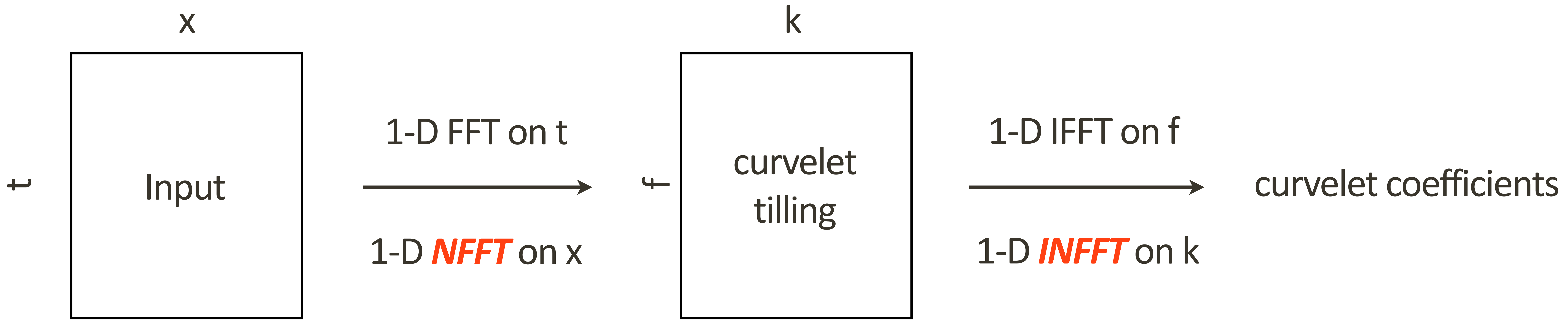


FDCT vs. NFDCT

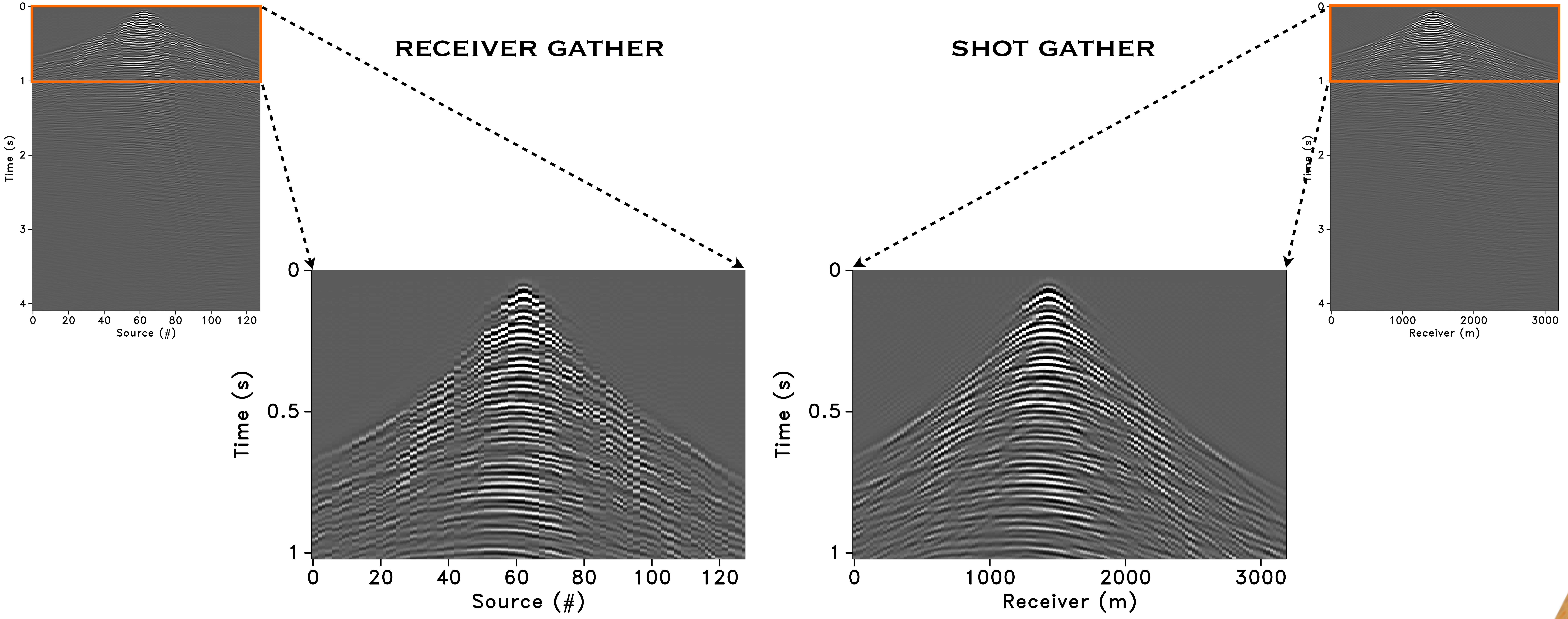
Fast Discrete Curvelet Transform



Non-equispaced Fast Discrete Curvelet Transform

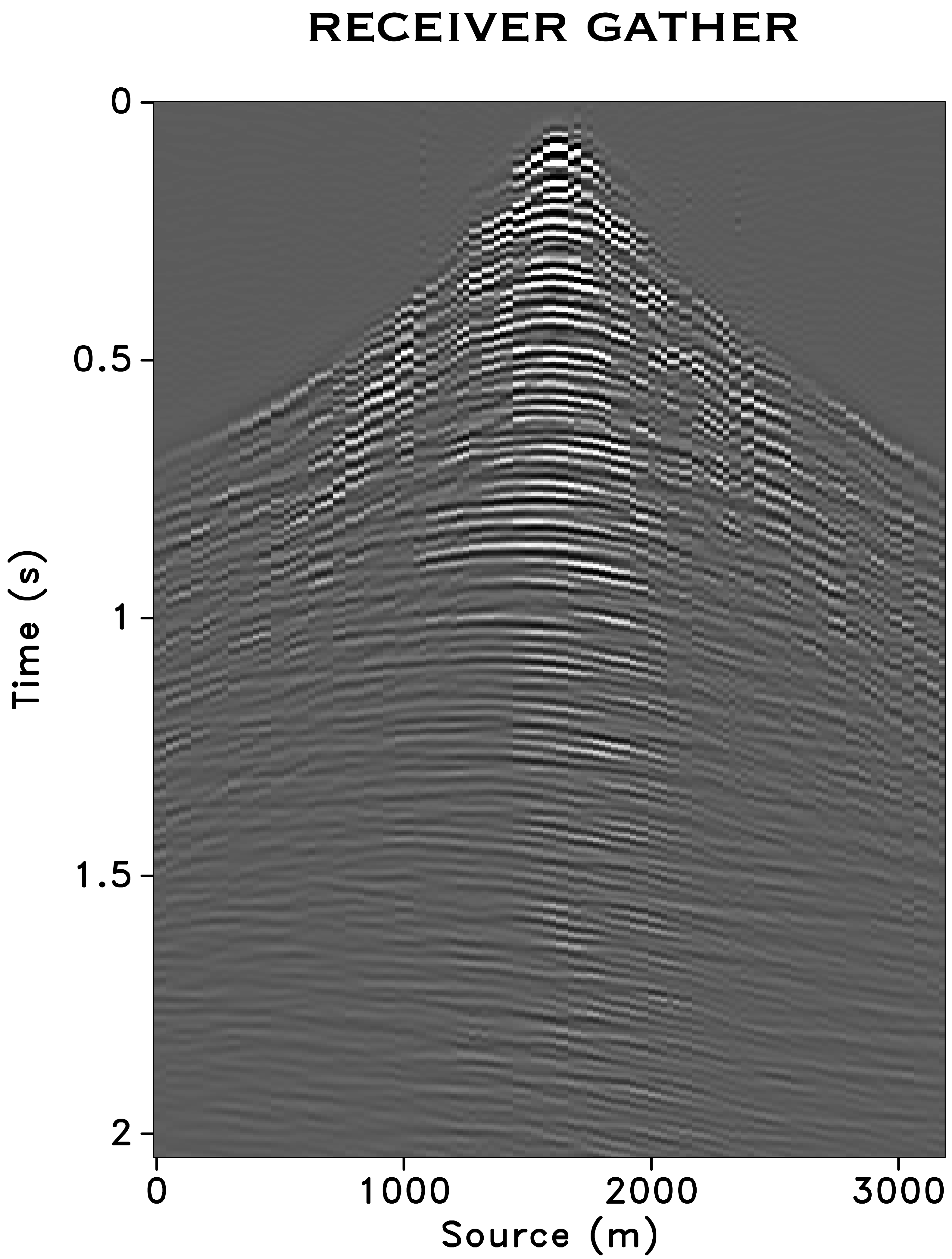


