Full-azimuth seismic data processing with coil acquisition

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SLIM
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Motivation

What are the advantages of exploiting sparse/low-rank structure at global scale?

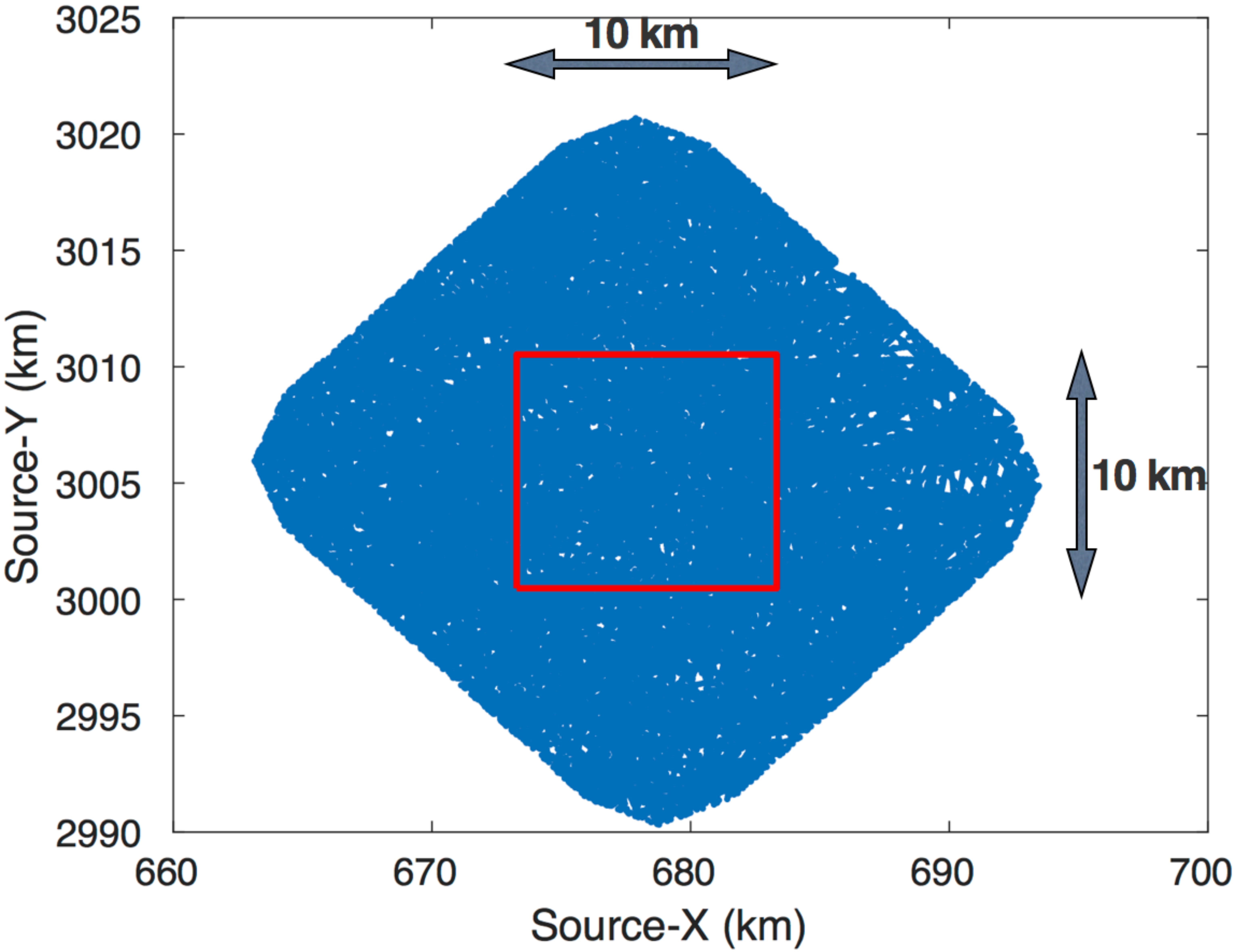
Should we window seismic data for processing?

Practical framework to handle production-scale interpolation w/o windowing

Validate SLIM technology on field data

Survey information—coil acquisition

Source map

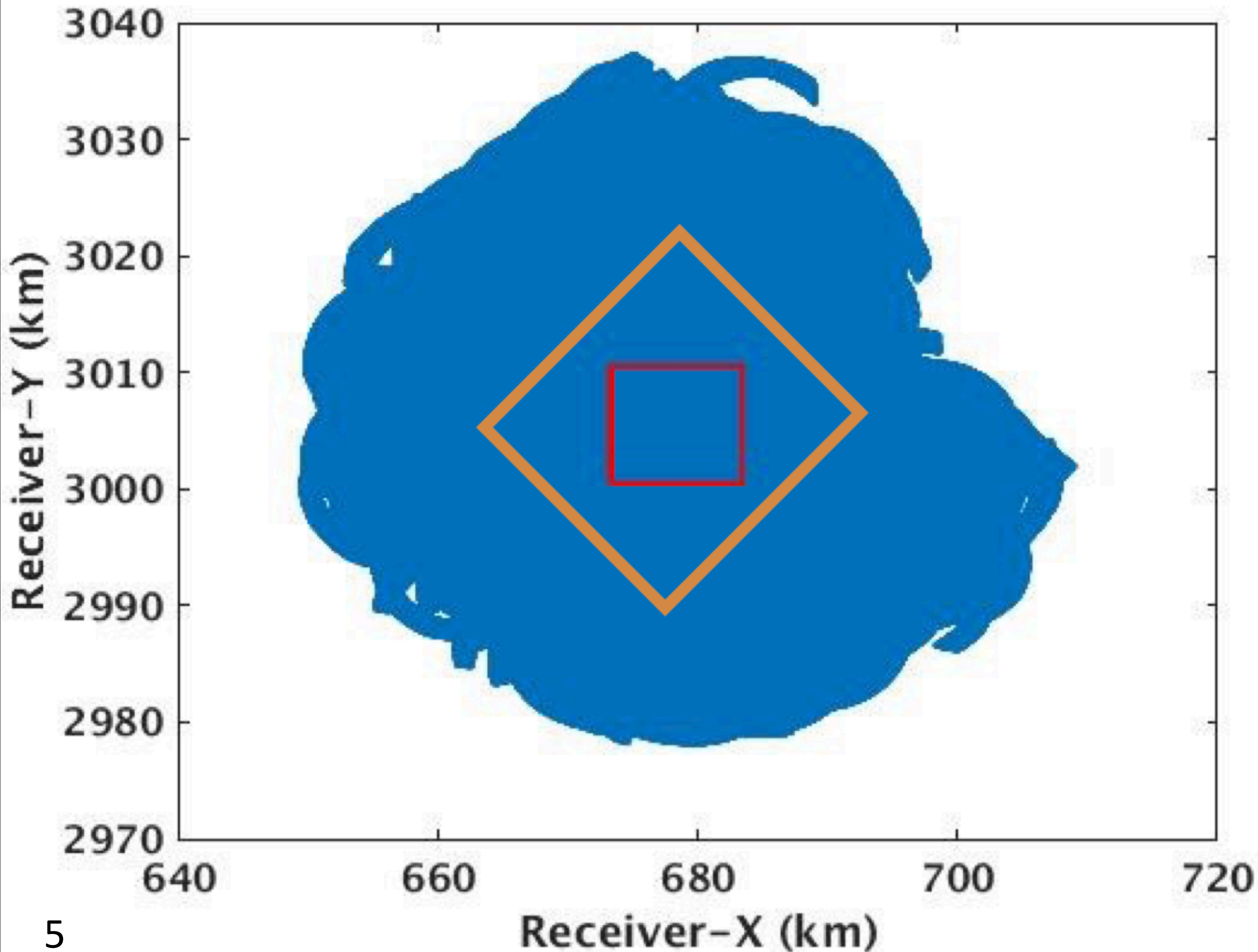


Blue region : source coverage map

Red region : 10x10 km test area selected for interpolation

Maximum offset along each coil is 8km

Receiver map

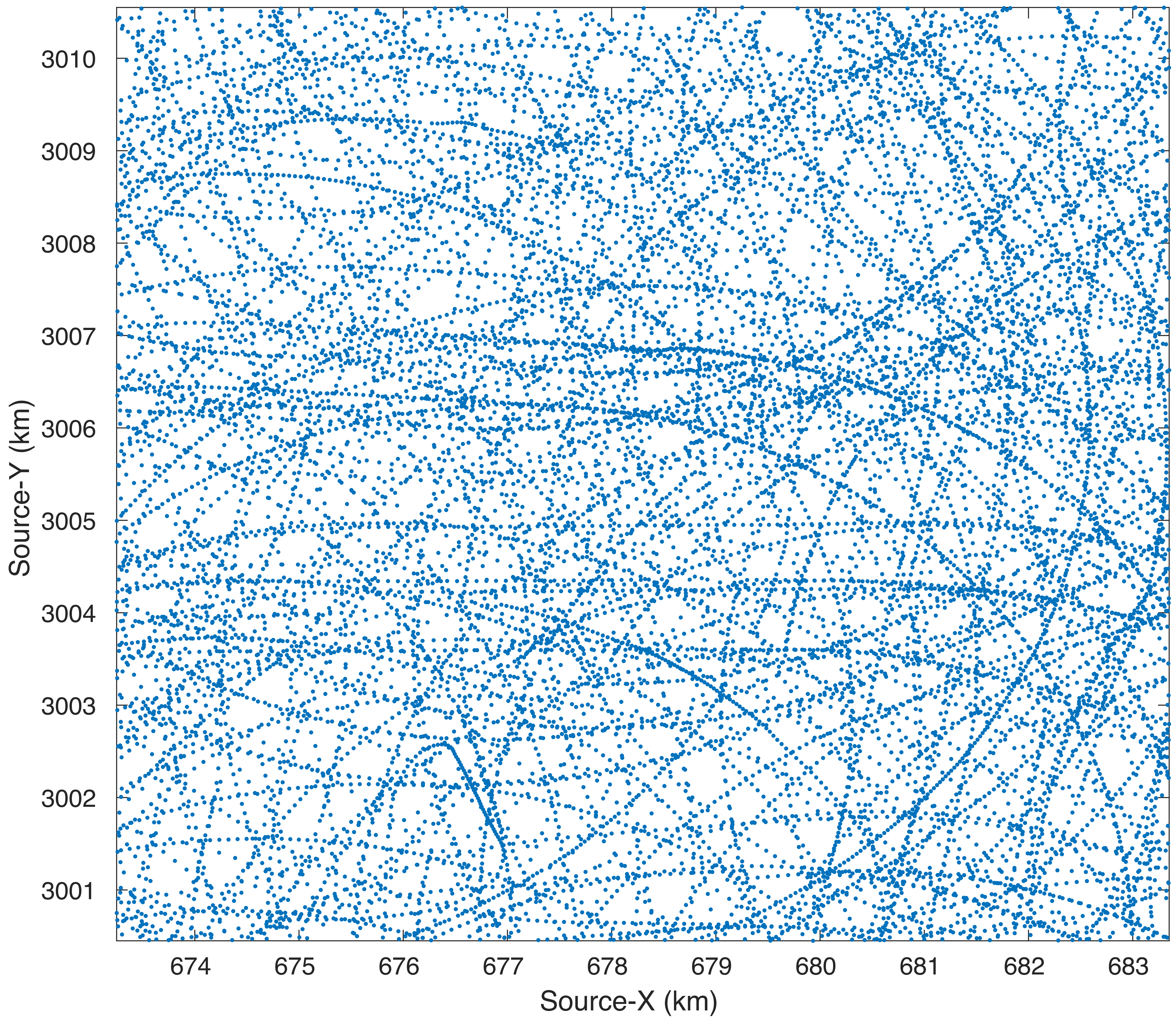


Blue region : receiver coverage map

Red region : 10x10 km test area selected for interpolation

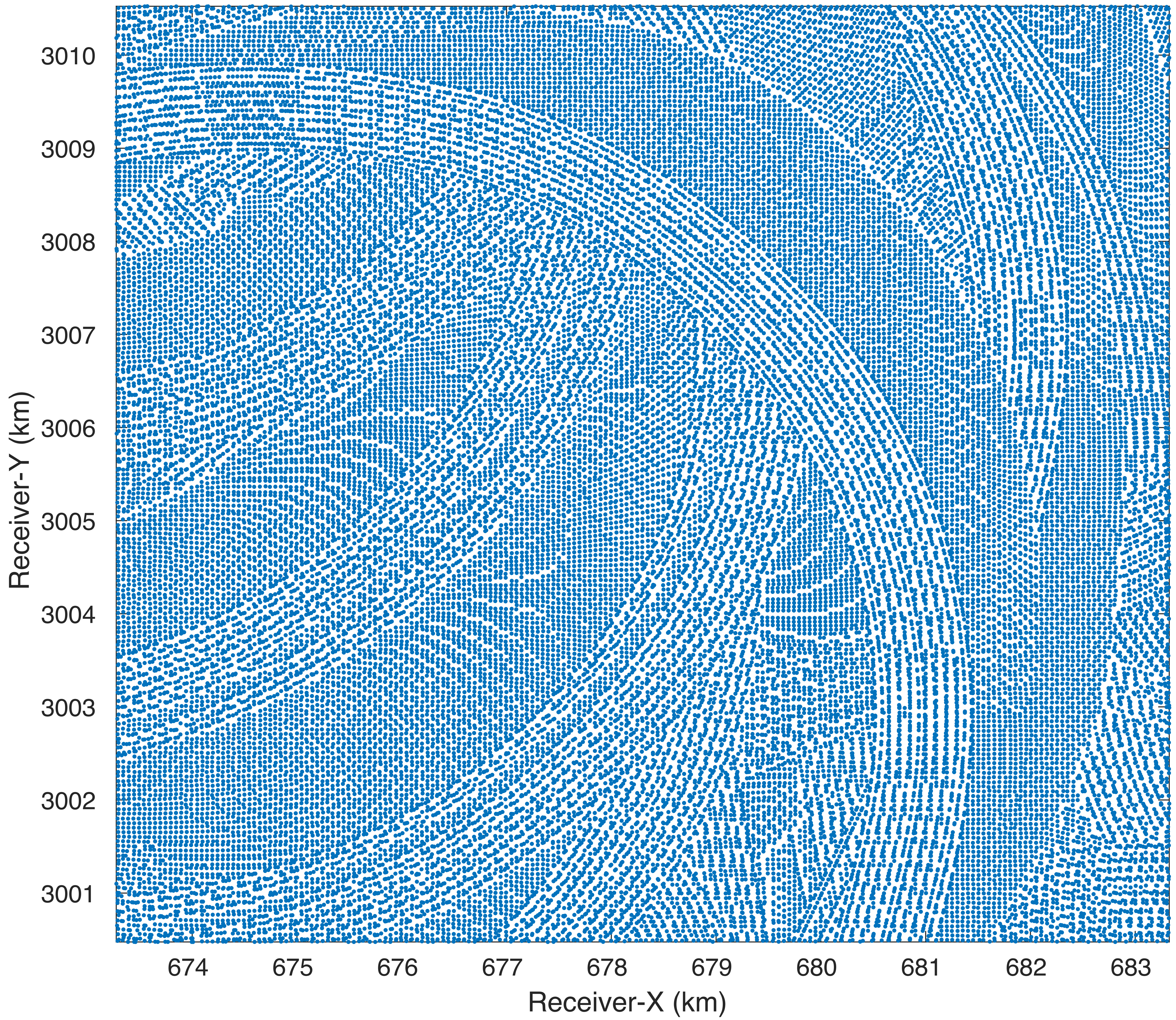
Orange region : source coverage map

Source coverage map (test area)



Overall source coverage : 70%
grid discretization : 100 x 100 m

Receiver coverage map (test area)



Overall receiver coverage : 99%
grid discretization : 50 x 50 m

Interpolation objective

Sources at every 100m grid in both inline & cross-line directions

Receivers at every 50m grid in both inline & cross-line directions

Output of interpolation resulted in full-azimuth OBN type acquisition for both sources & receivers

Quick recap—matrix completion

[Candes and Plan 2010, Oropeza and Sacchi 2011]