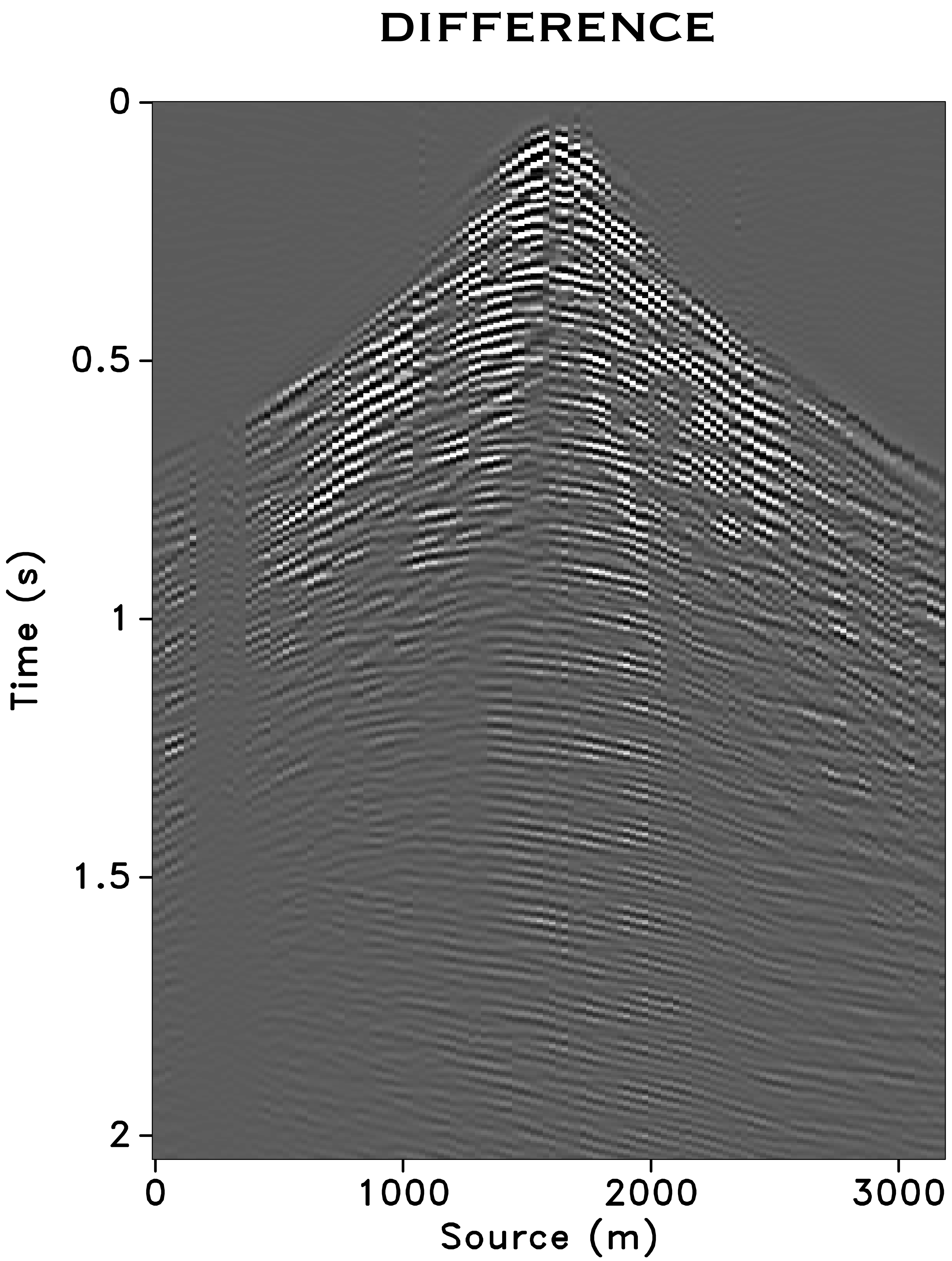
Irregular traces



Recovery with *FDCT* (‘*binning*’)

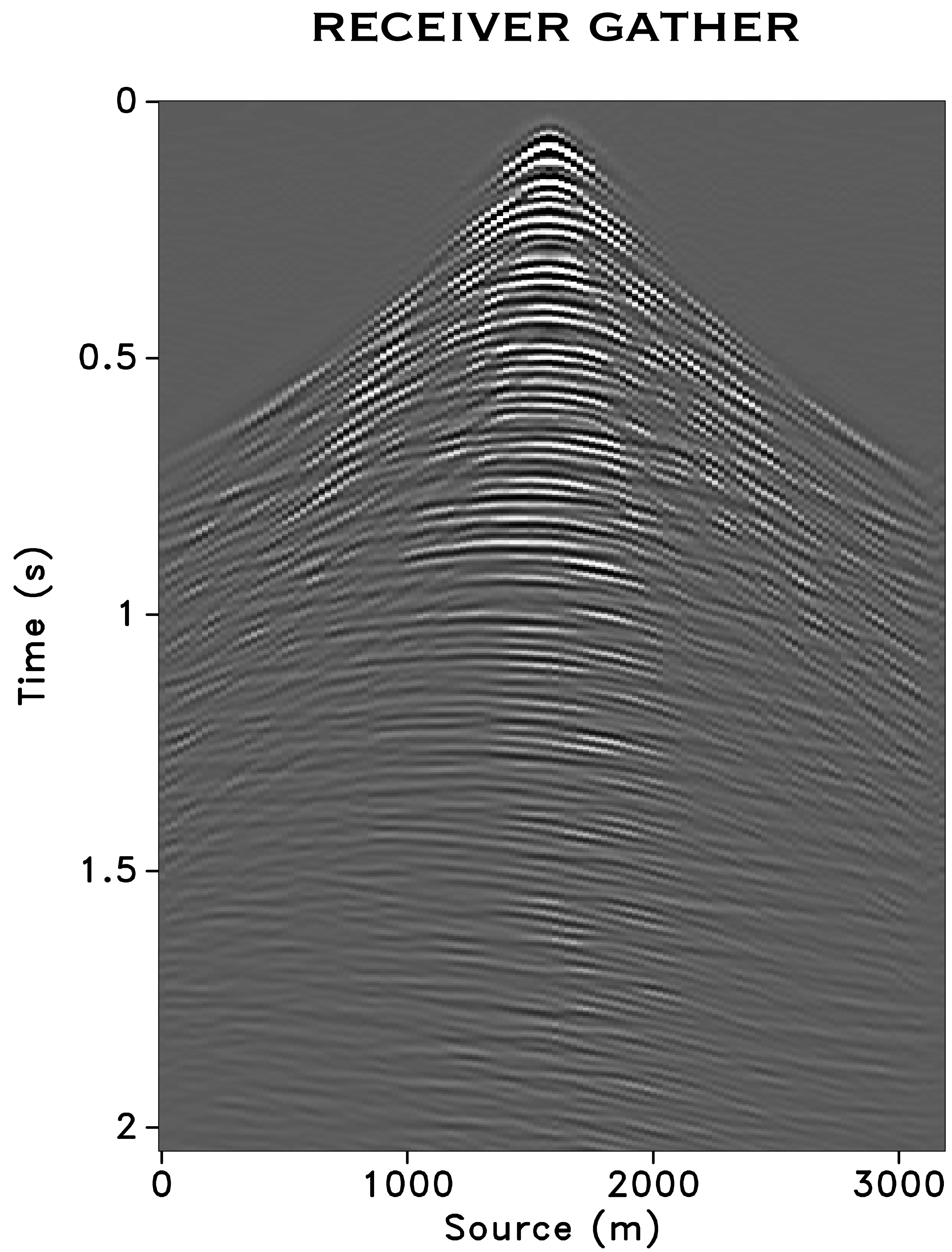
[“deblending” from *jittered* 50m grid to *regular* 25m grid]

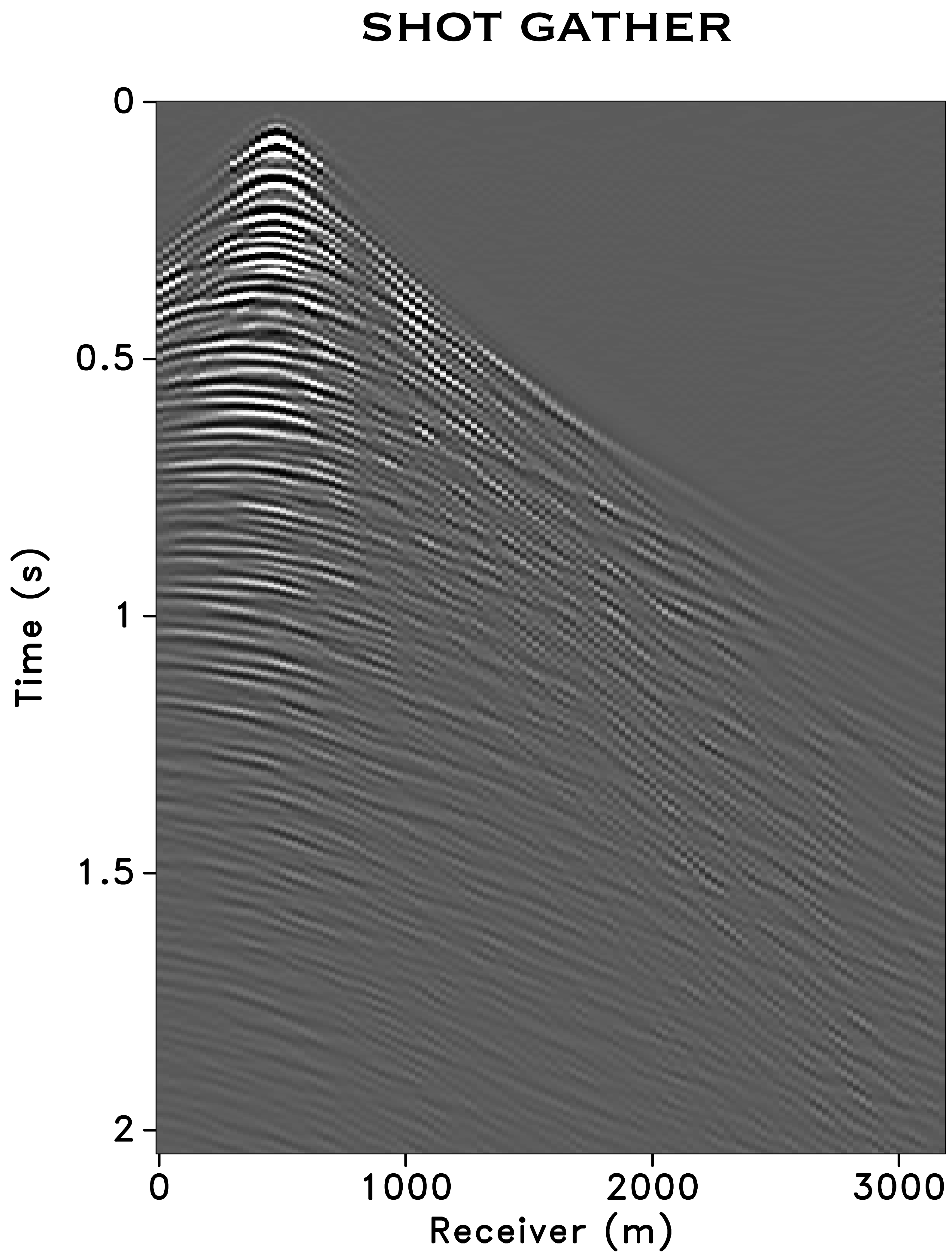




Sparsity-promoting recovery on *irregular* grid with *NFDCT* (17.1 dB)