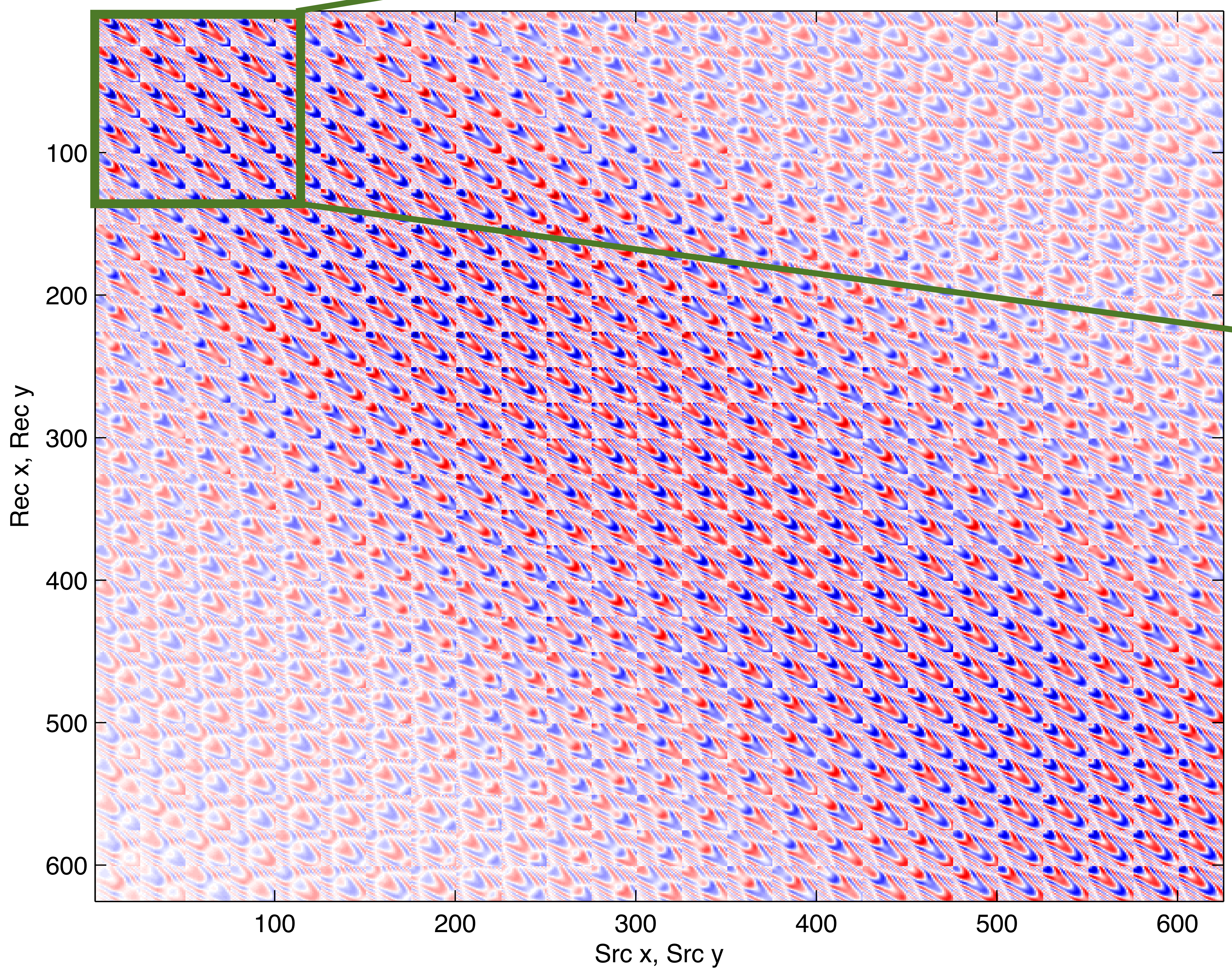
Matrix completion

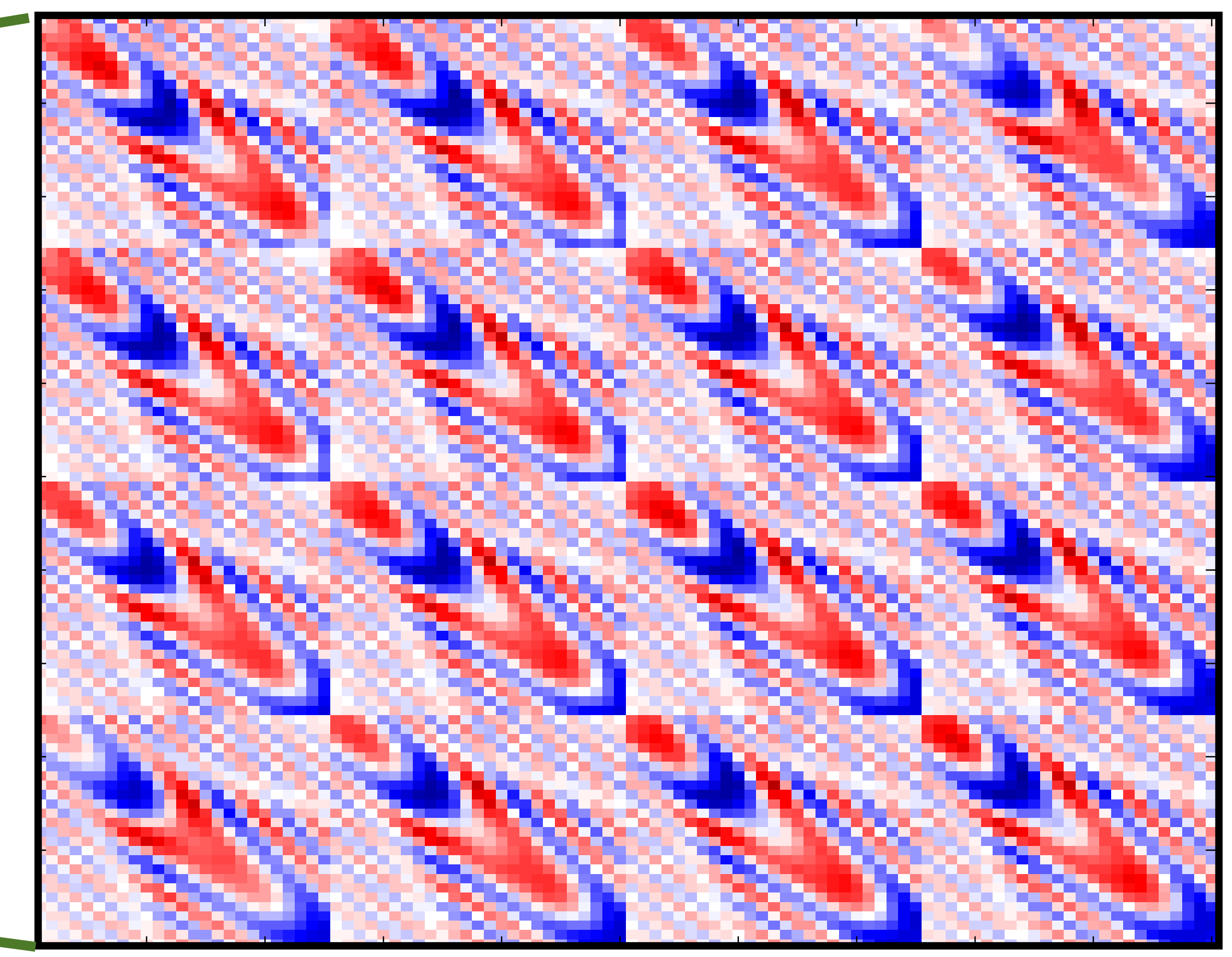
- signal structure
  - *low rank/fast decay* of singular values

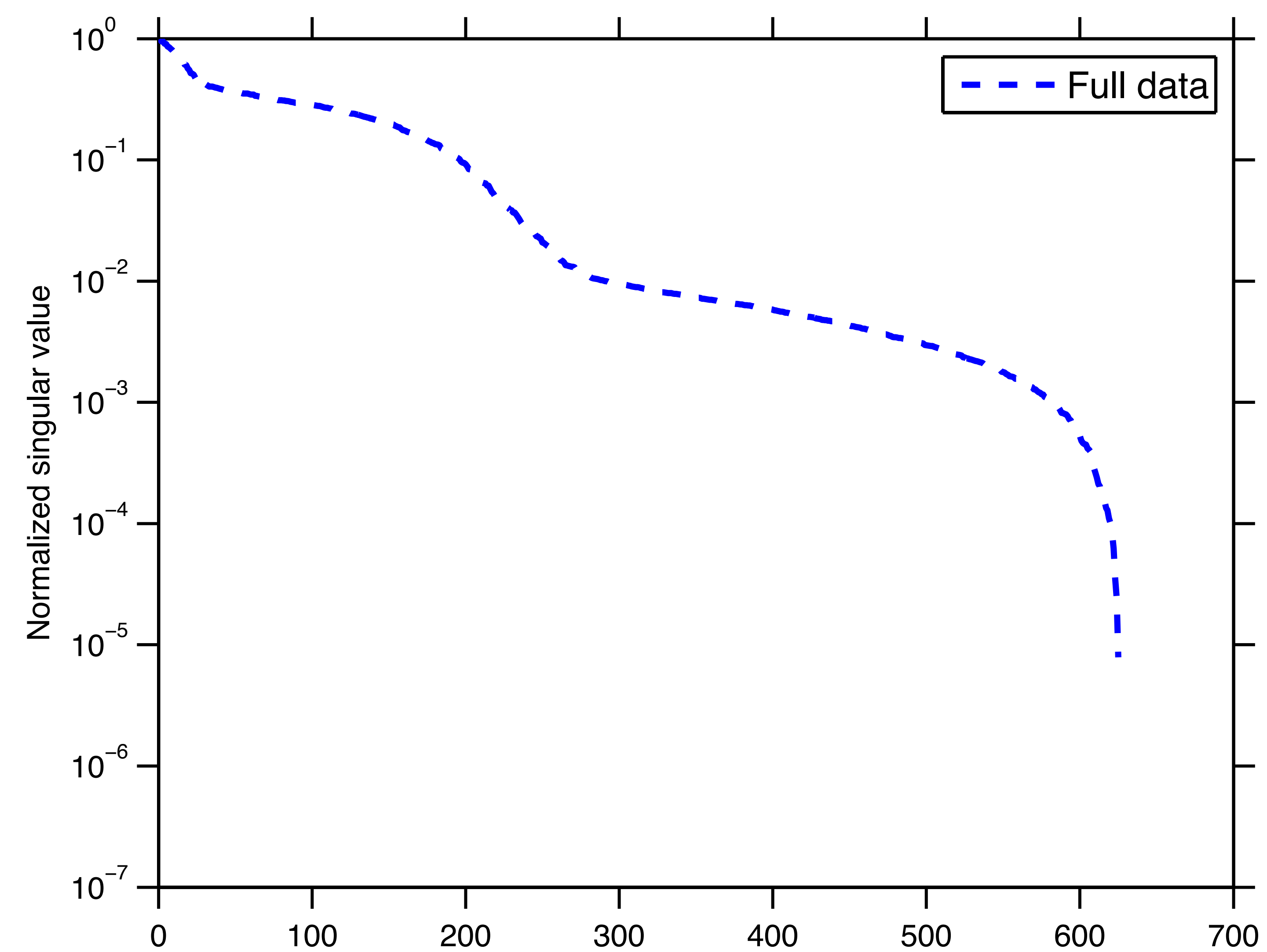
- sampling scheme
  - missing data *increase* rank in "transform domain"

- recovery using *rank penalization* scheme

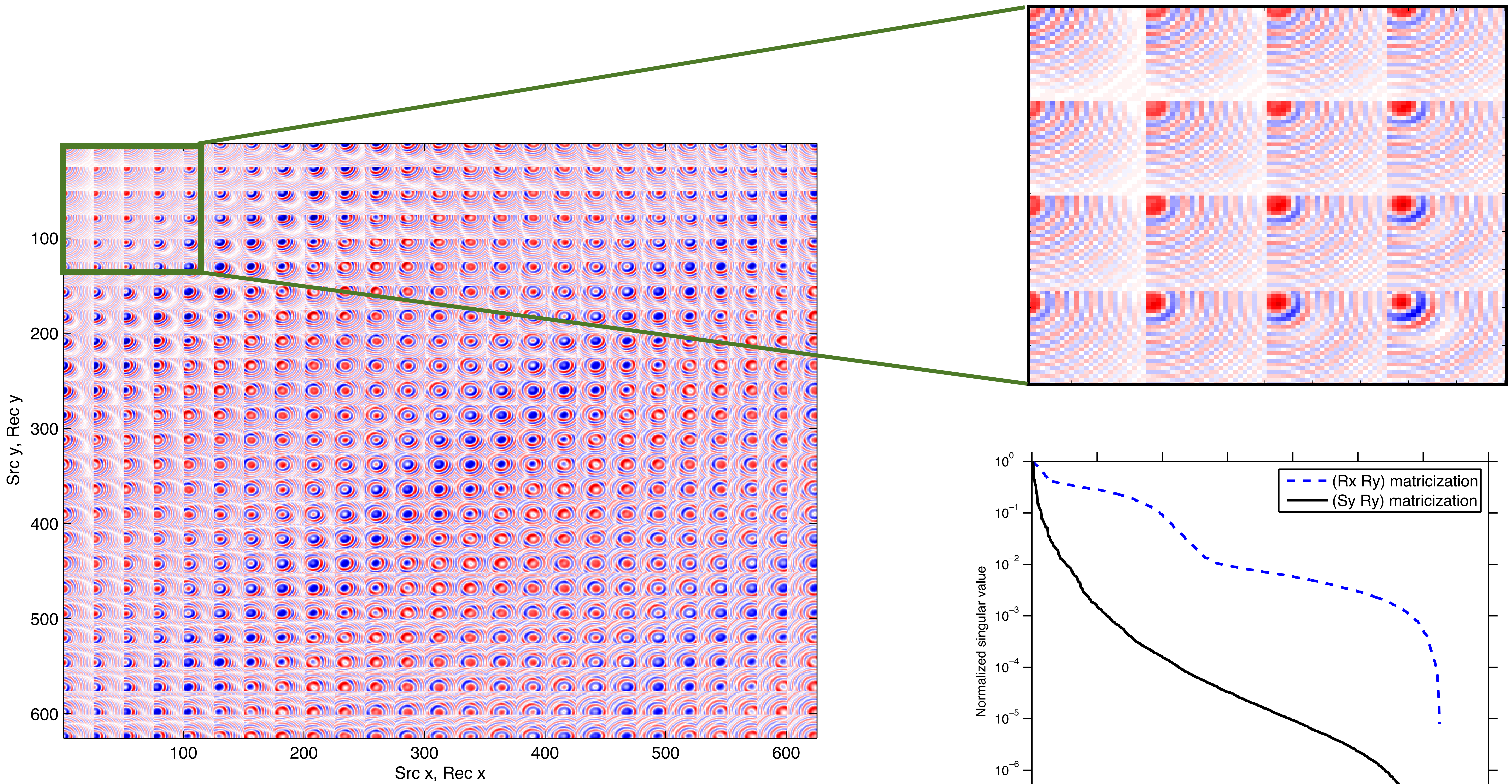
Low-rank structure
conventional 5D data, monochromatic slice, Sx-Sy matricization

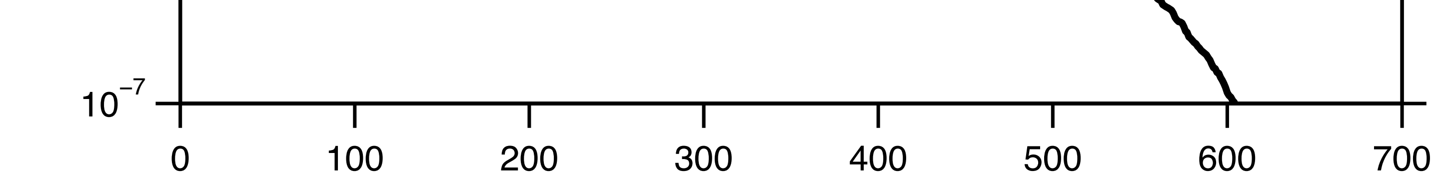






Low-rank structure
conventional 5D data, monochromatic slice, Sx-Rx matricization



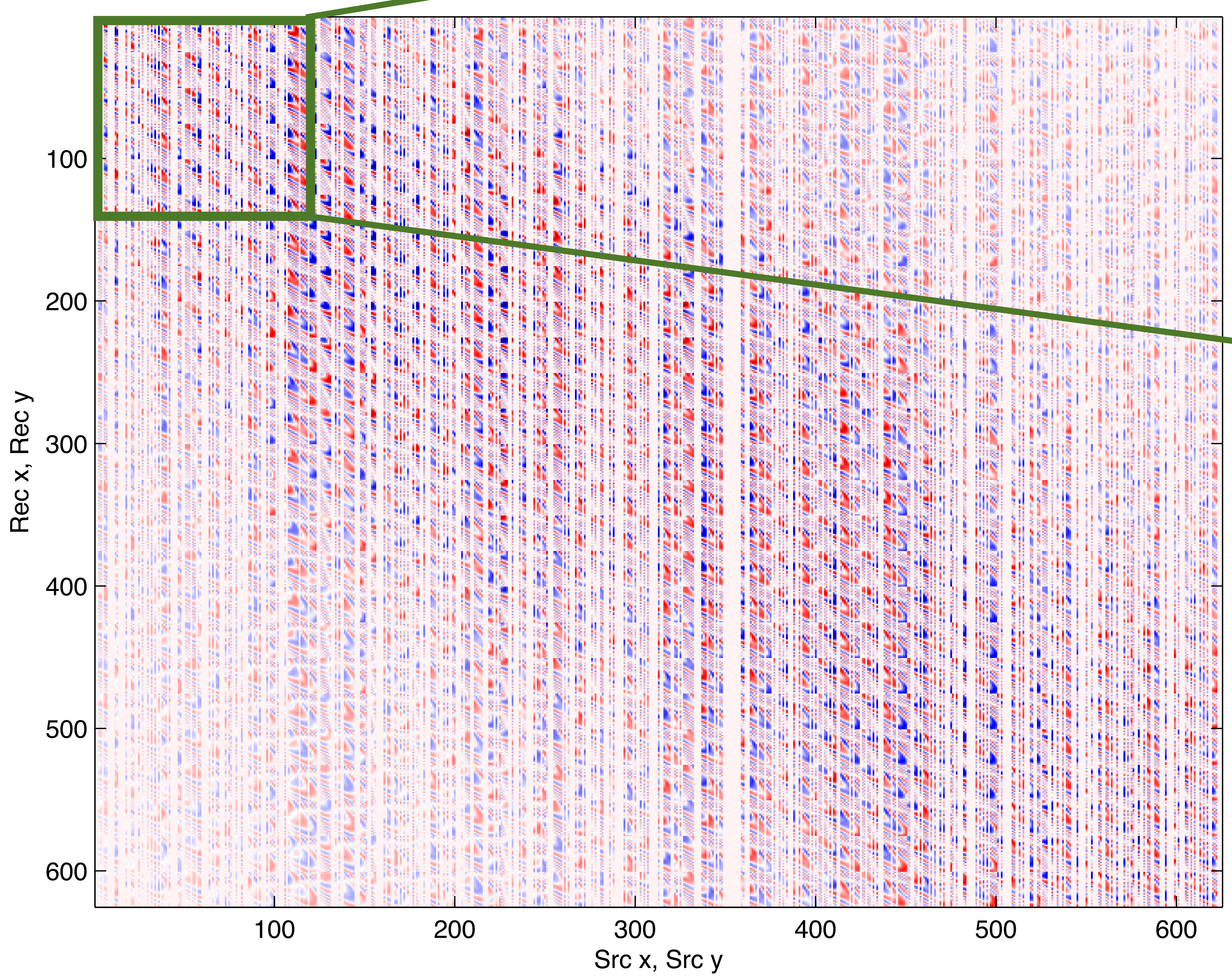


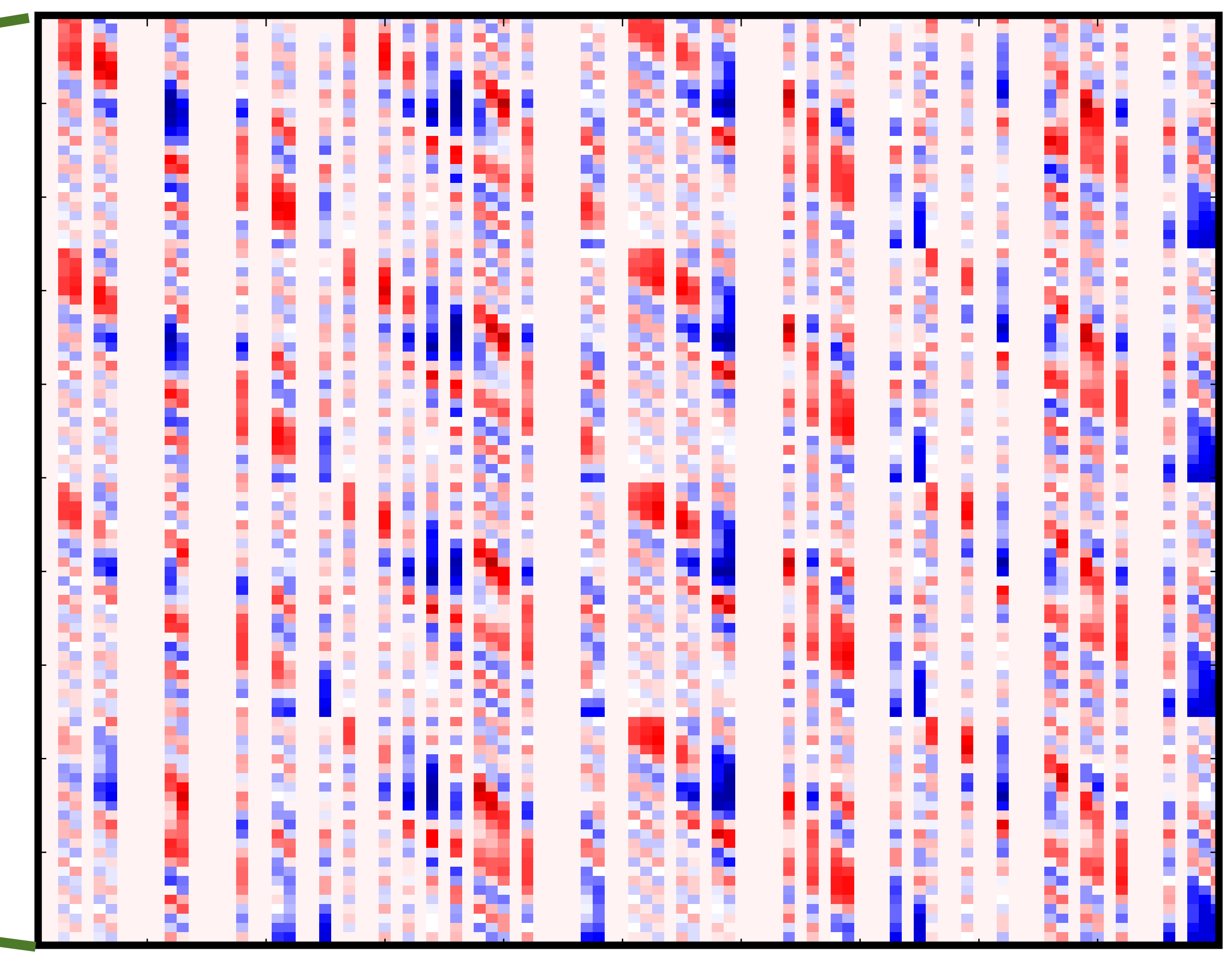
Matrix completion

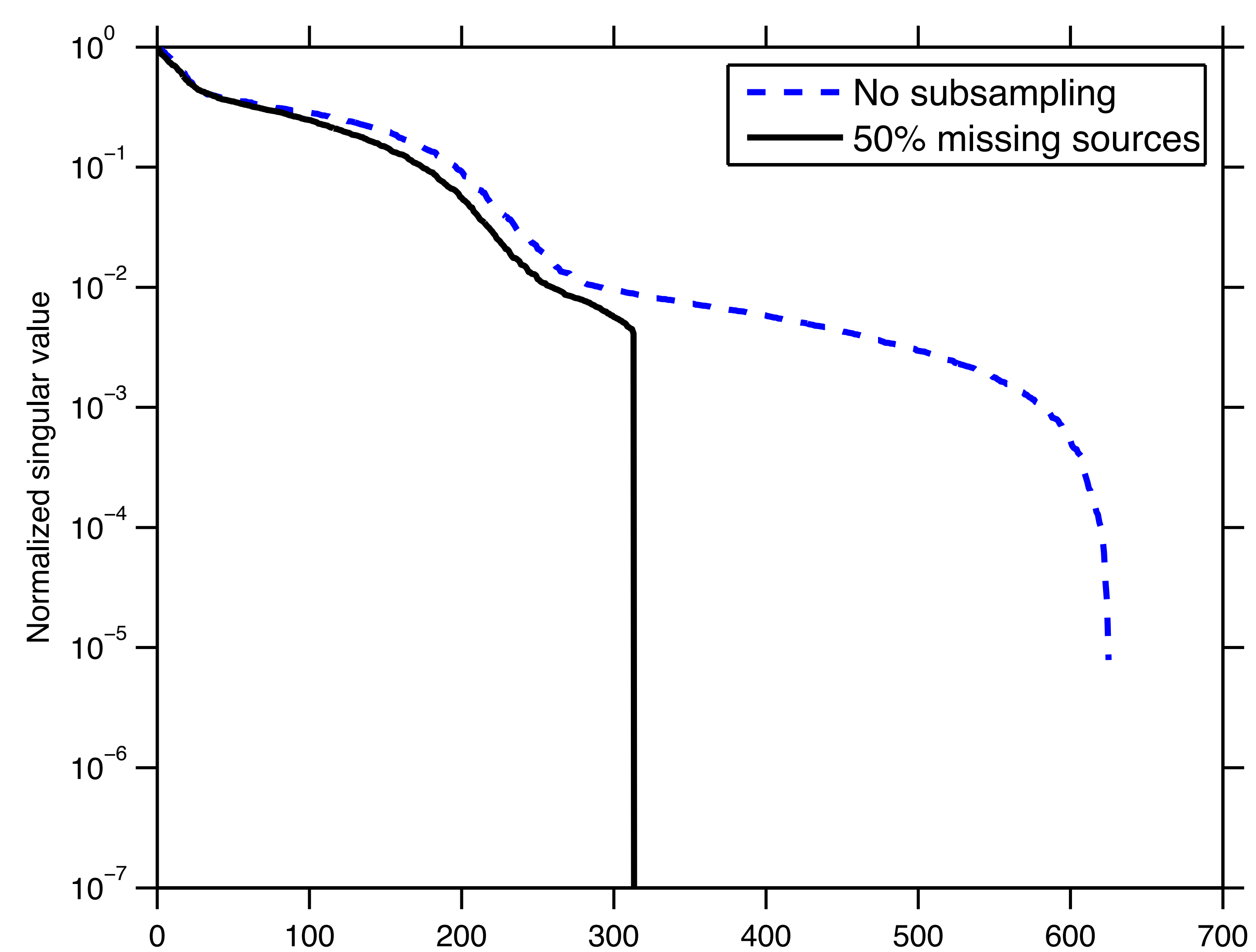
- signal structure
  - *low rank/fast decay* of singular values
- sampling scheme
  - missing data *increase* rank in "transform domain"
- recovery using *rank penalization* scheme

Low-rank structure

time-jittered data, monochromatic slice, Sx-Sy matricization

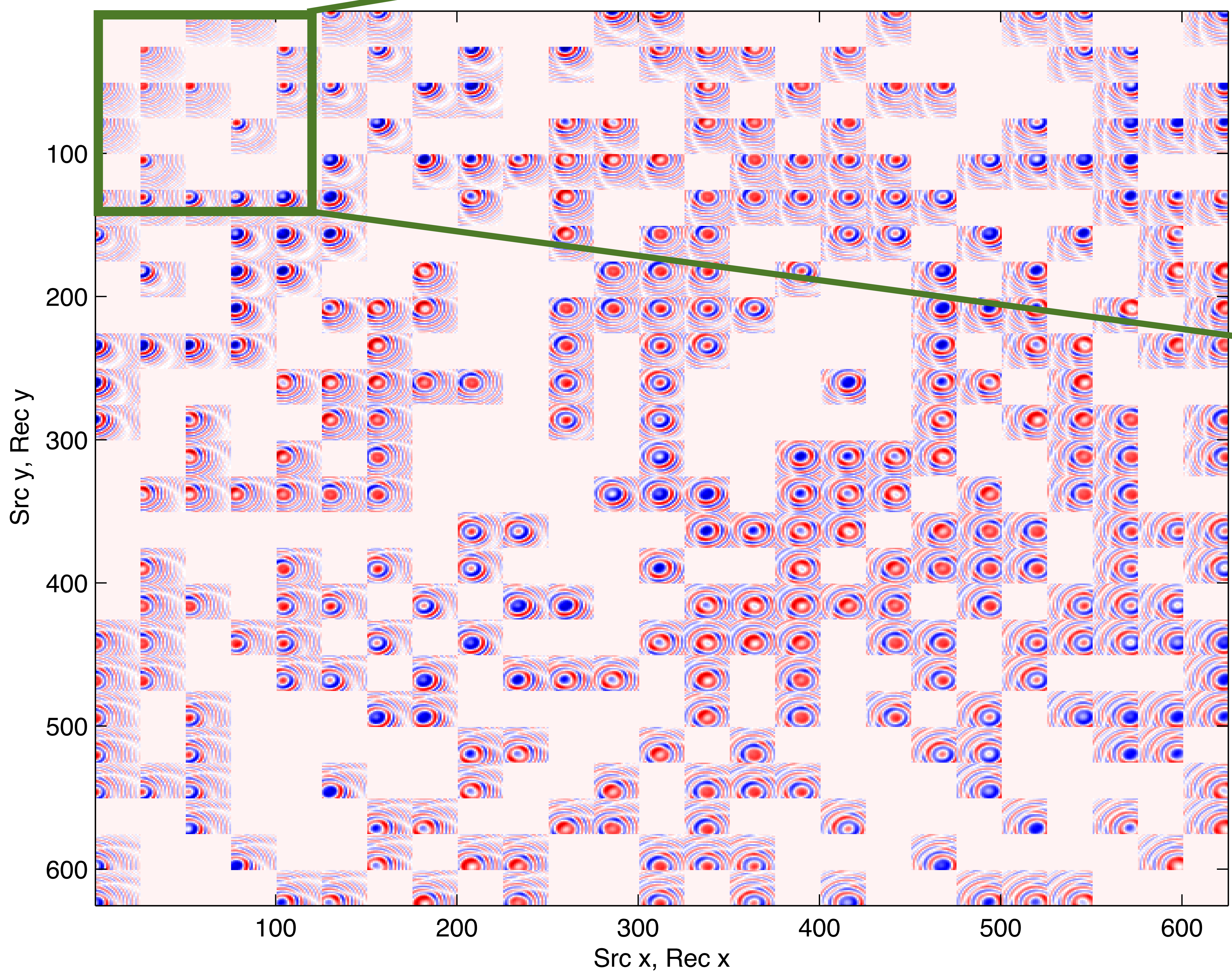


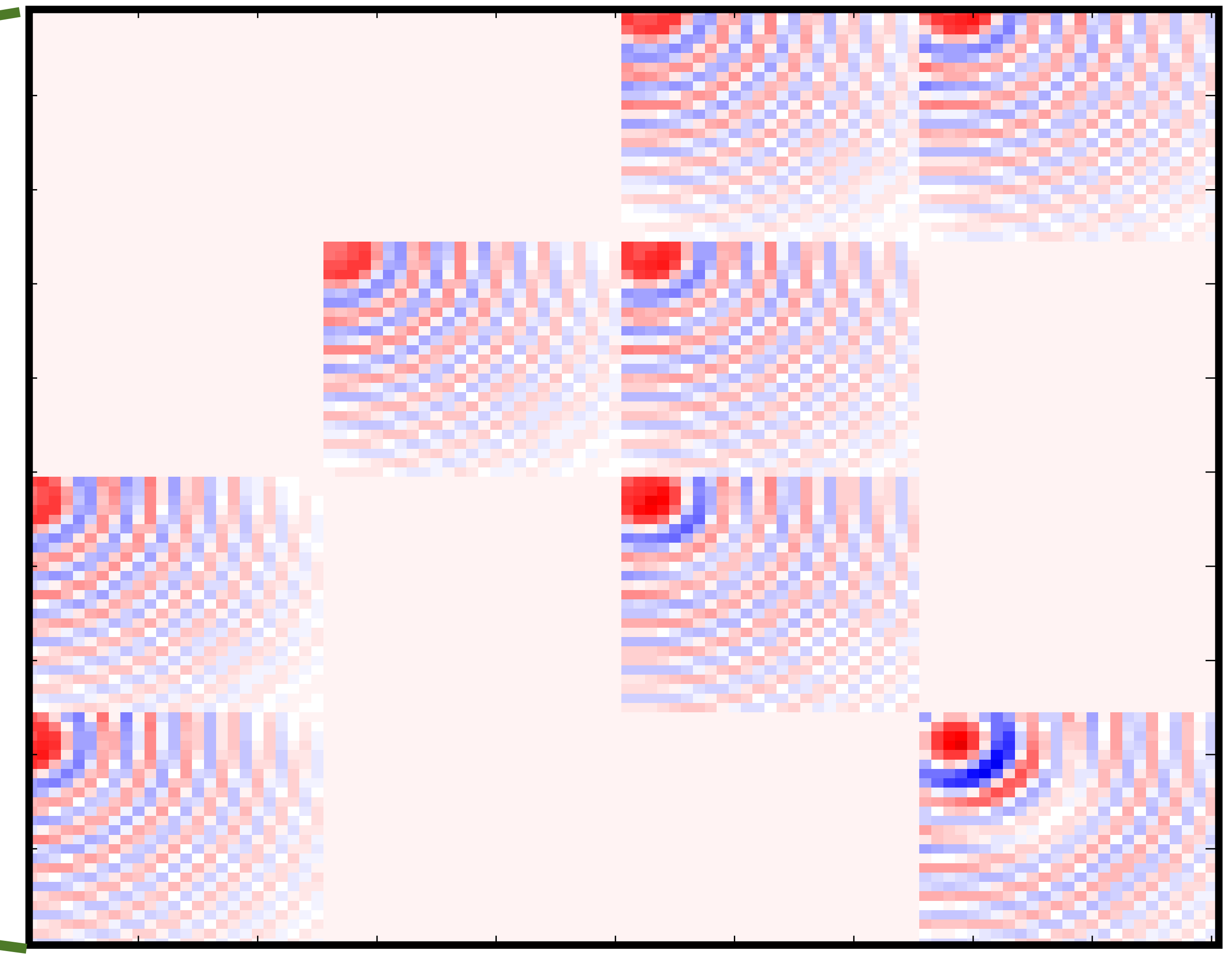


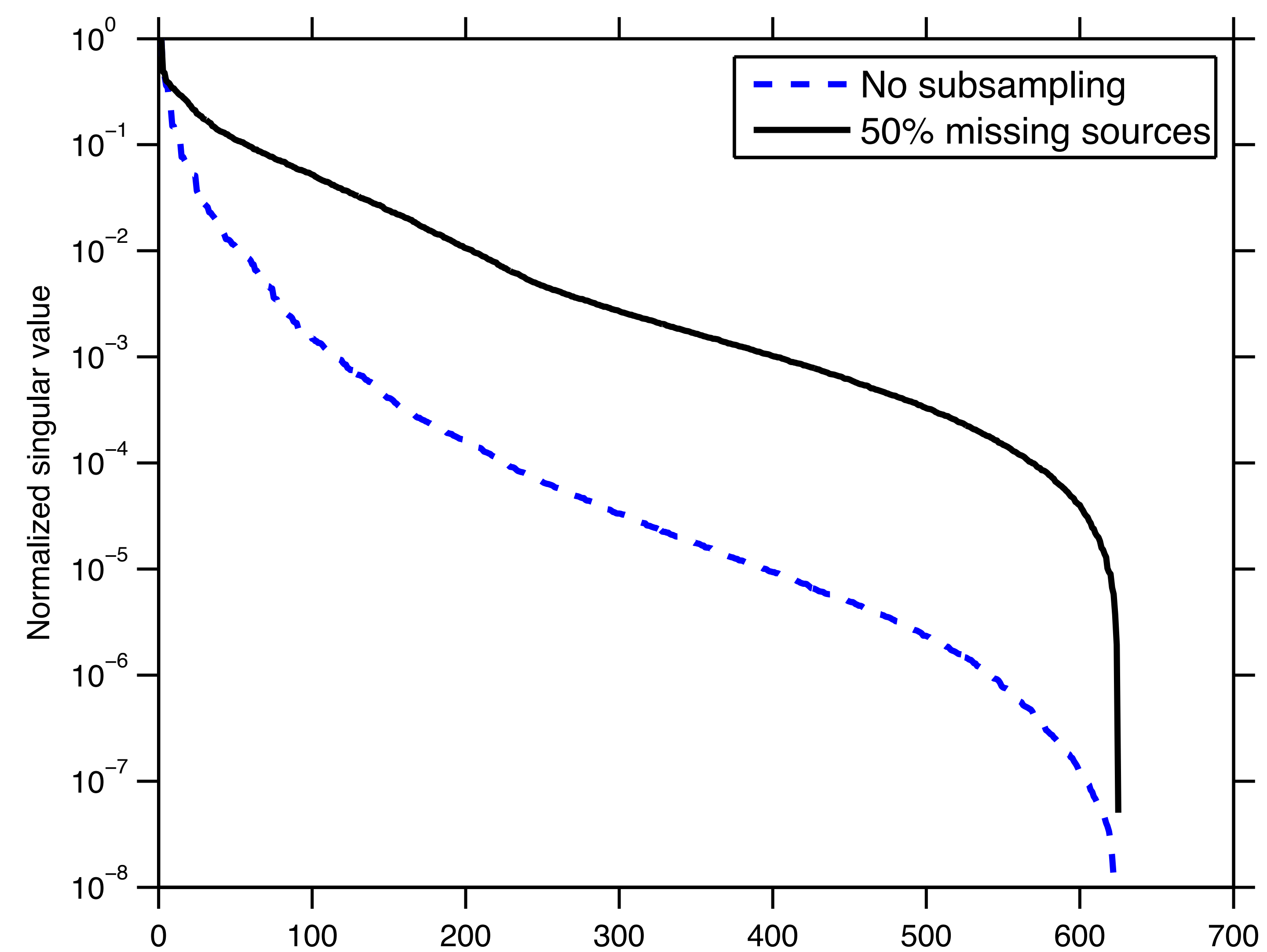


Thursday, October 5, 2017

Low-rank structure
time-jittered data, monochromatic slice, Sx-Rx matricization







Matrix completion

- signal structure
  - *low rank/fast decay* of singular values
- sampling scheme
  - missing data *increase* rank in "transform domain"
- recovery using *rank penalization* scheme

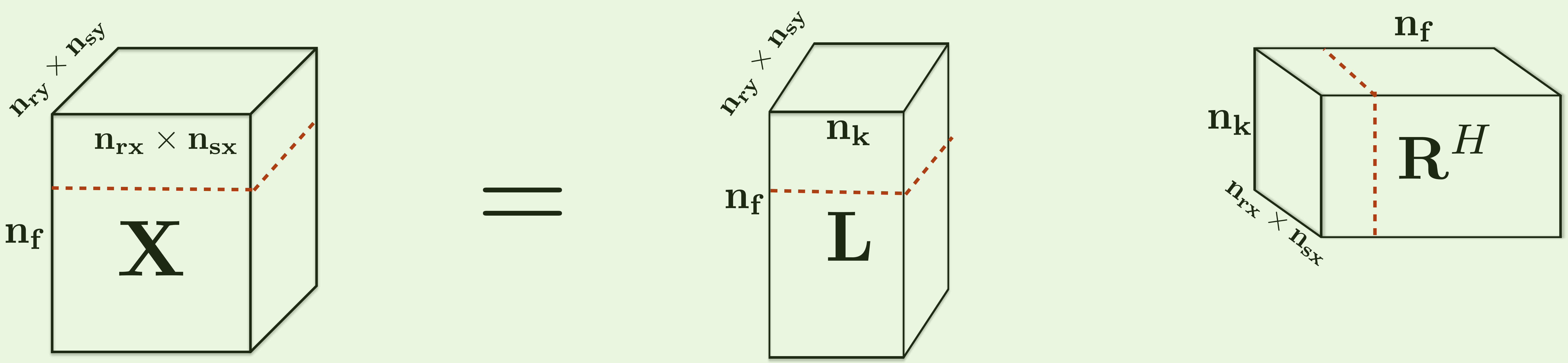
Nuclear-norm minimization *convex relaxation of rank-minimization*

[Recht et. al., 2010]

$$\min_{\mathbf{X}} \quad \underbrace{||\mathbf{X}||_*}_{\text{sum of singular values of } \mathbf{X}} \quad \text{s.t.} \quad \|\mathcal{A}(\mathbf{X}) - \mathbf{b}\|_2 \leq \epsilon$$