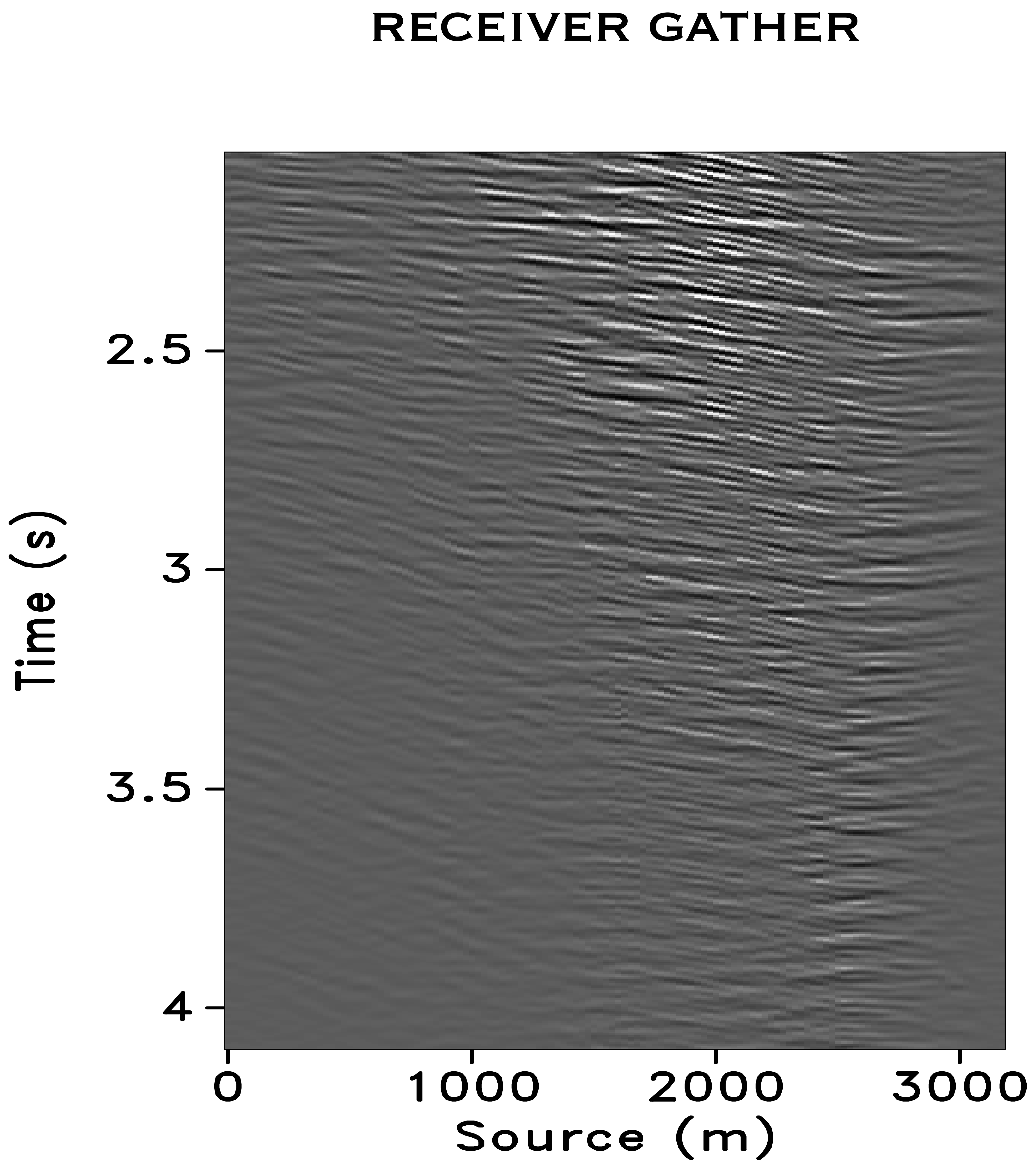
[“deblending” from *jittered* 50m grid to *regular* 25m grid]

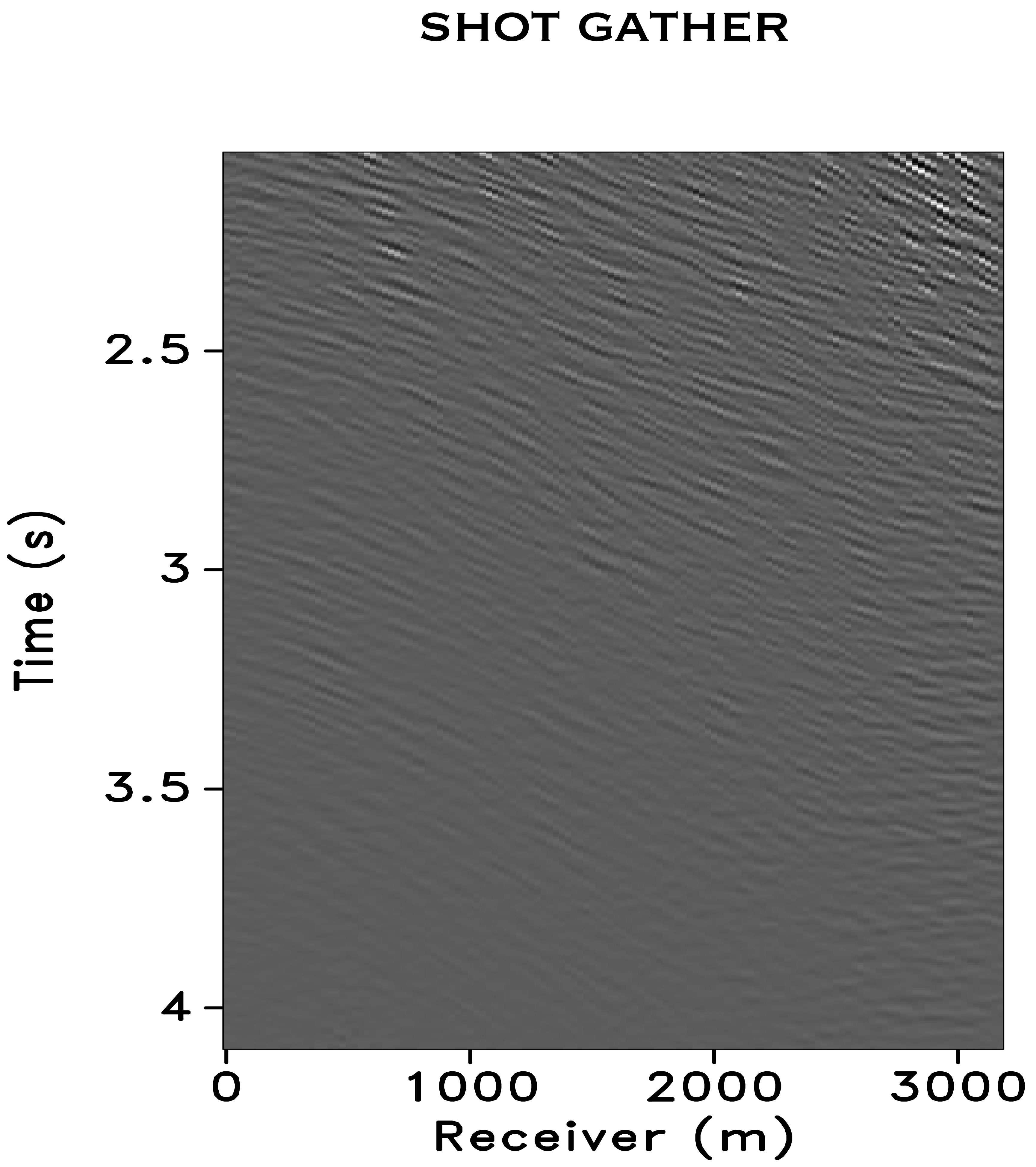




Sparsity-promoting recovery on *irregular* grid with *NFDCT* (17.1 dB)