[Rennie and Srebro 2005, Lee et. al. 2010, Recht and Re 2011]

$$\mathbf{X} = \mathbf{L}\mathbf{R}^H$$



$\mathbf{X} \in \mathbb{C}^{\mathbf{n_f} \times \mathbf{n_{rx}} \times \mathbf{n_{sx}} \times \mathbf{n_{ry}} \times \mathbf{n_{sy}}}$ $\quad$ $\mathbf{L} \in \mathbb{C}^{\mathbf{n_f} \times \mathbf{n_{rx}} \times \mathbf{n_{sx}} \times \mathbf{n_k}}$ $\quad$ $\mathbf{R} \in \mathbb{C}^{\mathbf{n_f} \times \mathbf{n_{ry}} \times \mathbf{n_{sy}} \times \mathbf{n_k}}$

[Rennie and Srebro 2005]

Factorized formulation

- Upper-bound on nuclear norm is defined as

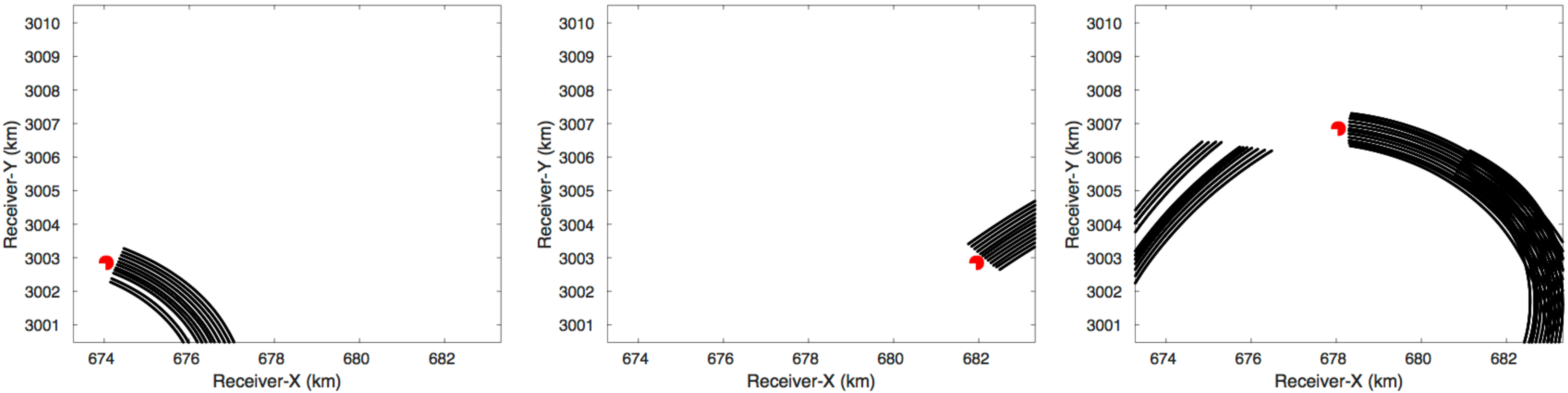
$$\|\mathbf{L}\mathbf{R}^H\|_* \leq \frac{1}{2}\left\|\begin{bmatrix}\mathbf{L}\\ \mathbf{R}\end{bmatrix}\right\|_F^2$$

where $\|\cdot\|_F^2$ is sum of squares of all entries

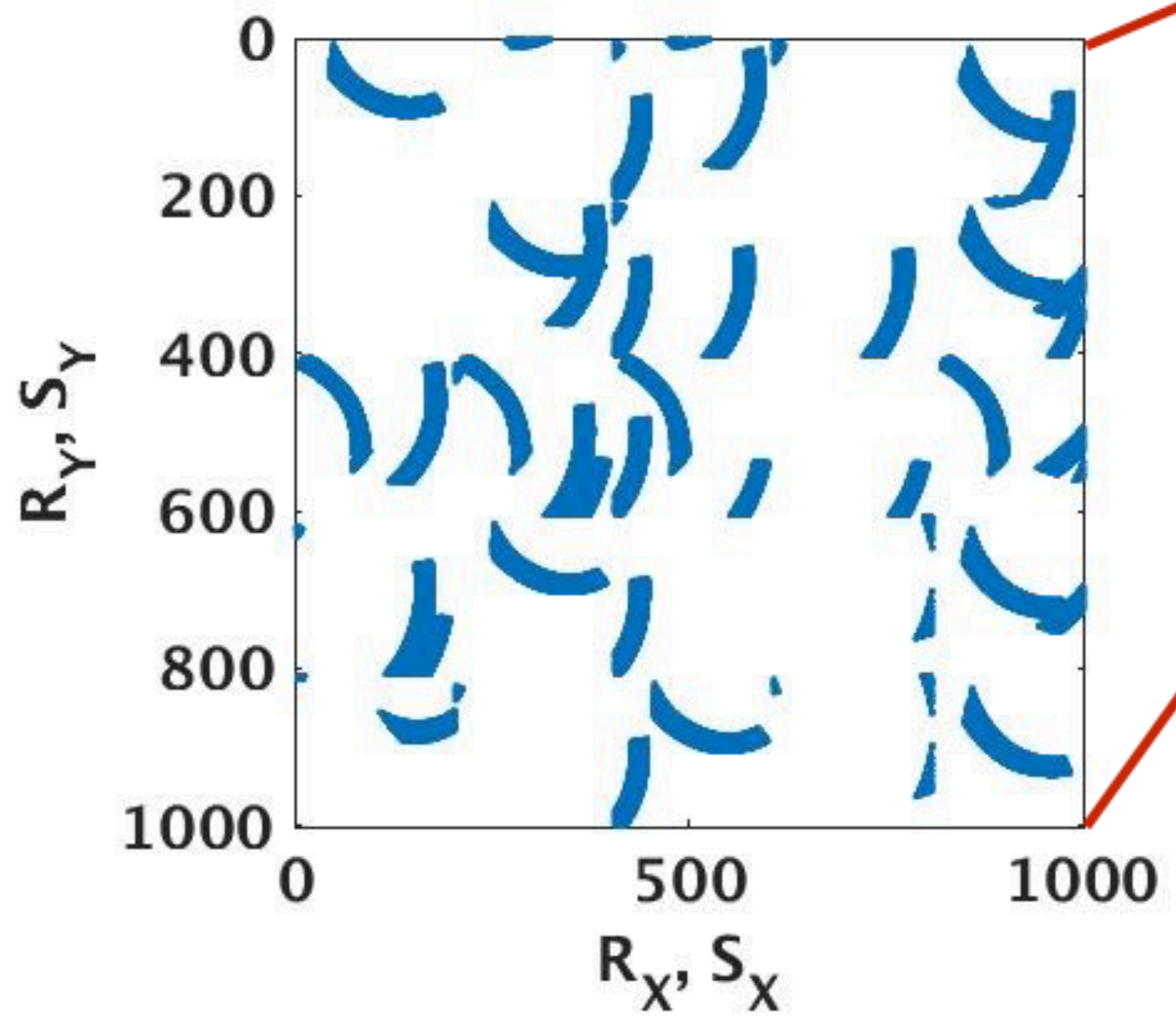
- choose k *explicitly* & avoid costly *SVD's*

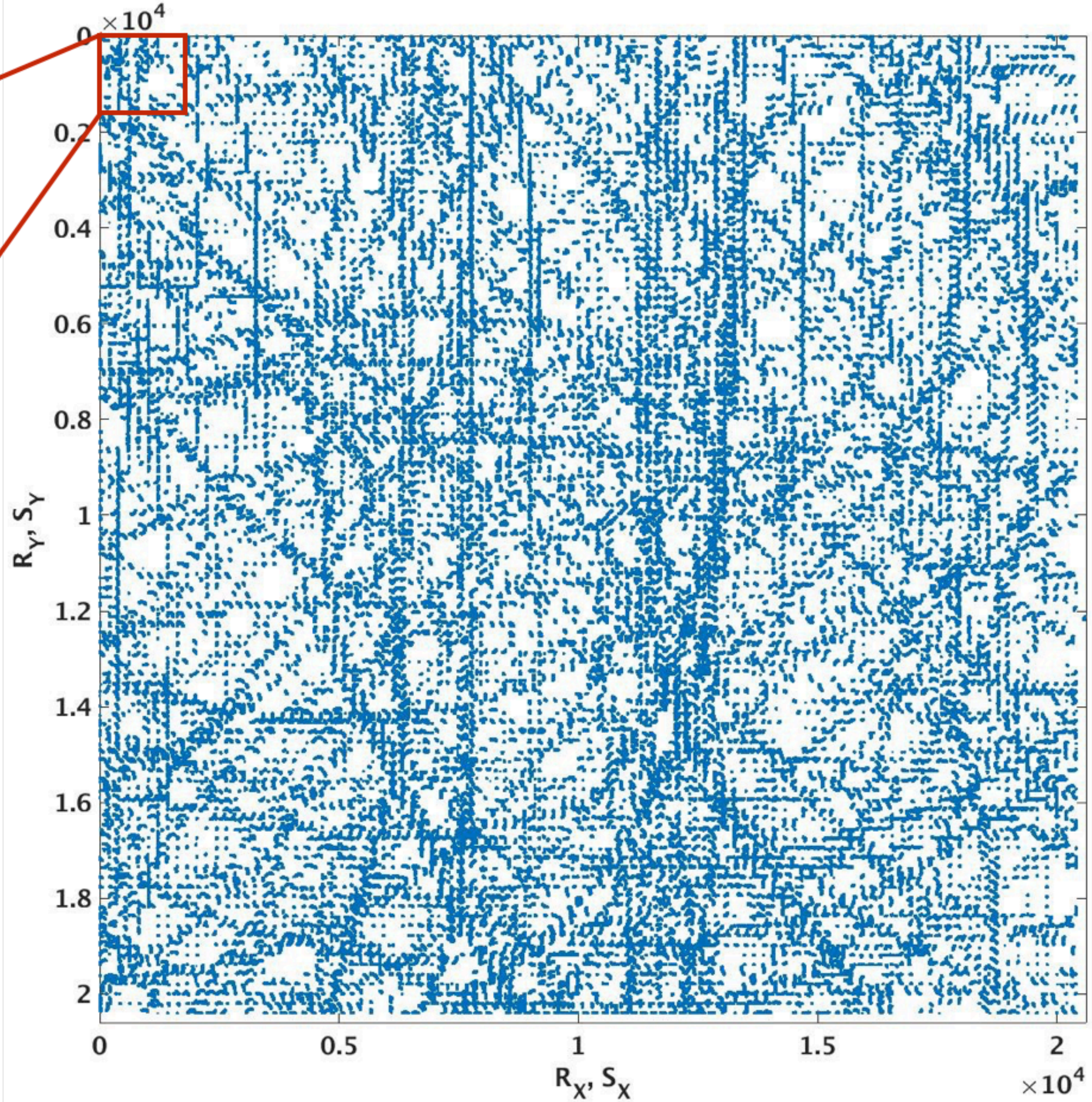
Case study—coil acquisition

Source-receiver acquisition mask



Acquisition mask
(10 x10 km)





Observed sampling = 16%
Effective sampling = 4%
Spectral Gap = 0.4

Optimization information

Parallelized factorization framework over sources & receivers

Number of iterations: 200

Computational time / frequency slice: 2 hours

Computational resource / frequency slice: 1 nodes w/ 128 GB RAM, 20-core processors, multithreading