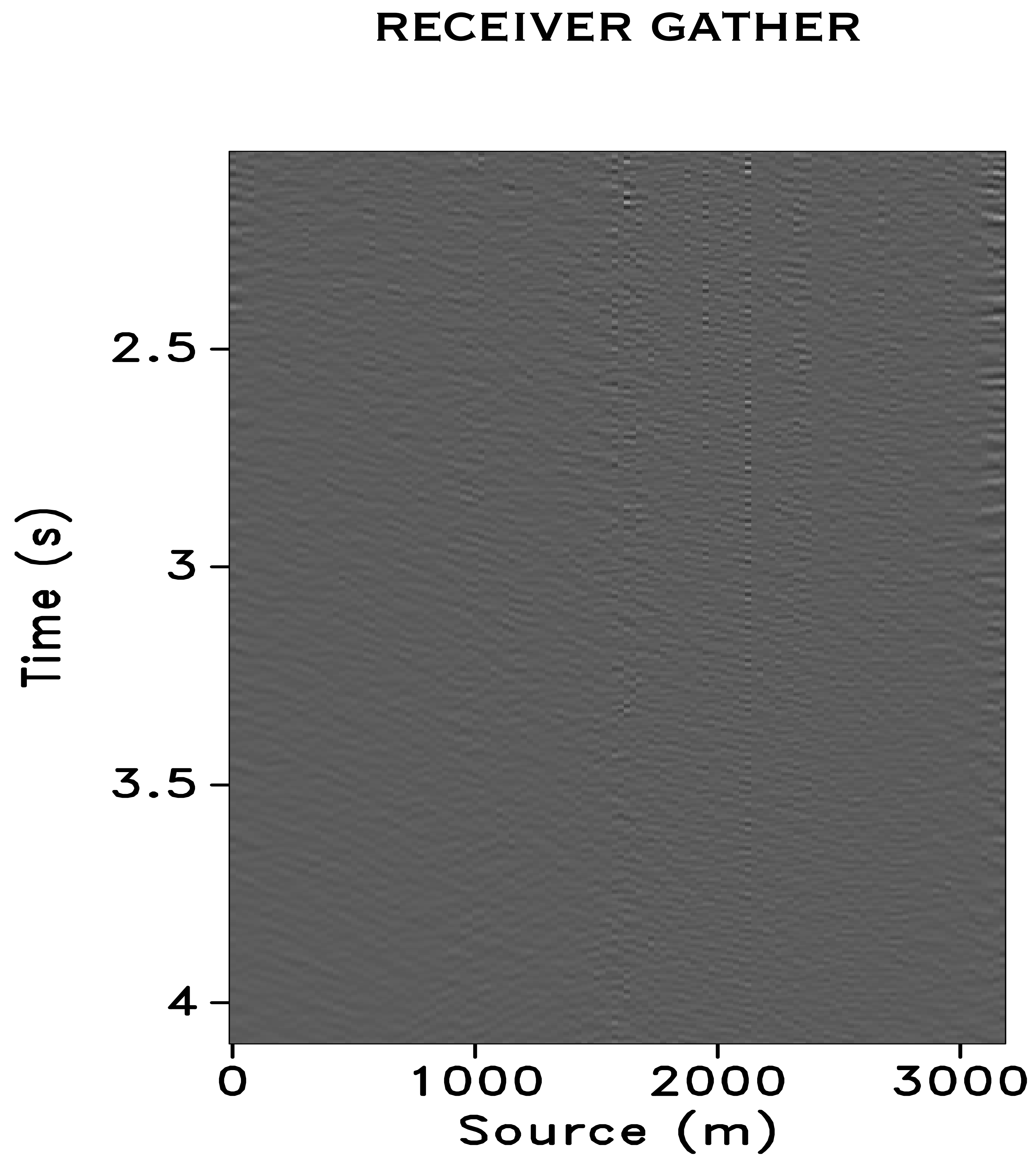
[“deblending” from *jittered* 50m grid to *regular* 25m grid]

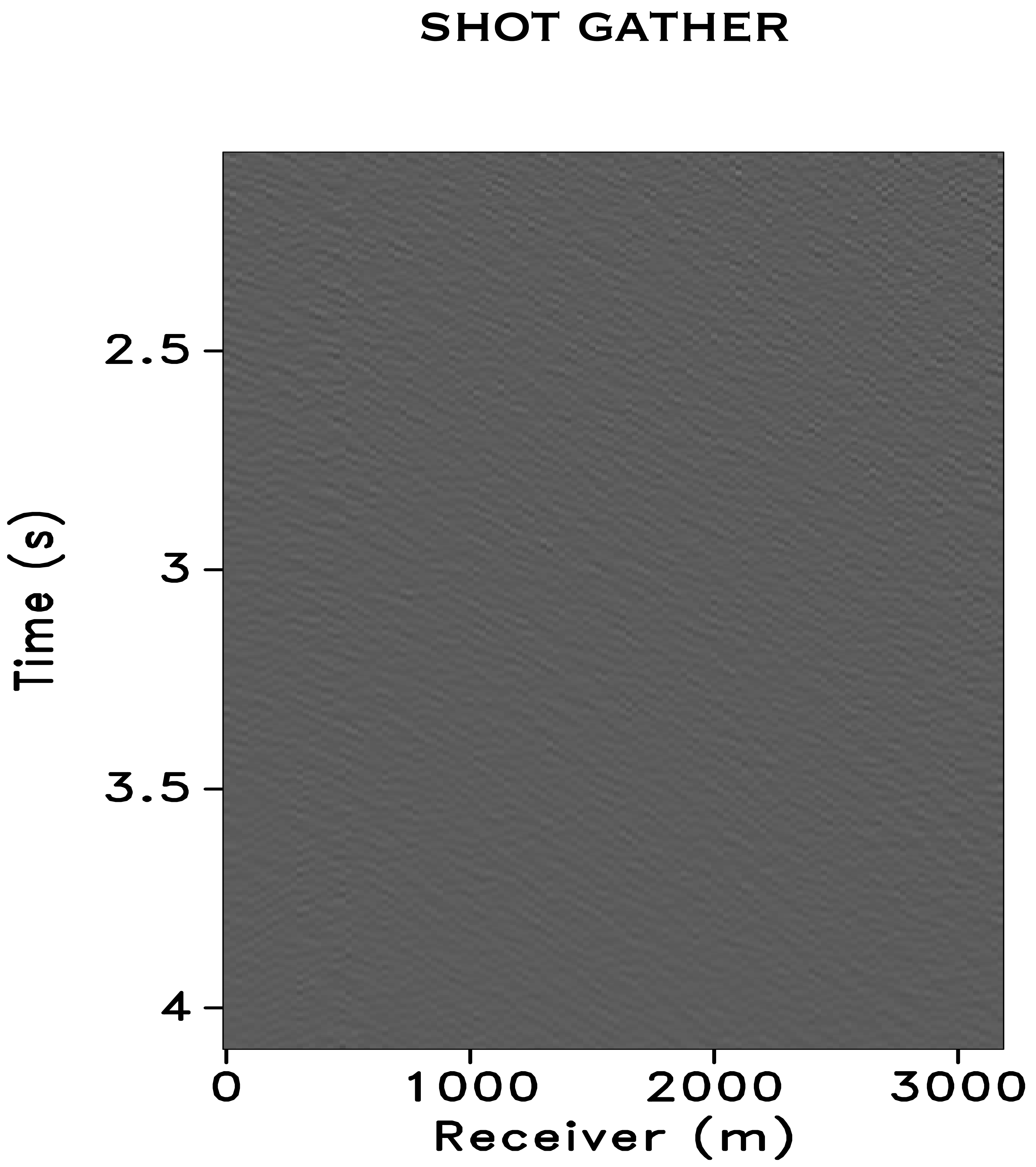




Sparsity-promoting recovery on *irregular* grid with *NFDCT* (17.1 dB)

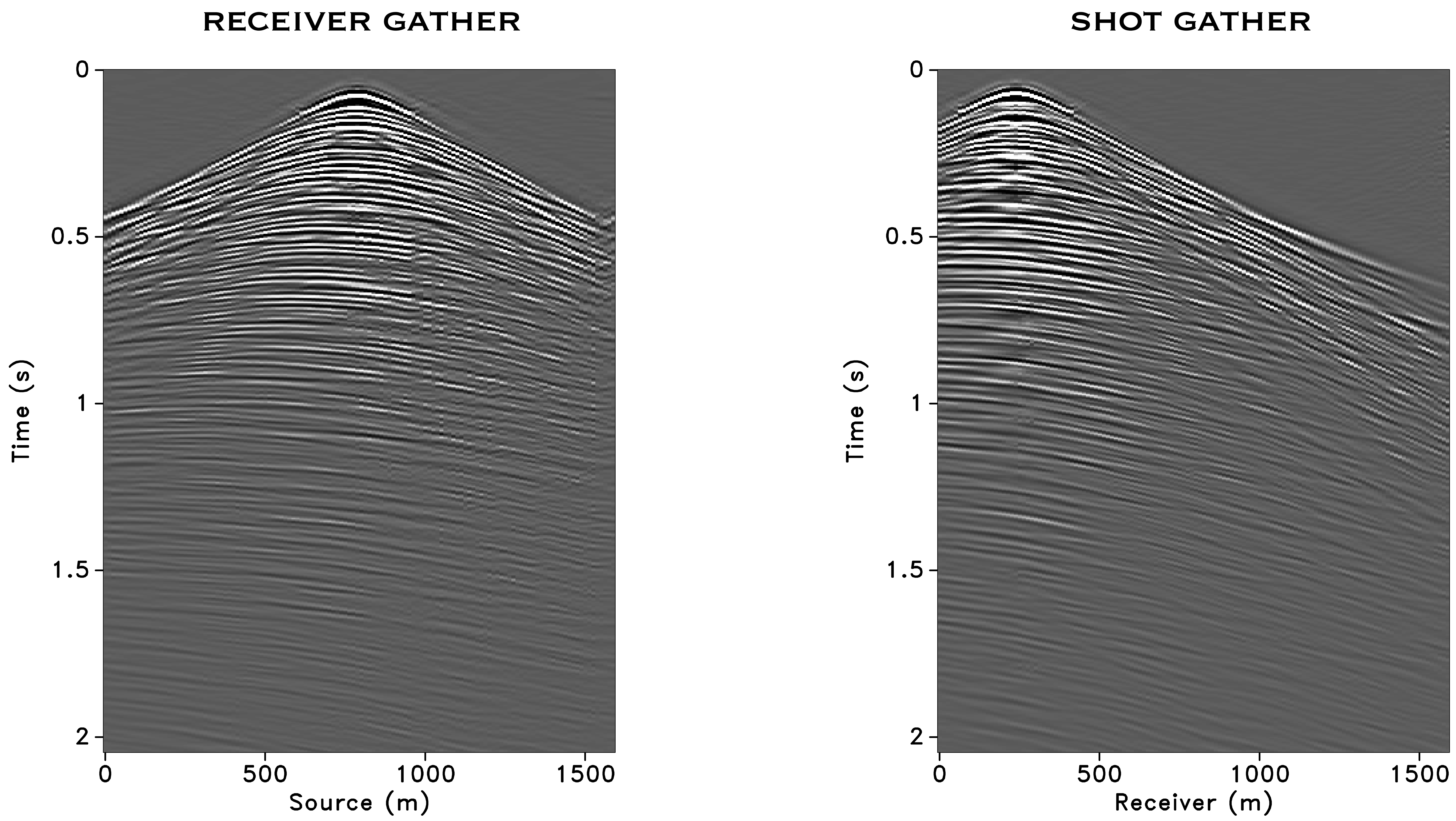
[“deblending” from *jittered* 50m grid to *regular* 25m grid] (difference)





Sparsity-promoting recovery on *irregular* grid with *NFDCT* (12.5 dB)

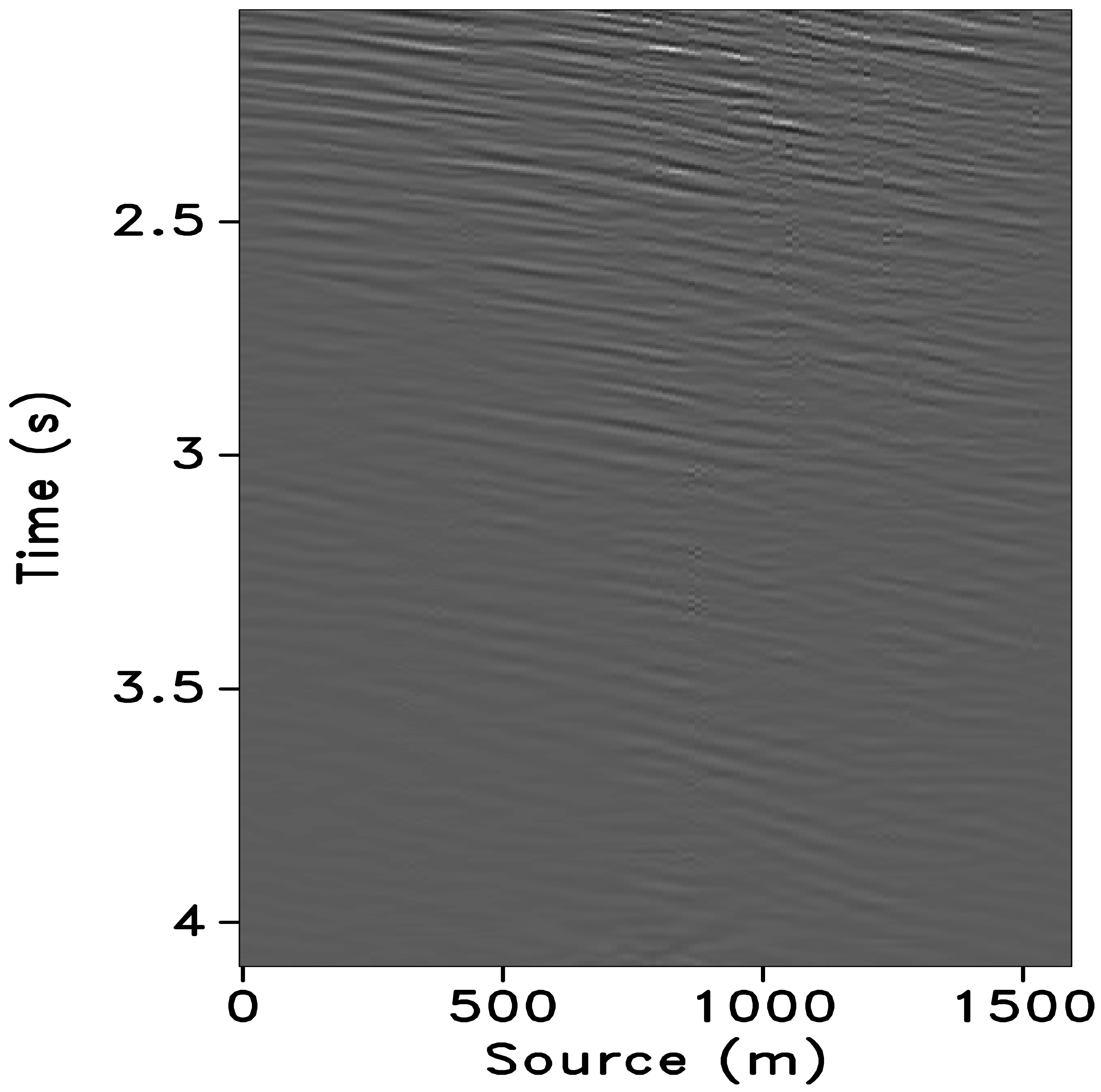
["deblending" + interpolation from *jittered* 50m grid to *regular* 12.5m grid]