Synthetic data

Acquisition information

3D overthrust model, 5km x 12km x 12km

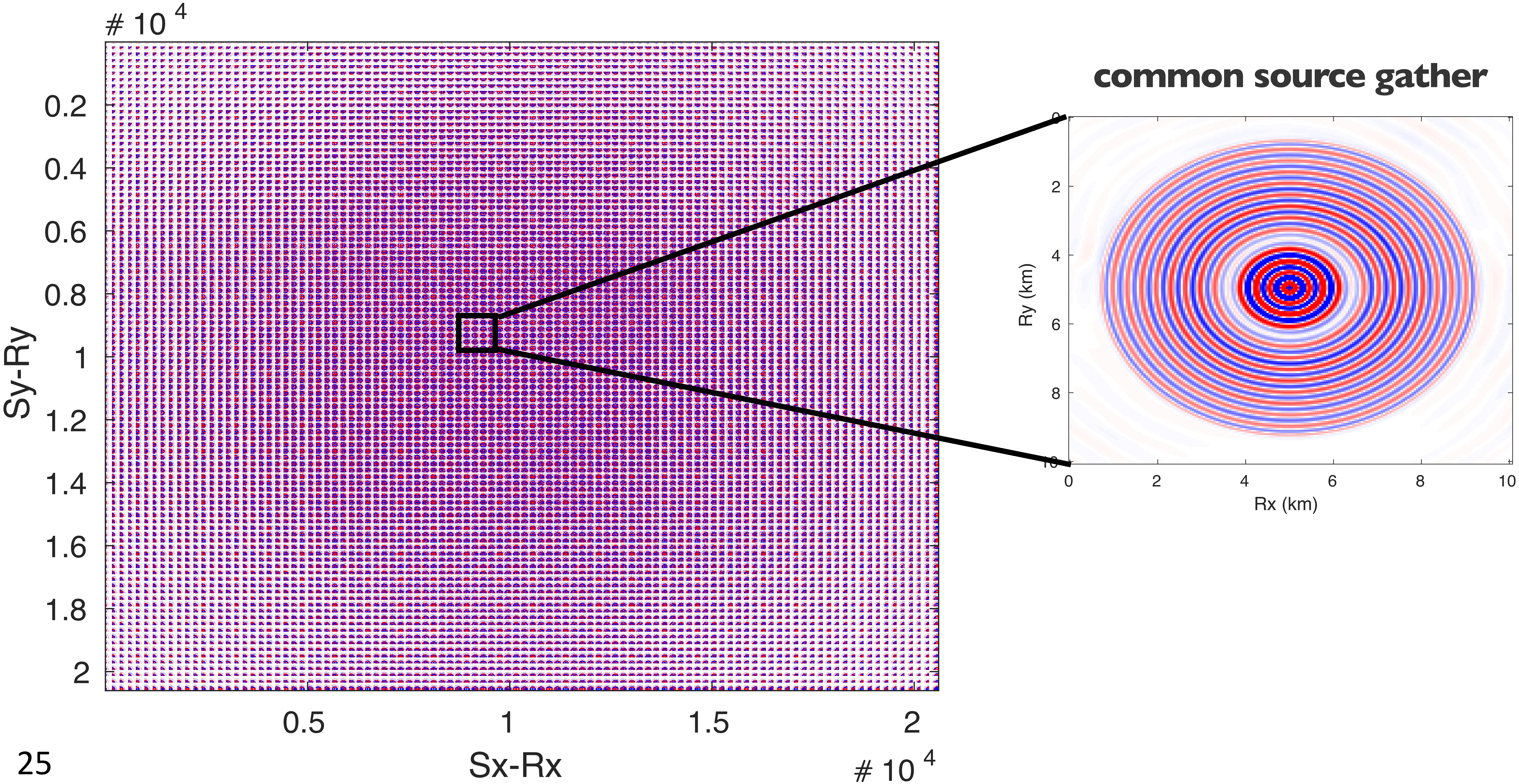
10404 sources @ 100m

40804 receivers @ 50m

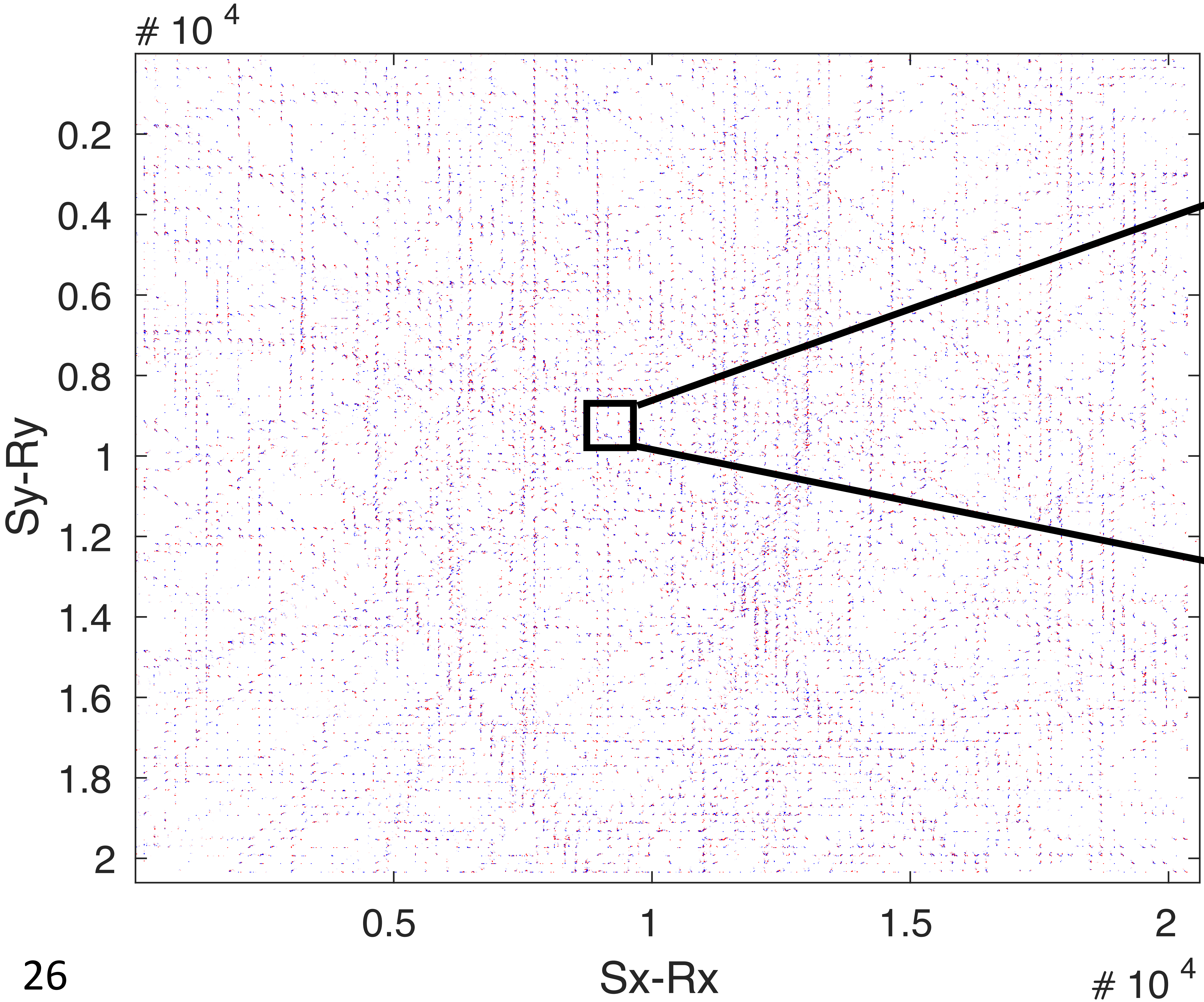
Time length : 3 second @ 0.004s

Interpolation from 1-50 Hz

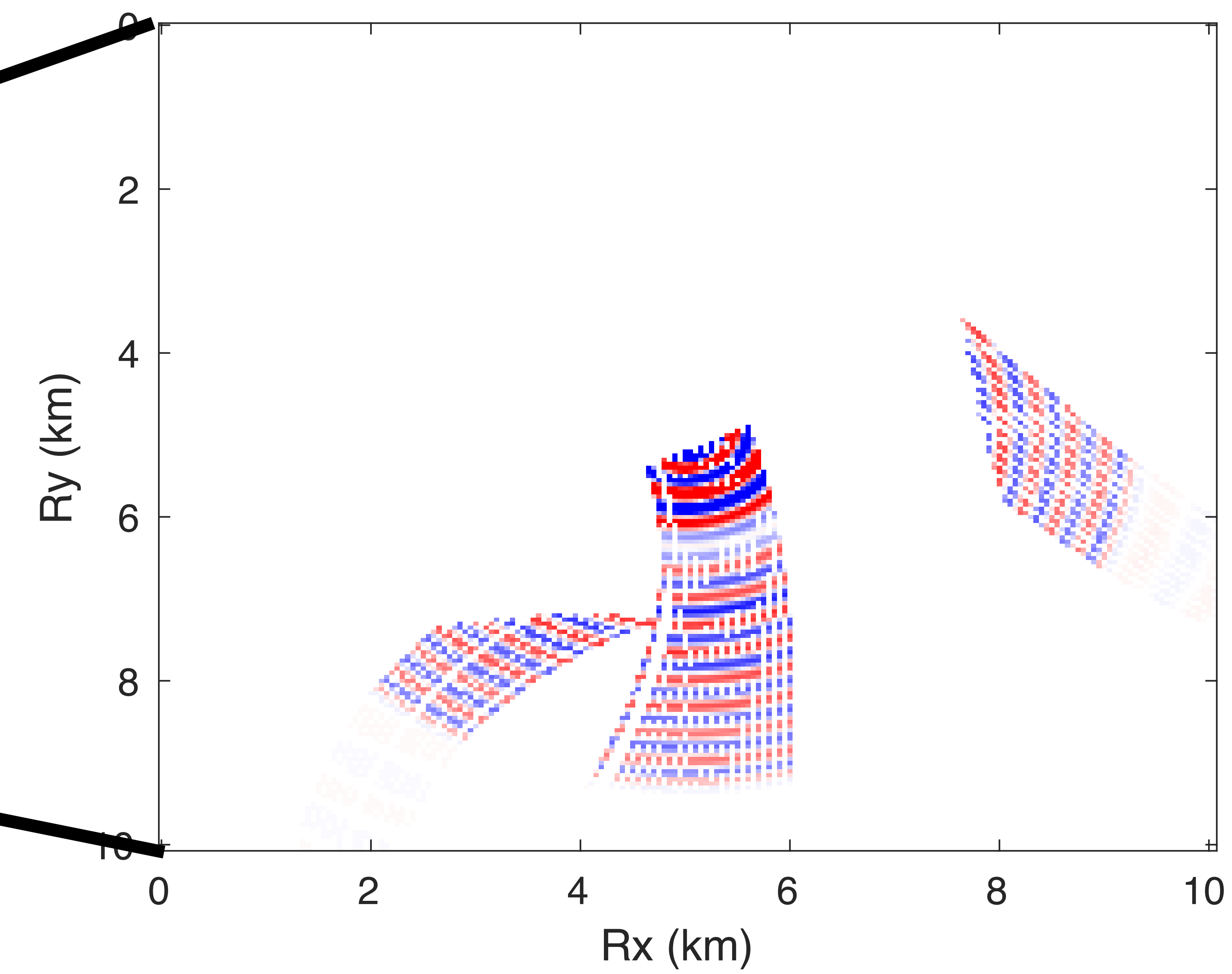
Frequency slice @ 7Hz
ground truth



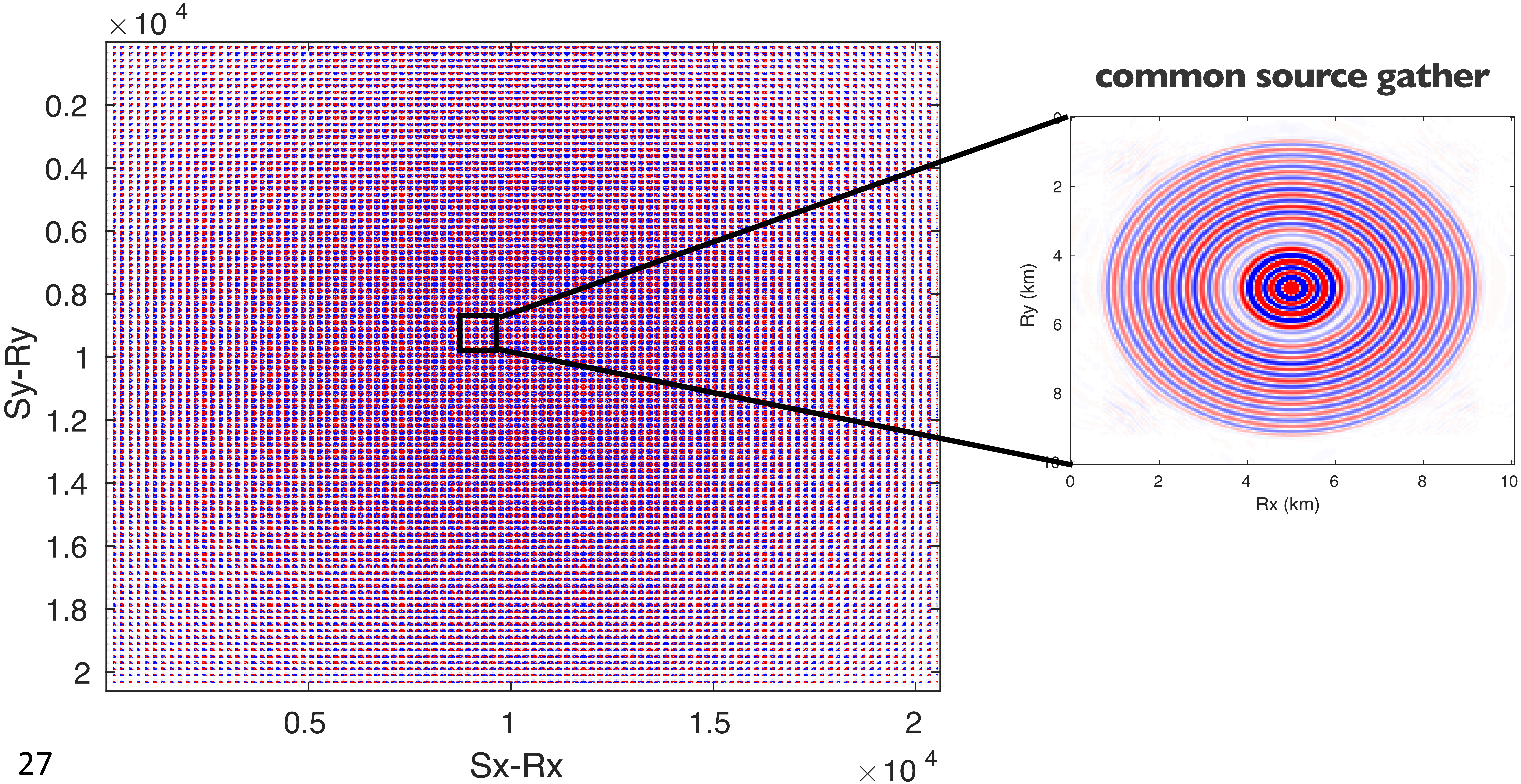
Frequency slice @ 7Hz
subsampled



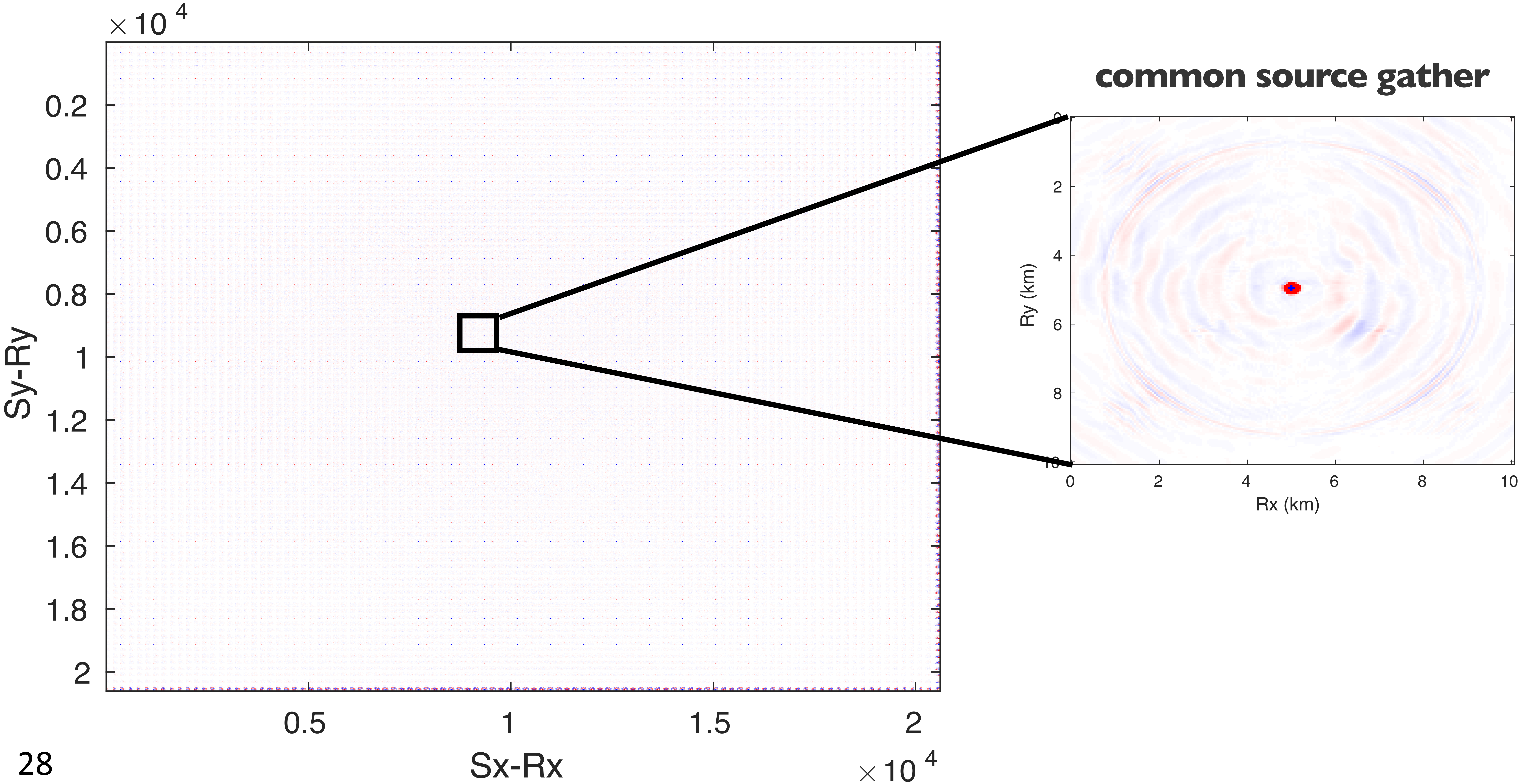
common source gather



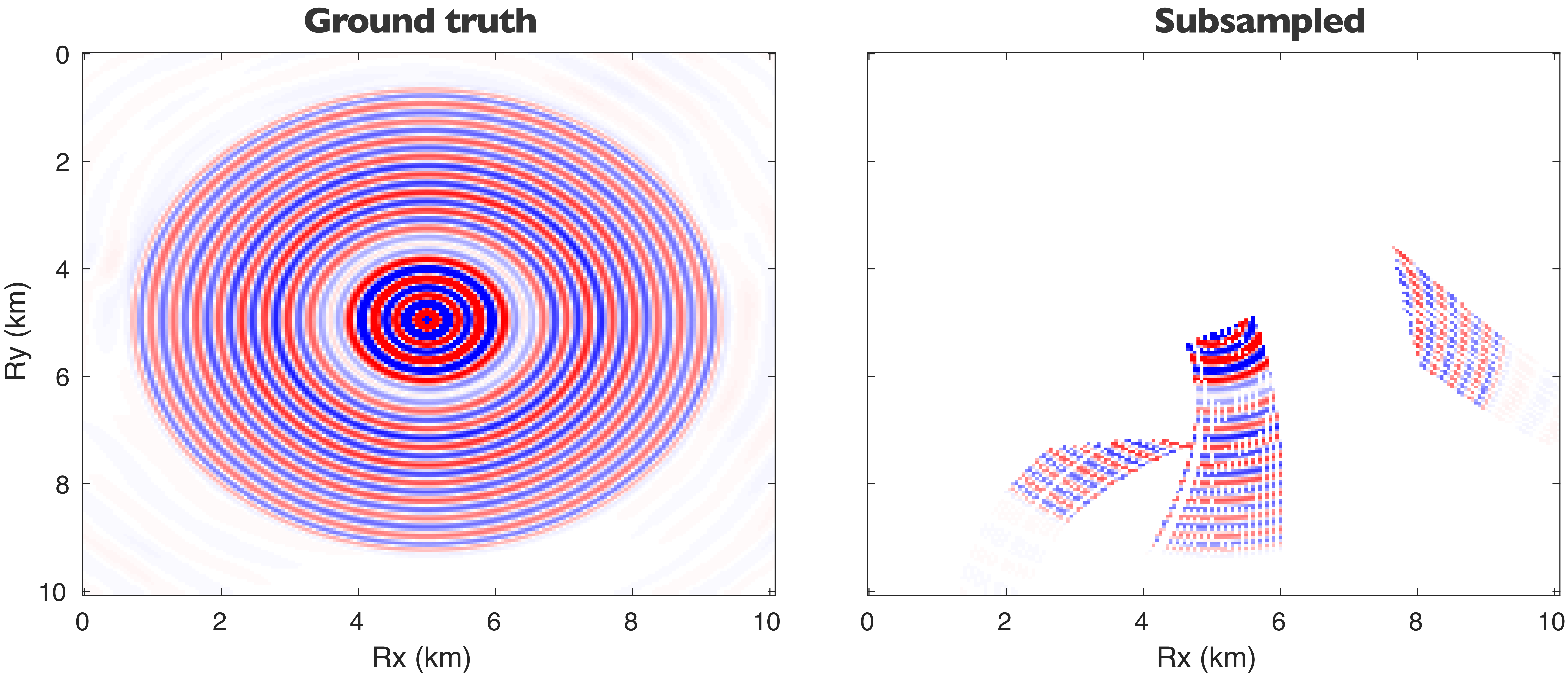
Frequency slice @ 7Hz
interpolated



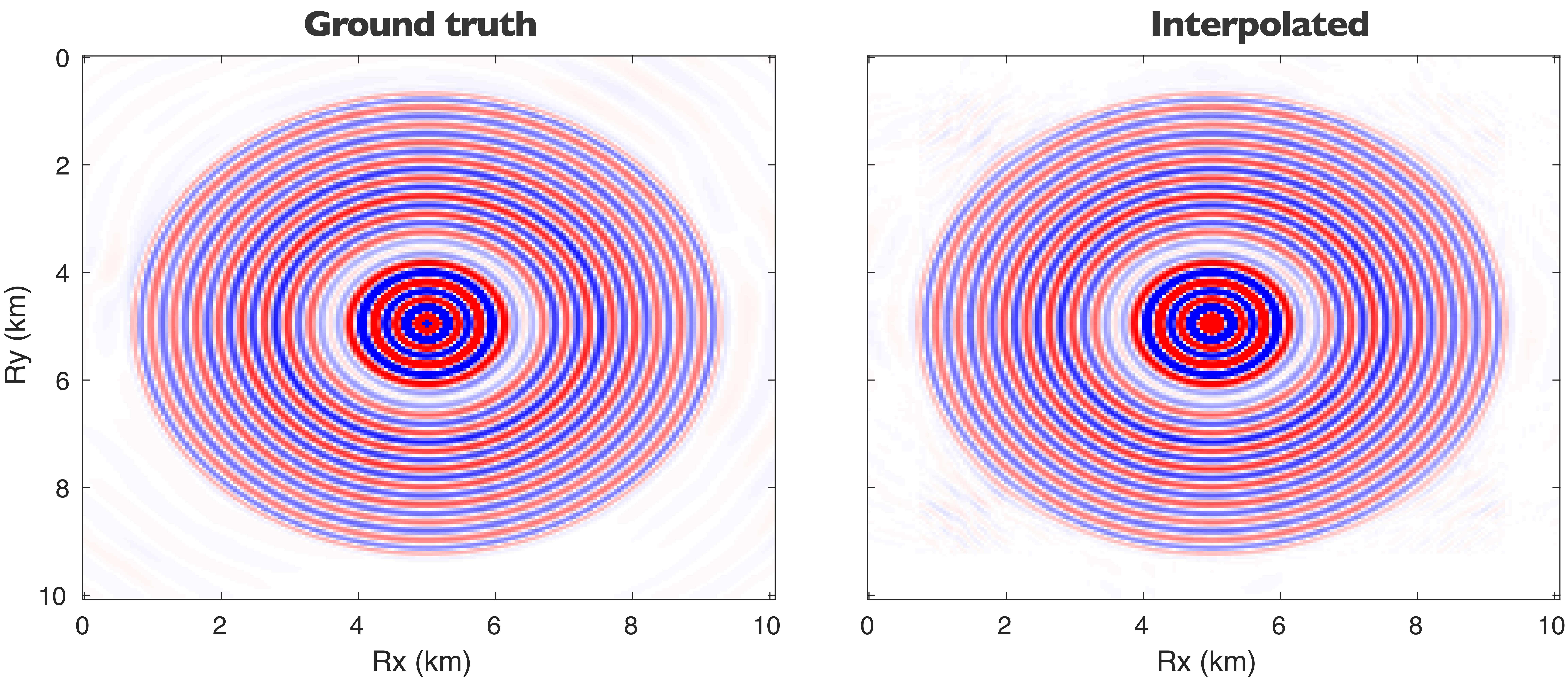
Frequency slice @ 7Hz
residual



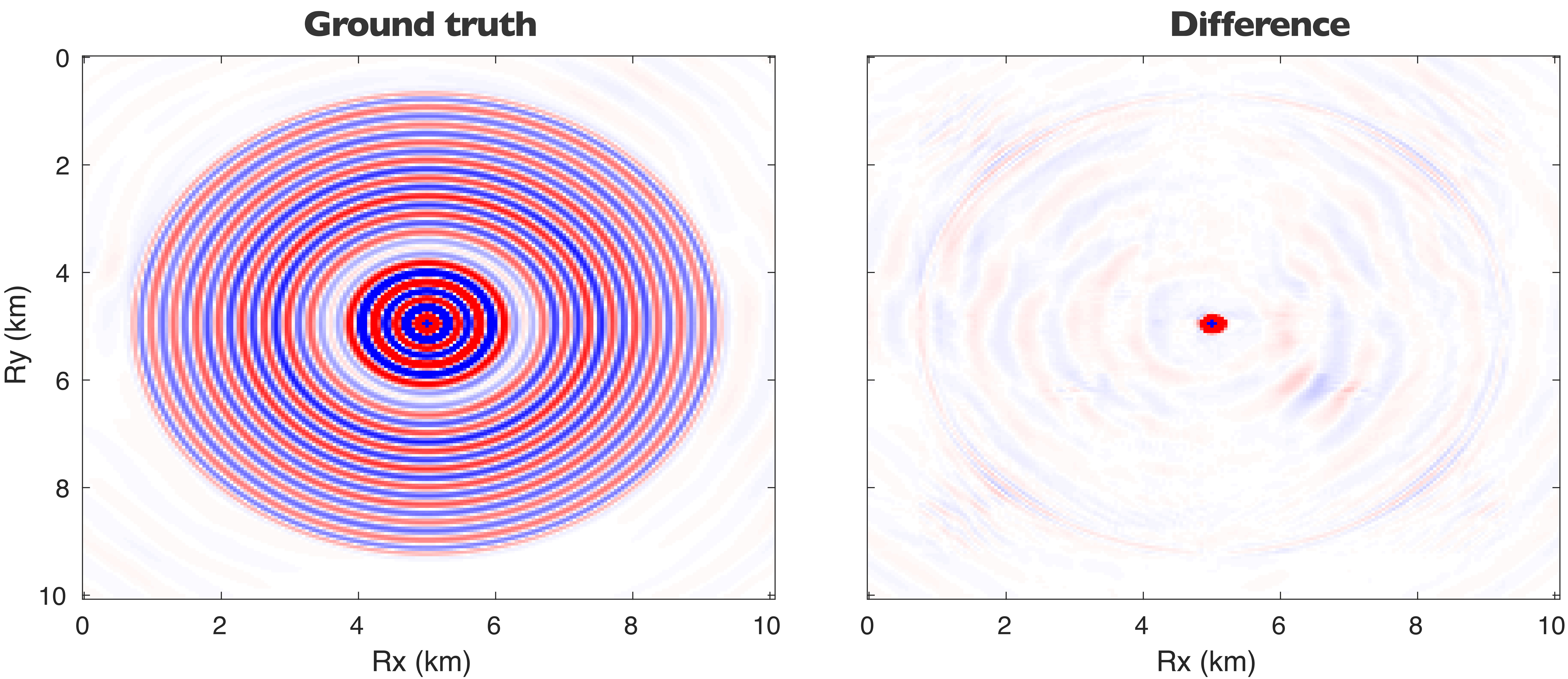
Common source gather
frequency slice @ 7 Hz



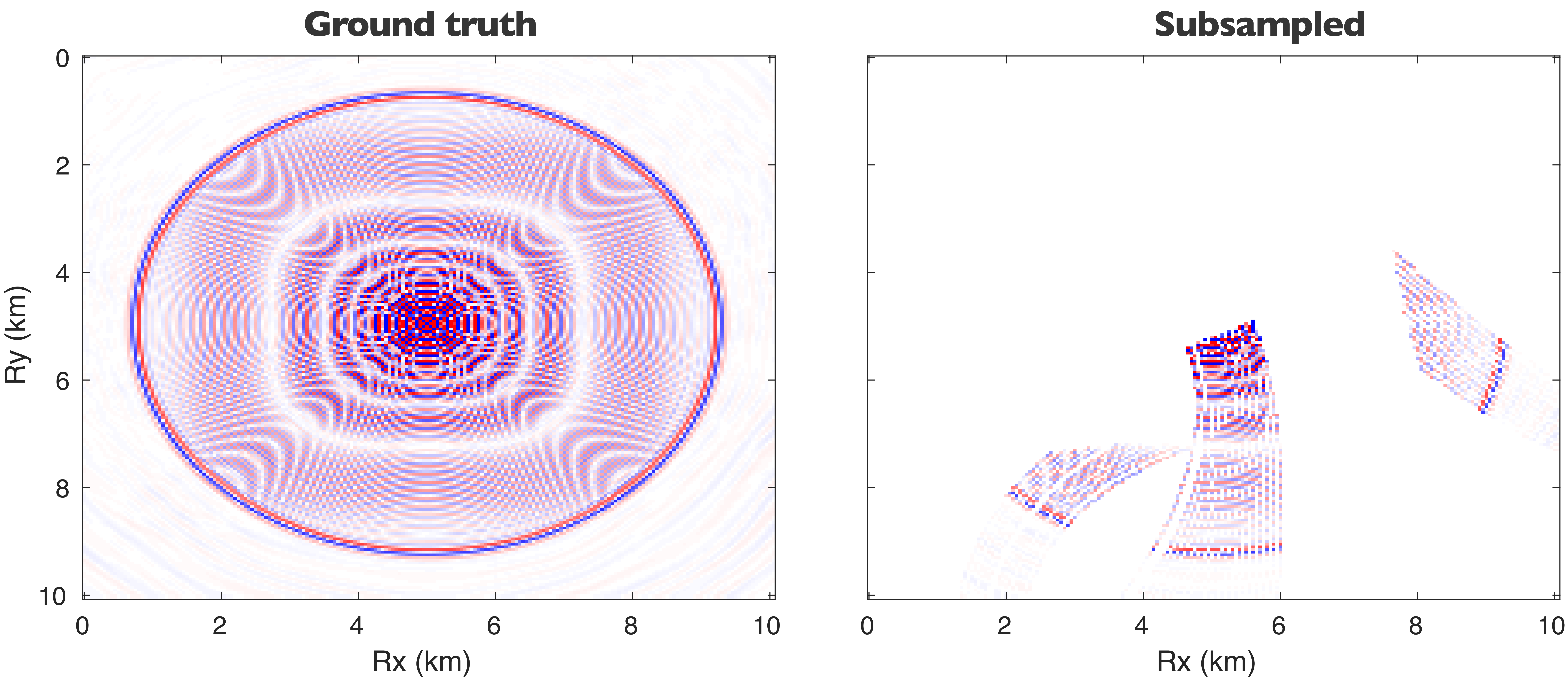
Common source gather
frequency slice @ 7 Hz



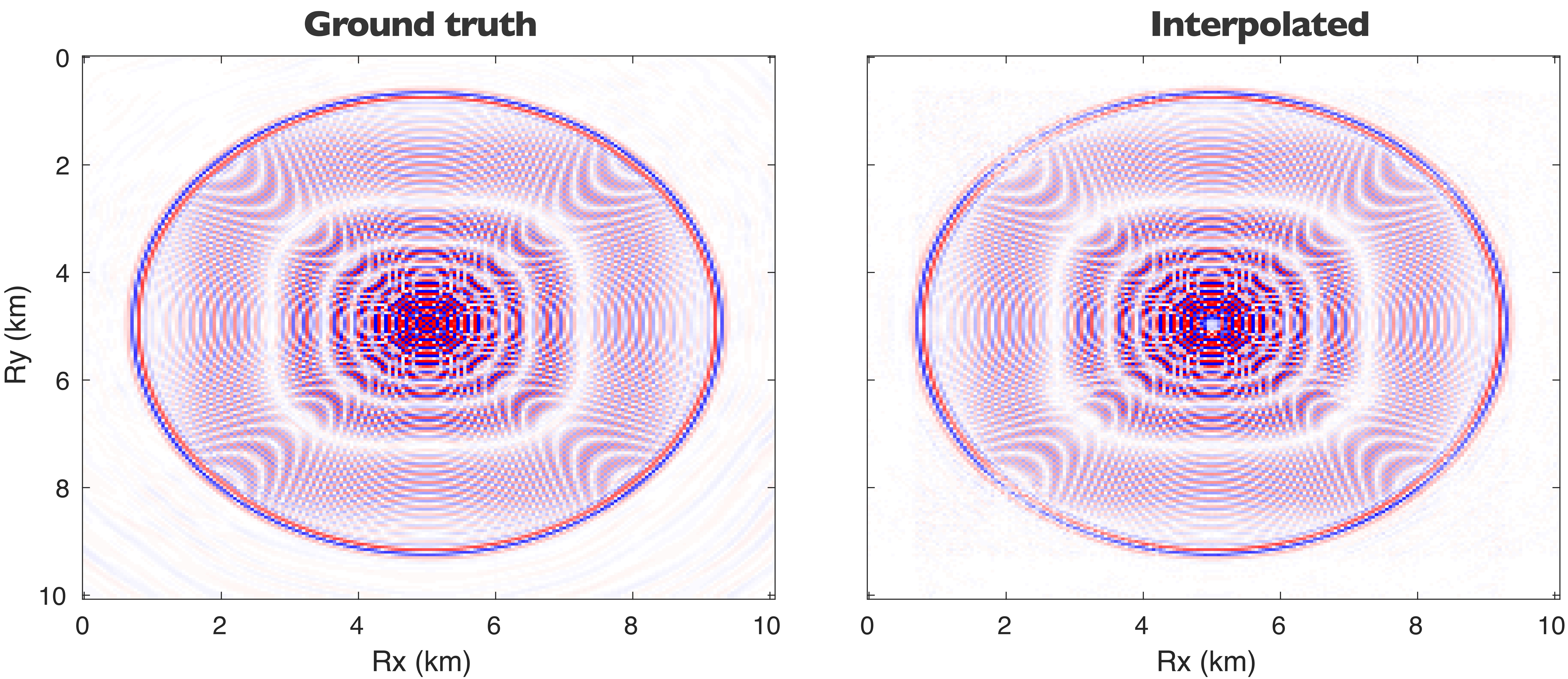
Common source gather
frequency slice @ 7 Hz



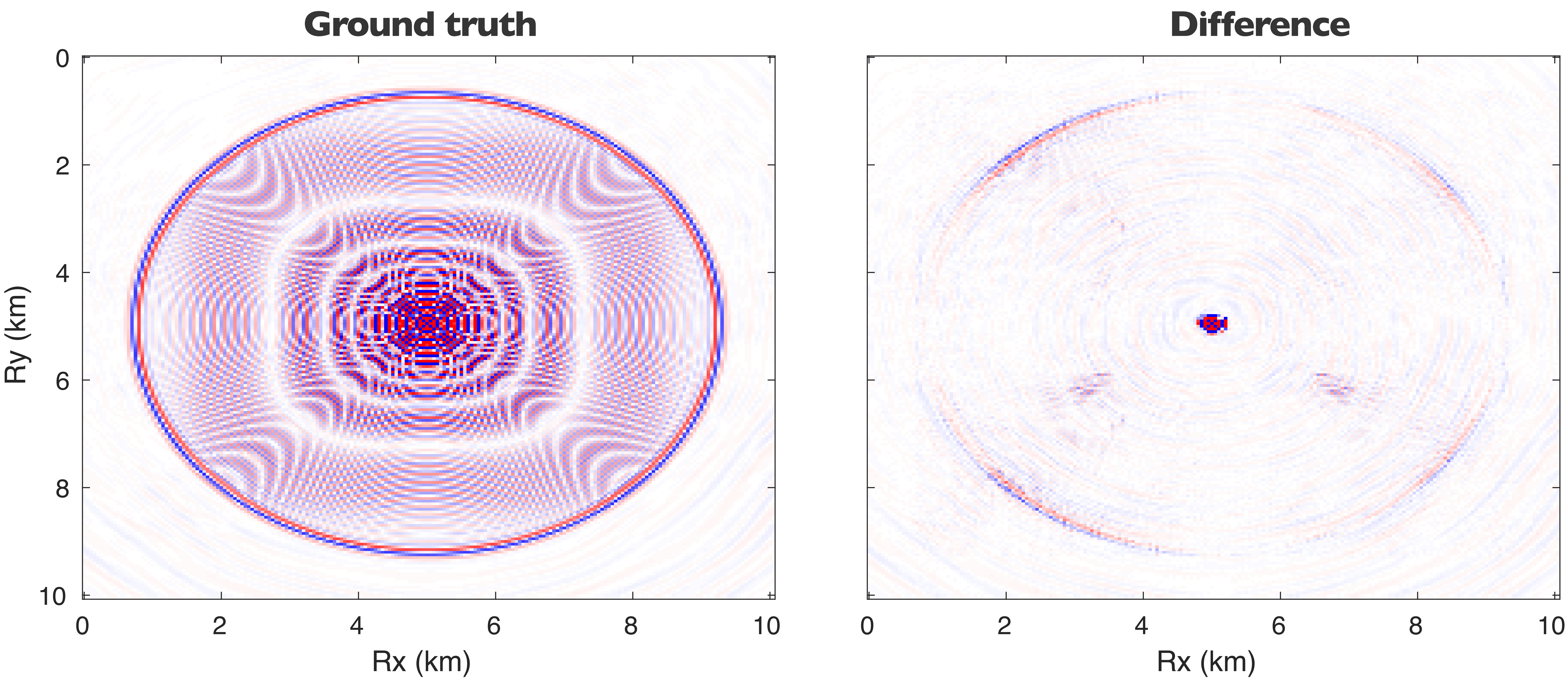
Common source gather
frequency slice @ 20 Hz



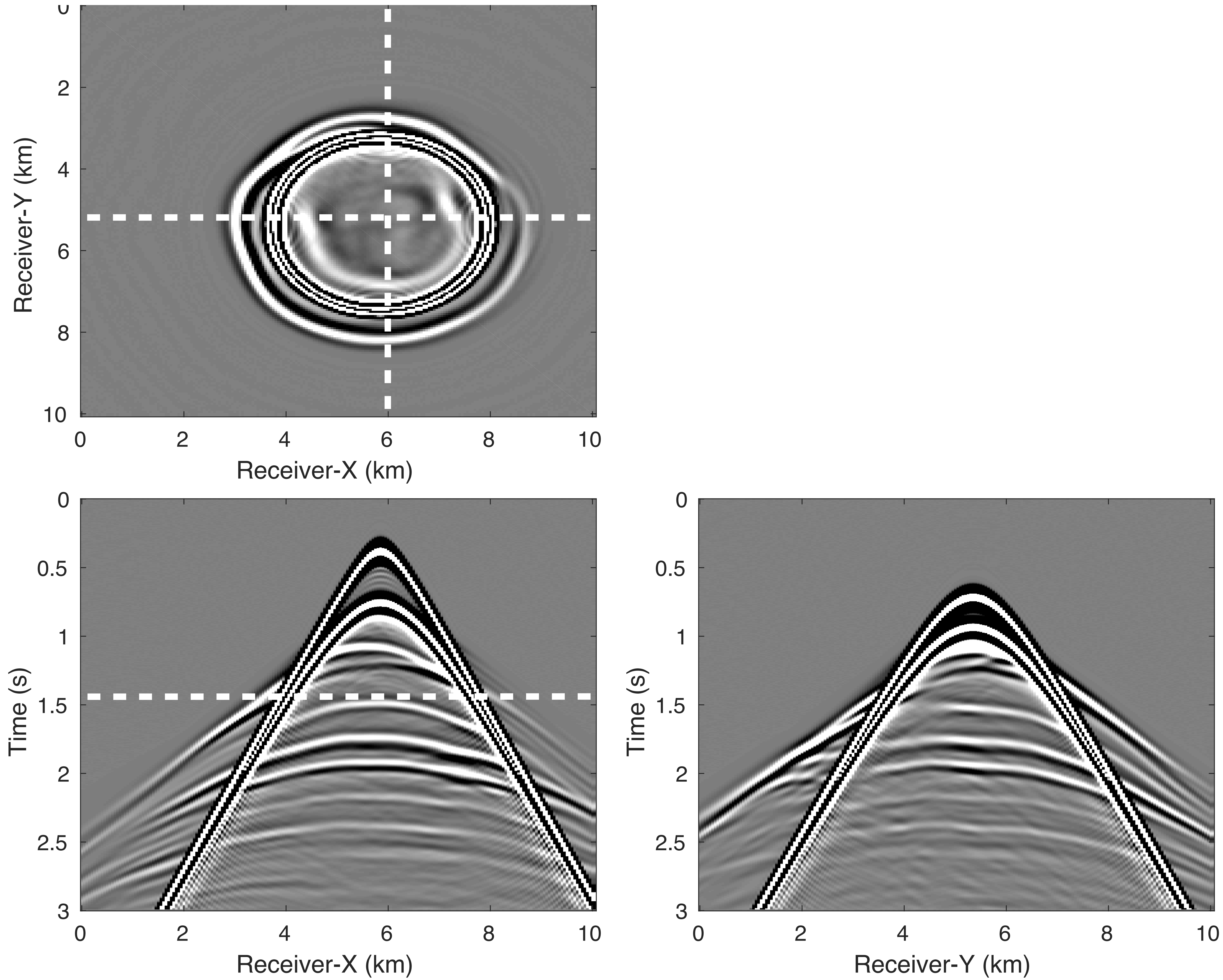
Common source gather
frequency slice @ 20 Hz



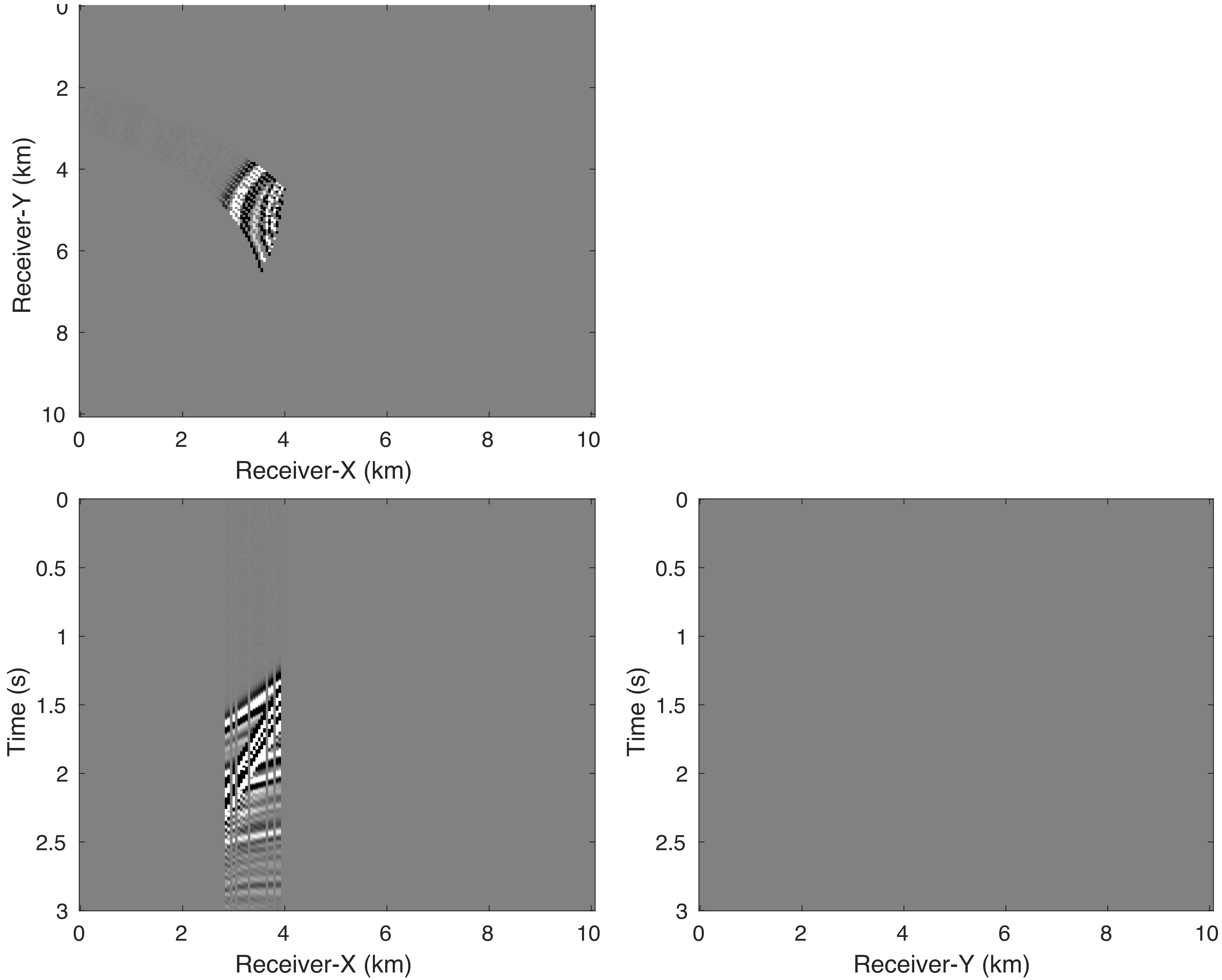
Common source gather
frequency slice @ 20 Hz