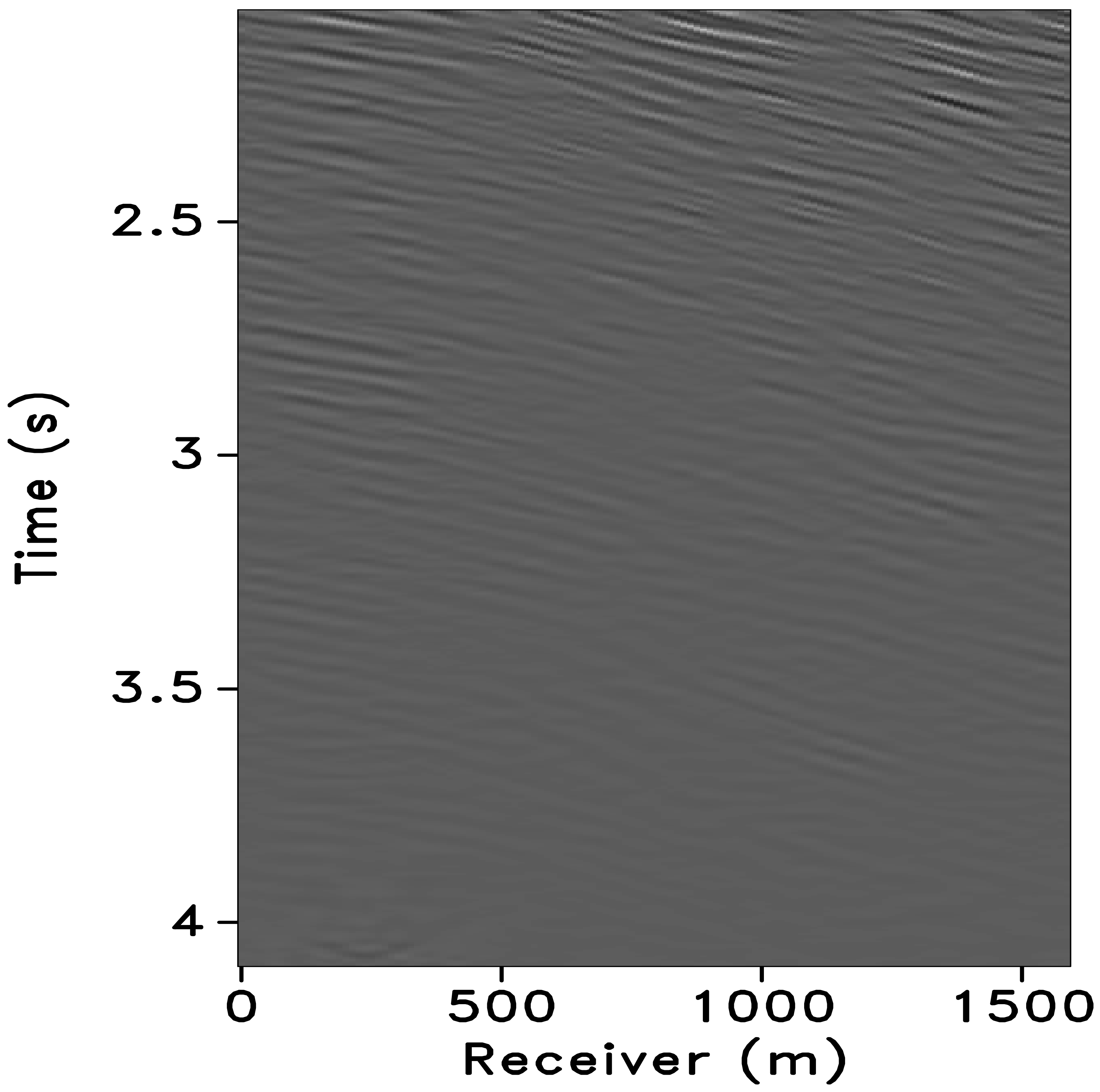
Sparsity-promoting recovery on *irregular* grid with *NFDCT* (12.5 dB)

[“deblending” + interpolation from *jittered* 50m grid to *regular* 12.5m grid]