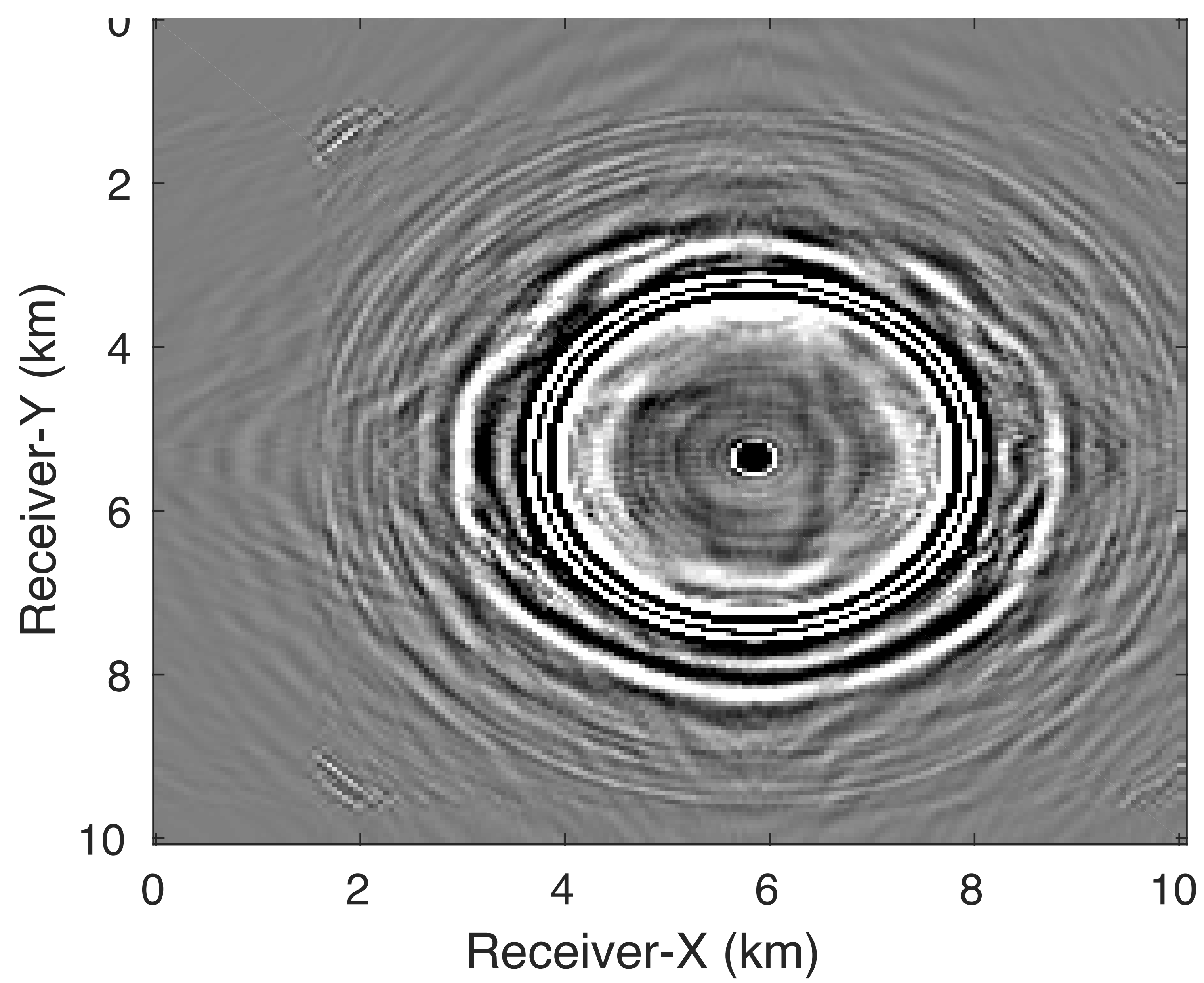
Common source gather
ground truth

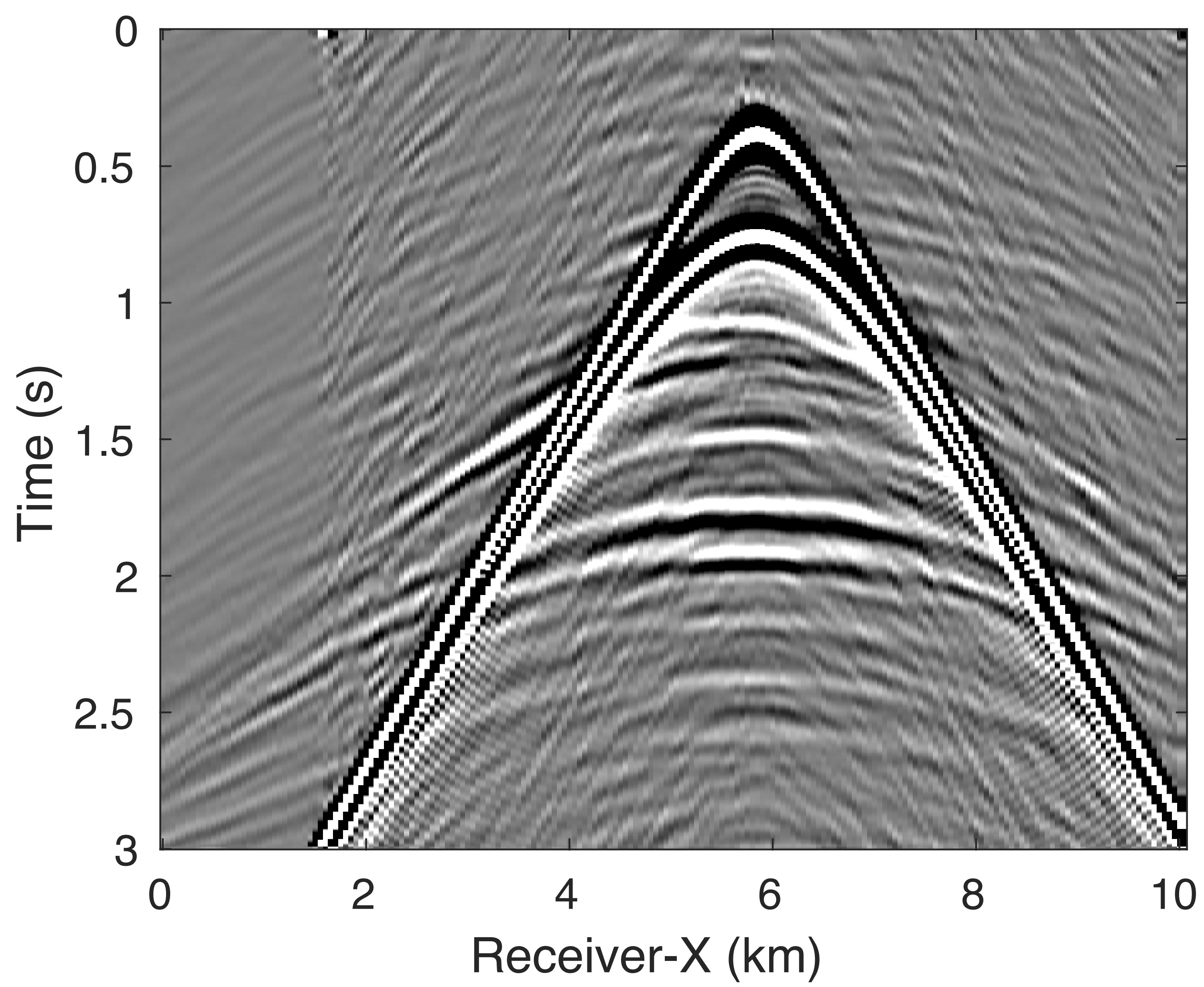


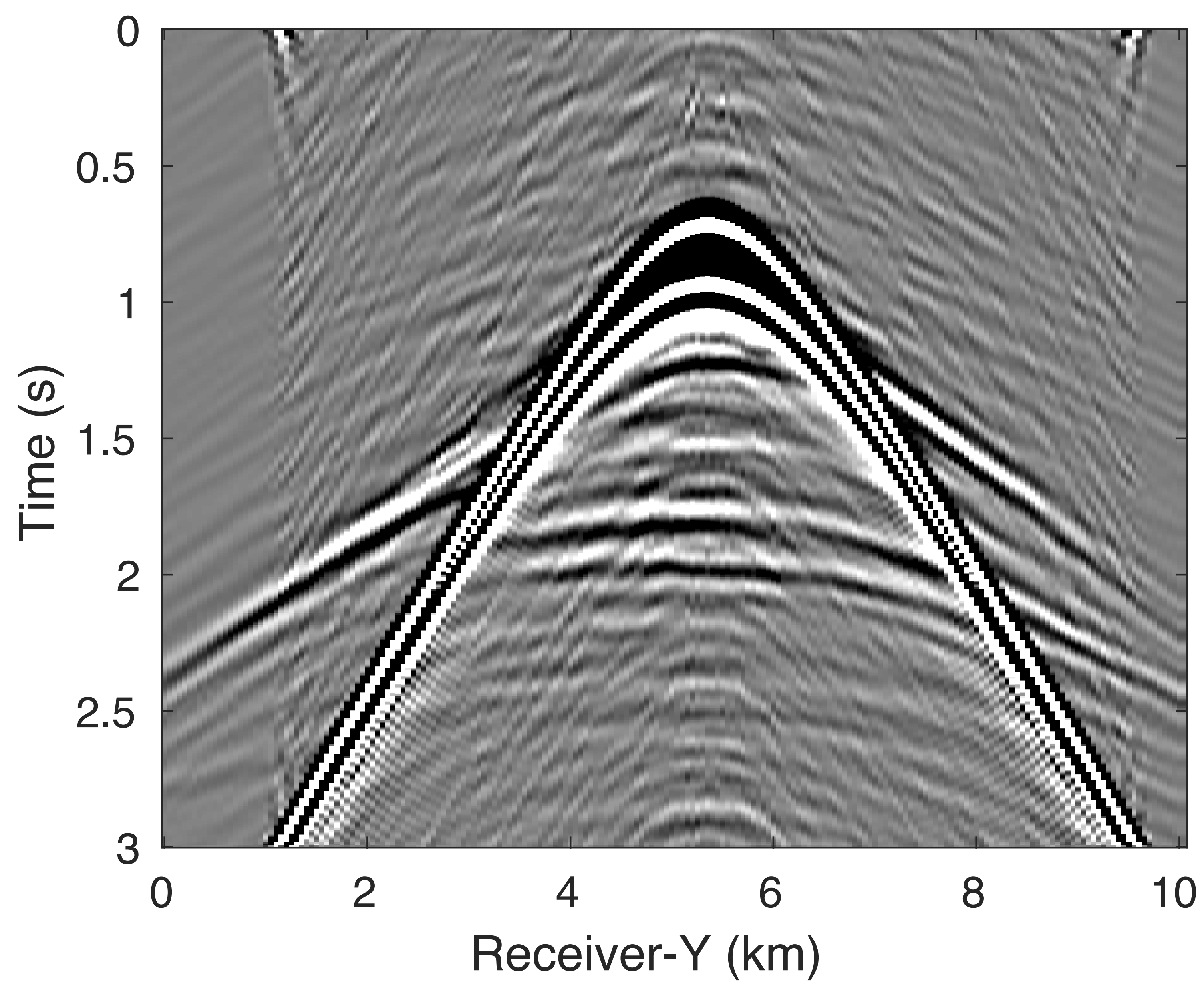
Common source gather
subsampled



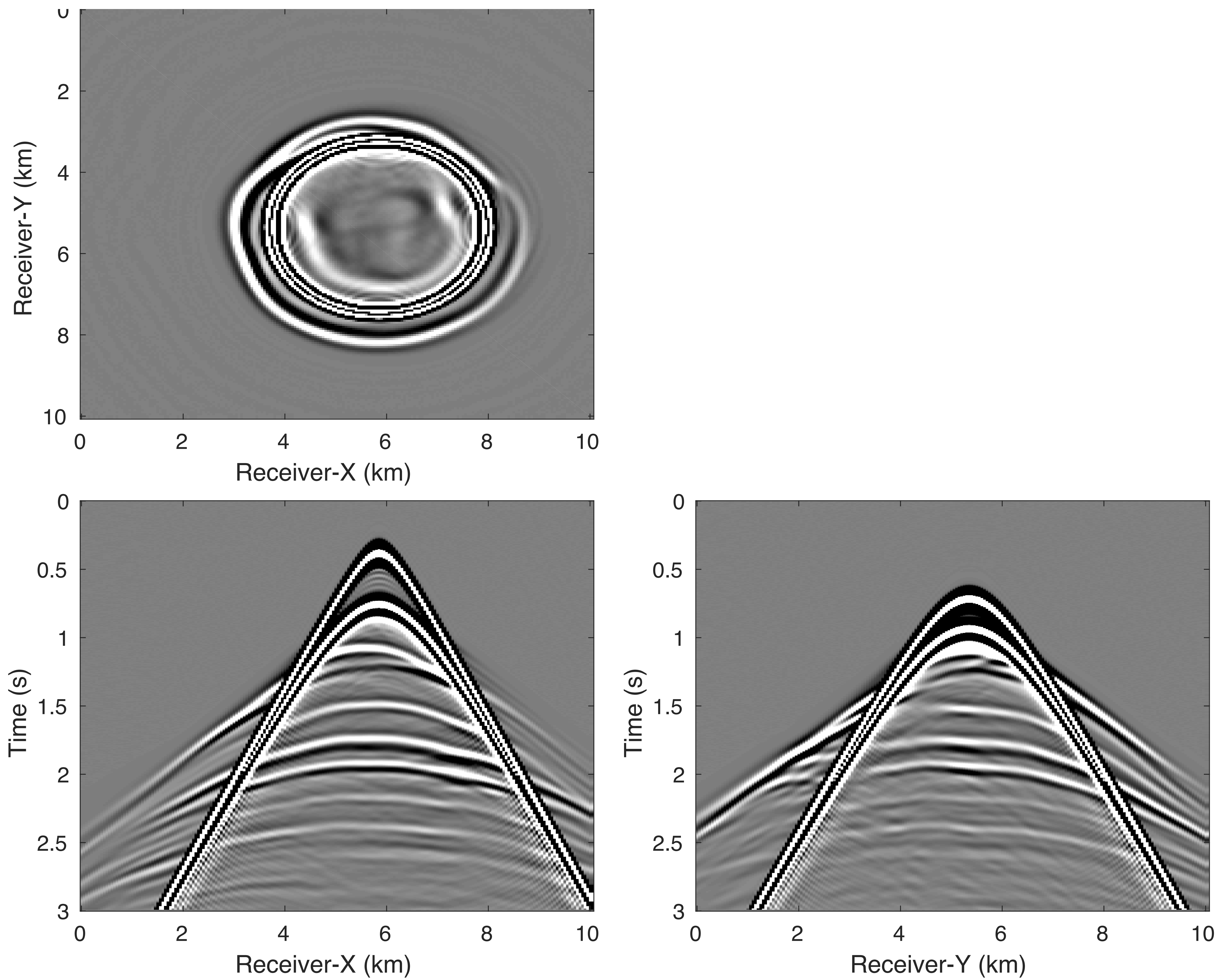
Common source gather
interpolated



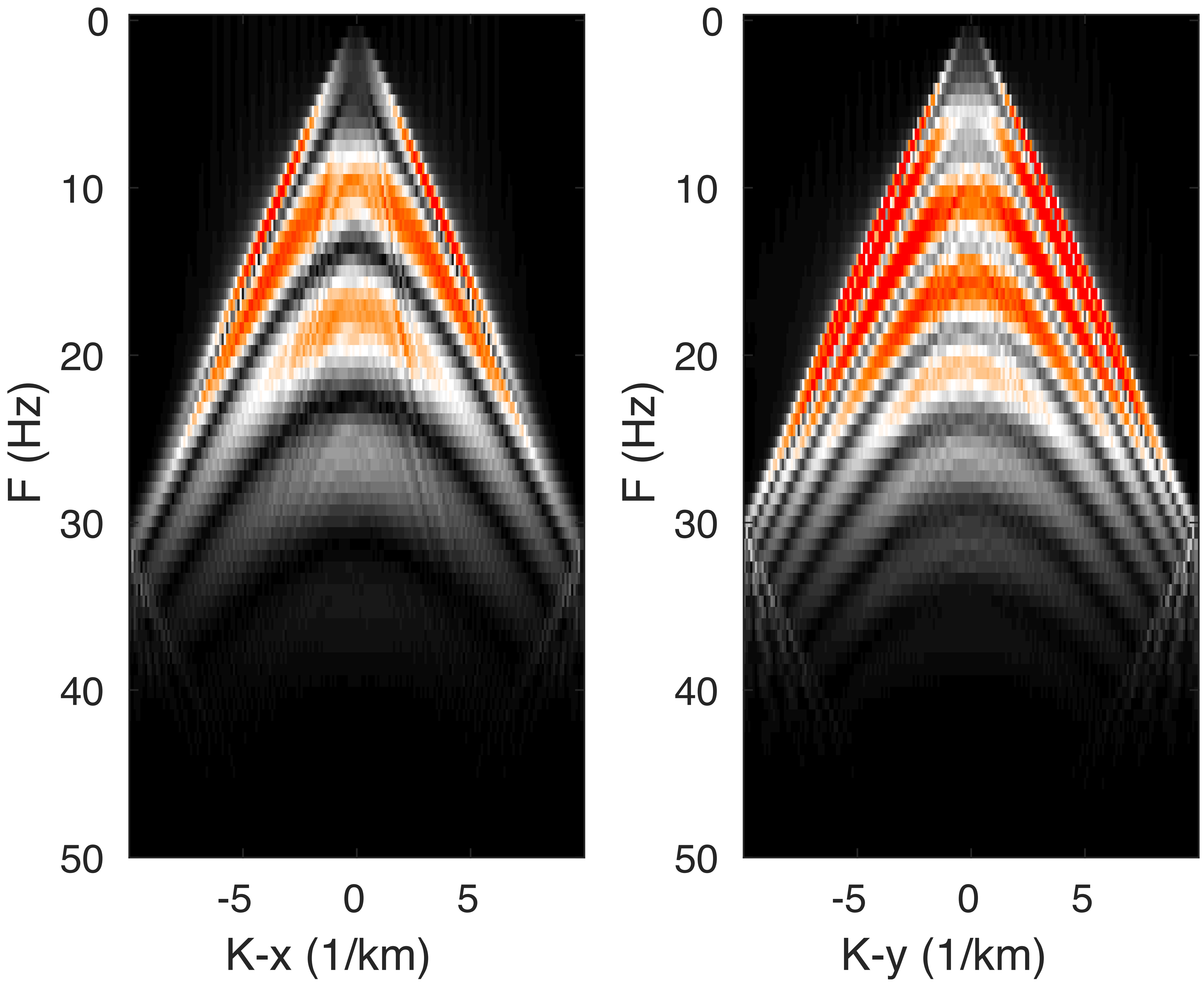




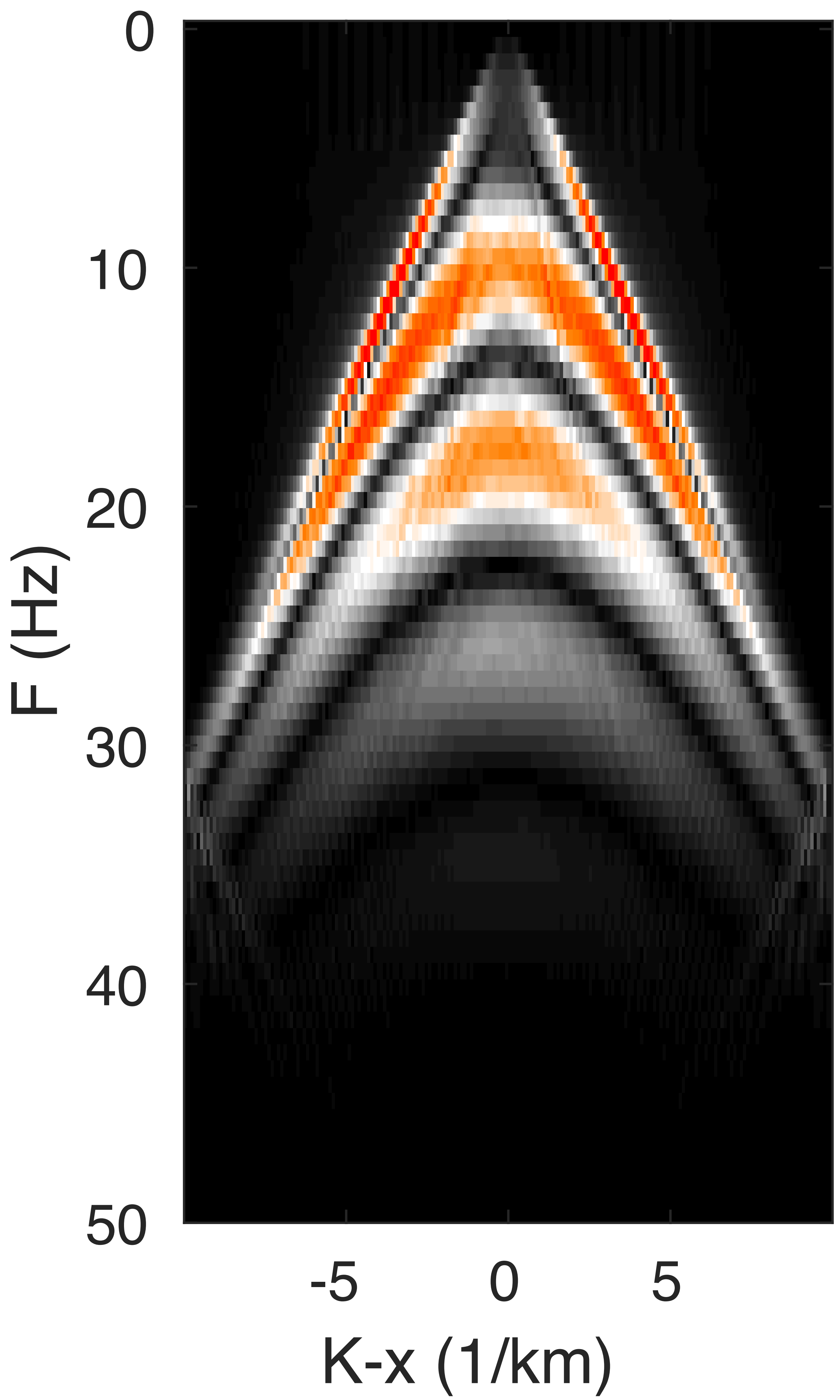
Common source gather
ground truth

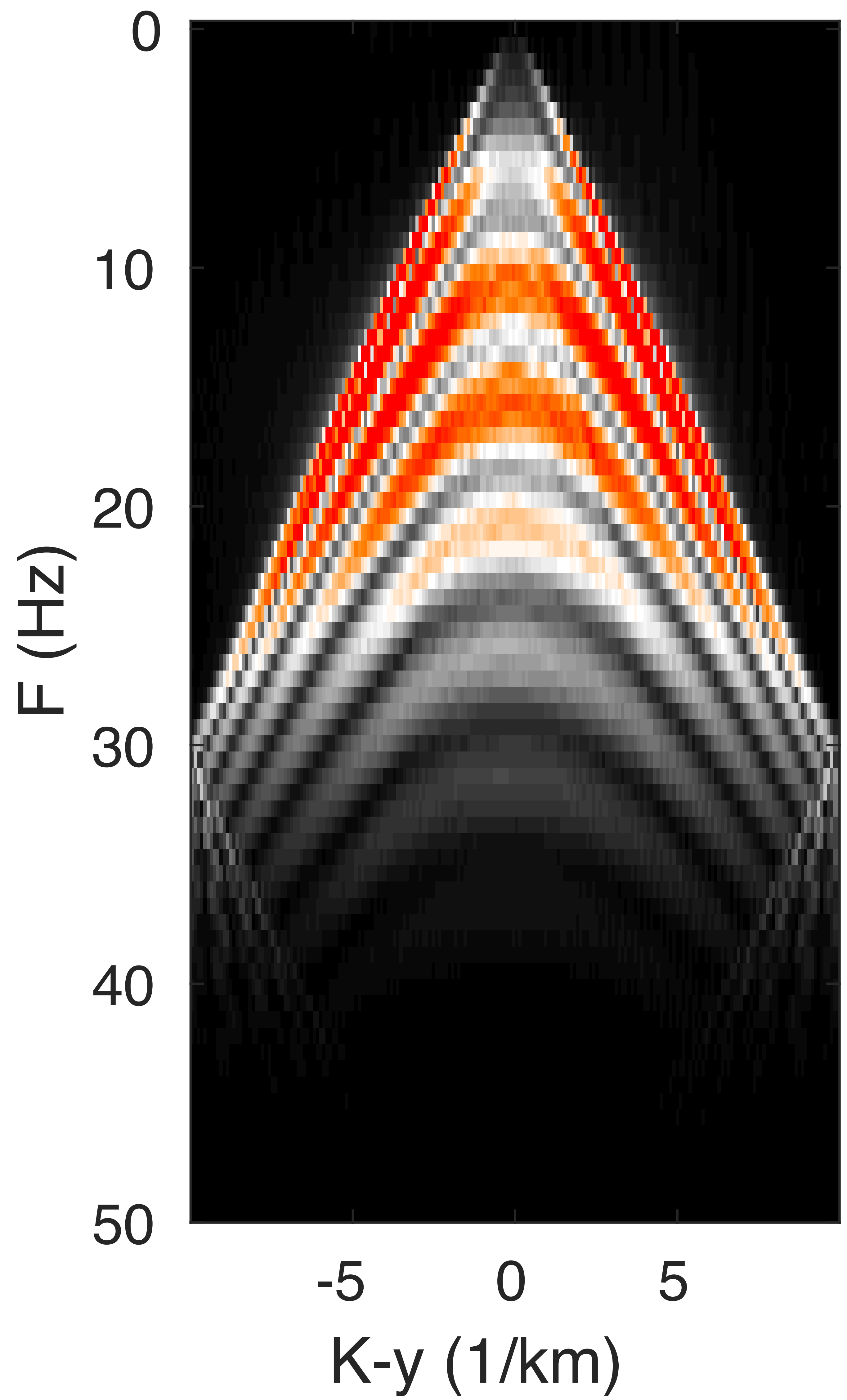


Common source gather