RECEIVER GATHER



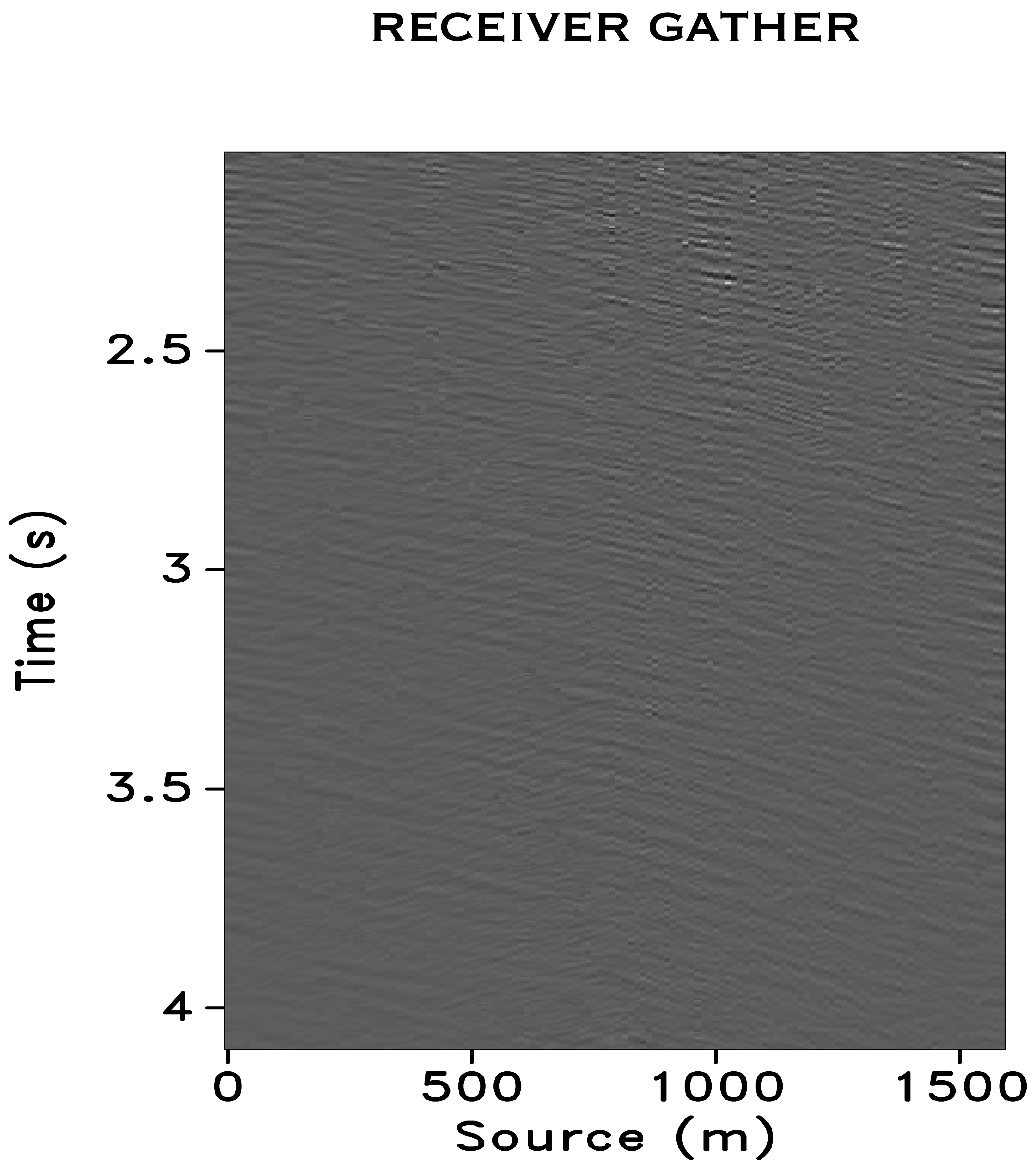
SHOT GATHER

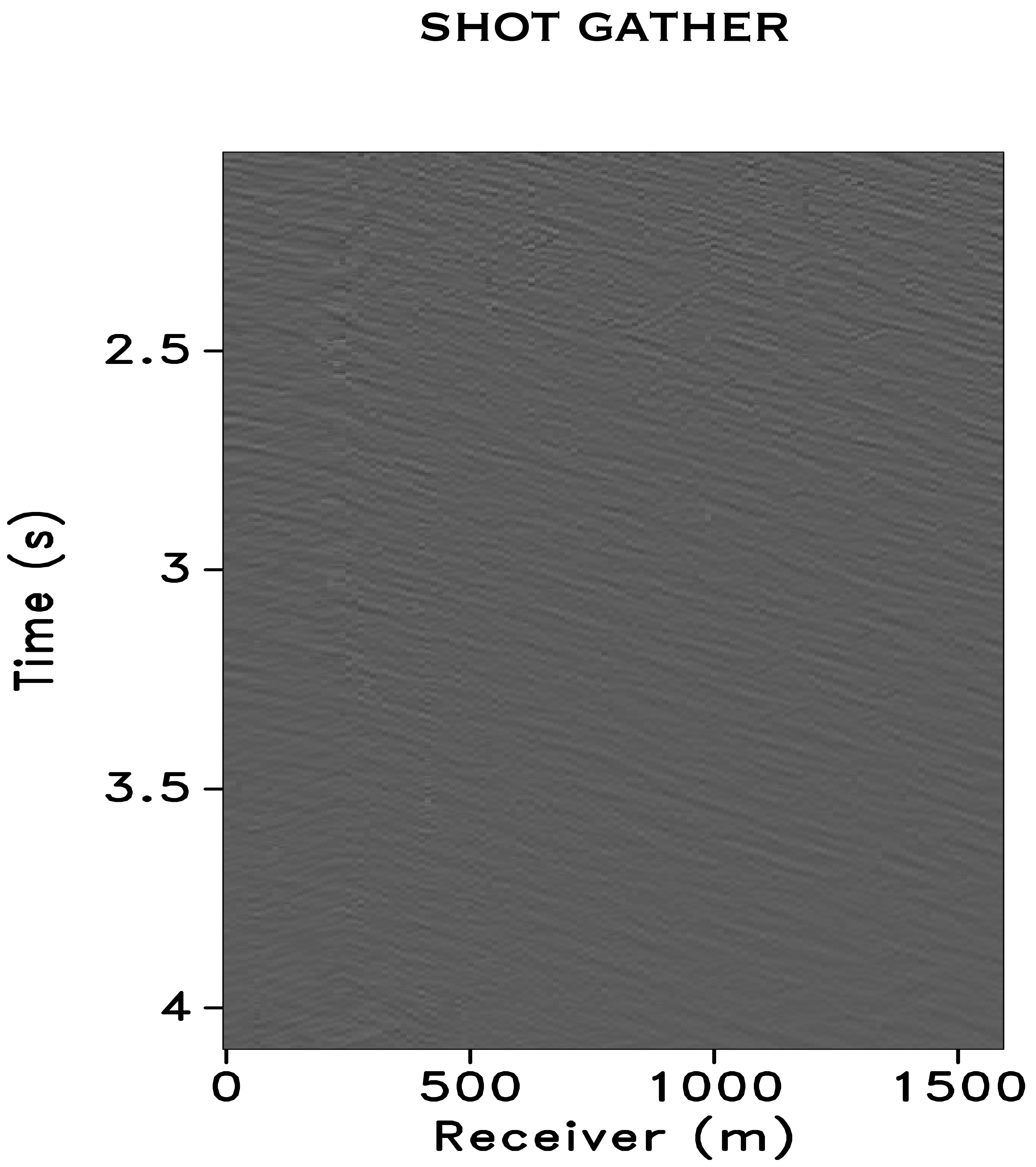


SLIM

Sparsity-promoting recovery on *irregular* grid with *NFDCT* (12.5 dB)

["deblending" + interpolation from *jittered* 50m grid to *regular* 12.5m grid] (difference)





Performance

Improvement spatial sampling ratio (50m to 12.5m)

$$= \frac{\text{no. of spatial grid points recovered from jittered sampling via sparse recovery}}{\text{no. of spatial grid points in conventional sampling}}$$

$$= \frac{128}{64} = 2$$

Summary

	jittered to regular (m)	recovery with ***FDCT*** [SNR (dB)]	recovery with ***NFDCT*** [SNR (dB)]
1 source vessel (2 airgun arrays)	50 to 25	14.2	17.1
	50 to 12.5	11.1	12.5
2 source vessels (2 airgun arrays per vessel)	50 to 25	19.7	21.5
	50 to 12.5	15.0	16.3

Observations

- Larger variability in shot-times seems desirable
  - *incoherent* aliasing
  - wavenumber diversity

- *Source separation* and *interpolation* can be treated as sparse inversion problems - *together*

- With *sparsity*-promoting recovery we can
  - *deblend*, recover the wavefield
  - *regularize*, from a *jittered/irregular* to a *regular* grid
  - *interpolate*, from a *coarse jittered* (50m) grid to a *fine regular* grid (25m, 12.5m, and finer)

Future work

- How much randomness (in shot-times) is sufficient to ensure good source separation?
- Source separation for small variability in shot-times
  - towed streamer acquisition
- Comparisons with rank minimization technique for source separation

Acknowledgements

Thank you!

This work was in part financially supported by the Natural Sciences and Engineering Research Council of Canada Discovery Grant (22R81254) and the Collaborative Research and Development Grant DNOISE II (375142-08). This research was carried out as part of the SINBAD II project with support from the following organizations: BG Group, BGP, BP, Chevron, ConocoPhillips, Petrobras, PGS, Total SA, and WesternGeco.

References

van den Berg, E., and Friedlander, M.P., 2008, Probing the Pareto frontier for basis pursuit solutions, *SIAM Journal on Scientific Computing, 31, 890-912.*

Candès, E. J., and L. Demanet, 2005, The curvelet representation of wave propagators is optimally sparse: *Comm. Pure Appl. Math, 58, 1472–1528.*

Candès, E. J., L. Demanet, D. L. Donoho, and L. Ying, 2005, Fast discrete curvelet transforms: *Multiscale Modeling and Simulation, 5, 861–899.*

Donoho, D. L., 2006, Compressed sensing: *IEEE Trans. Inform. Theory, 52, 1289–1306.*

Hennenfent, G., and Felix J. Herrmann, 2008, Simply denoise: wavefield reconstruction via jittered undersampling, *Geophysics, 73, 19-28.*

Hennenfent, G., L. Fenelon, and Felix J. Herrmann, 2010, Nonequispaced curvelet transform for seismic data reconstruction: a sparsity-promoting approach, *Geophysics, 75, WB203-WB210.*

Mansour, H., Haneet Wason, Tim T. Y. Lin, and Felix J. Herrmann, 2012, Randomized marine acquisition with compressive sampling matrices: *Geophysical Prospecting, 60, 648–662.*

Wason, H., and Felix J. Herrmann, 2013, Ocean bottom seismic acquisition via jittered sampling: *75th EAGE Conference and Exhibition*

Wason, H., and Felix J. Herrmann, 2013, Time-jittered ocean bottom seismic acquisition: *SEG Technical Program Expanded Abstracts*