F-K spectrum, ground truth



Common source gather
F-K spectrum, interpolated





Coil acquisition—field data

Acquisition information

Gulf of Mexico, coil acquisition

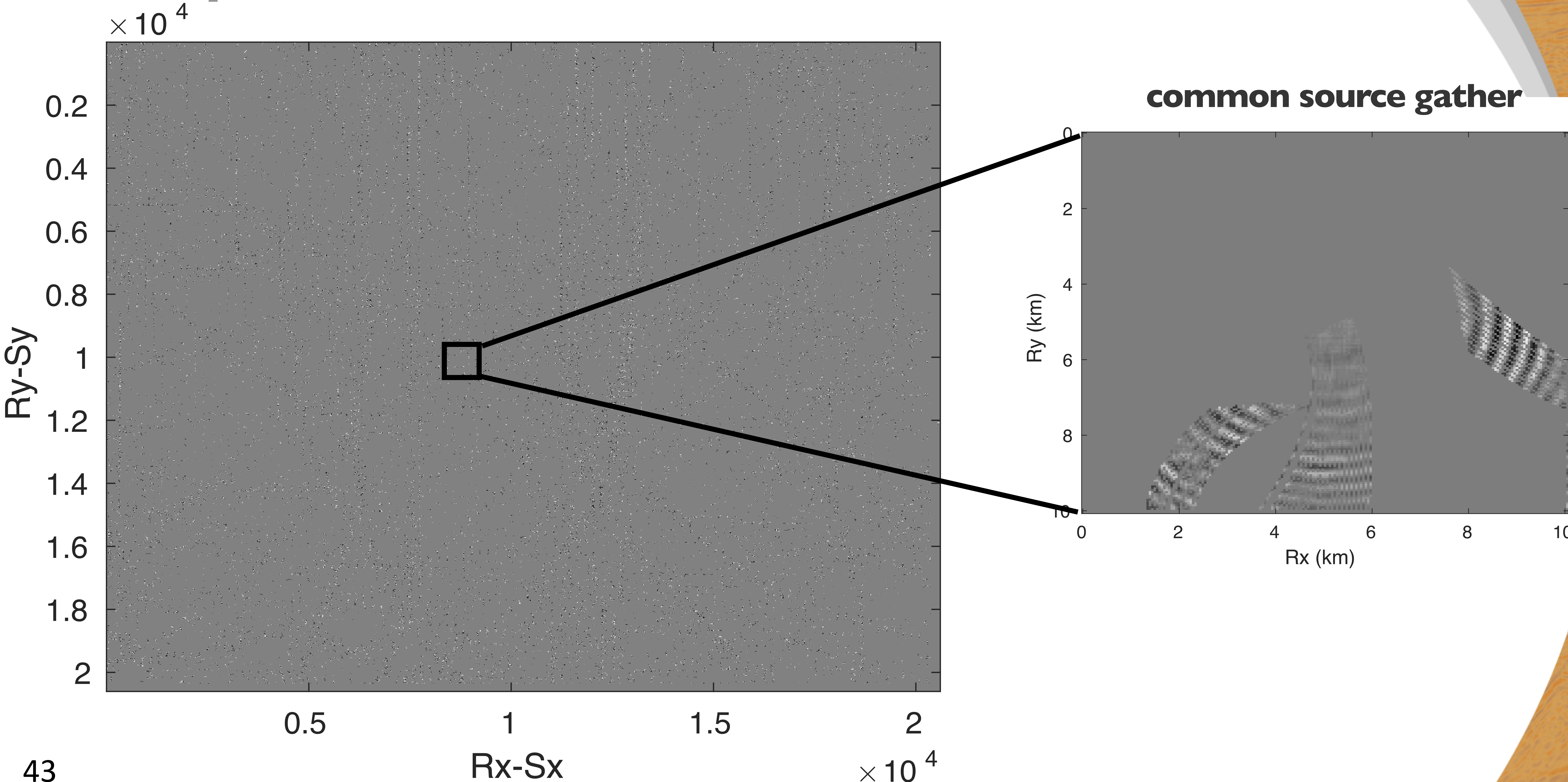
10404 sources after interpolation @ 100m

40804 receivers after interpolation @ 50m

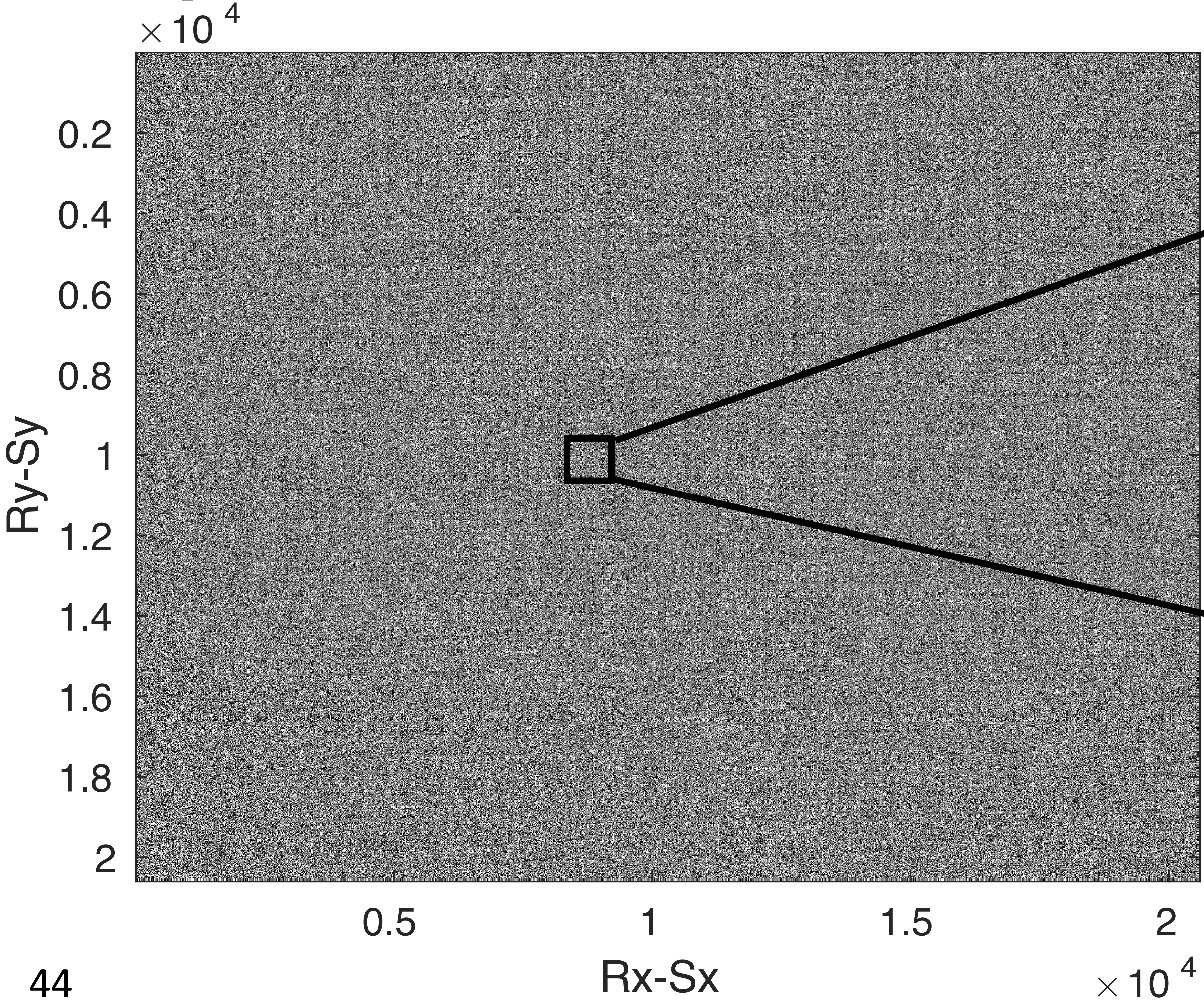
Time length : 15 second @ 0.008s

Interpolation from 3-20 Hz

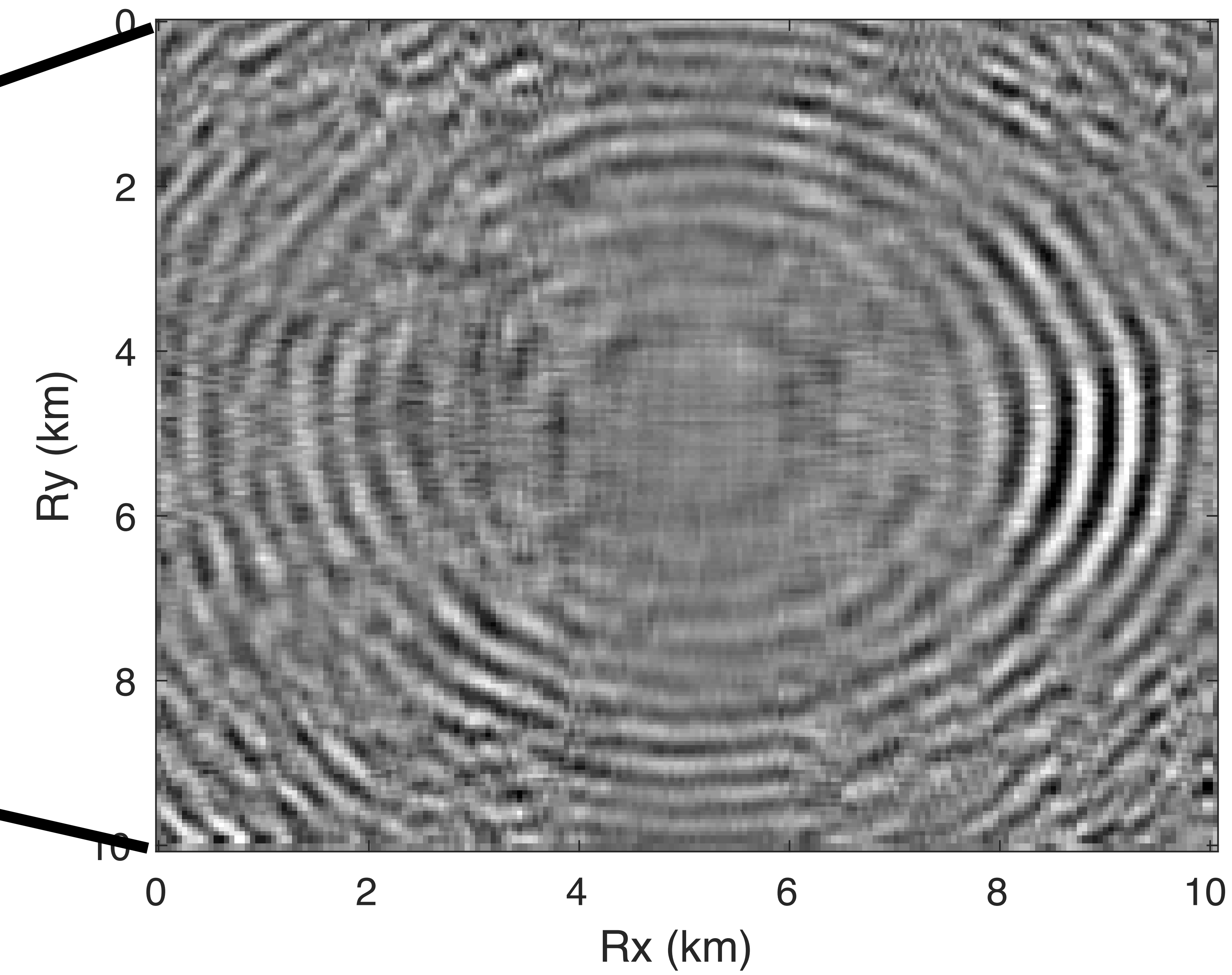
Frequency slice @ 5Hz
subsampled



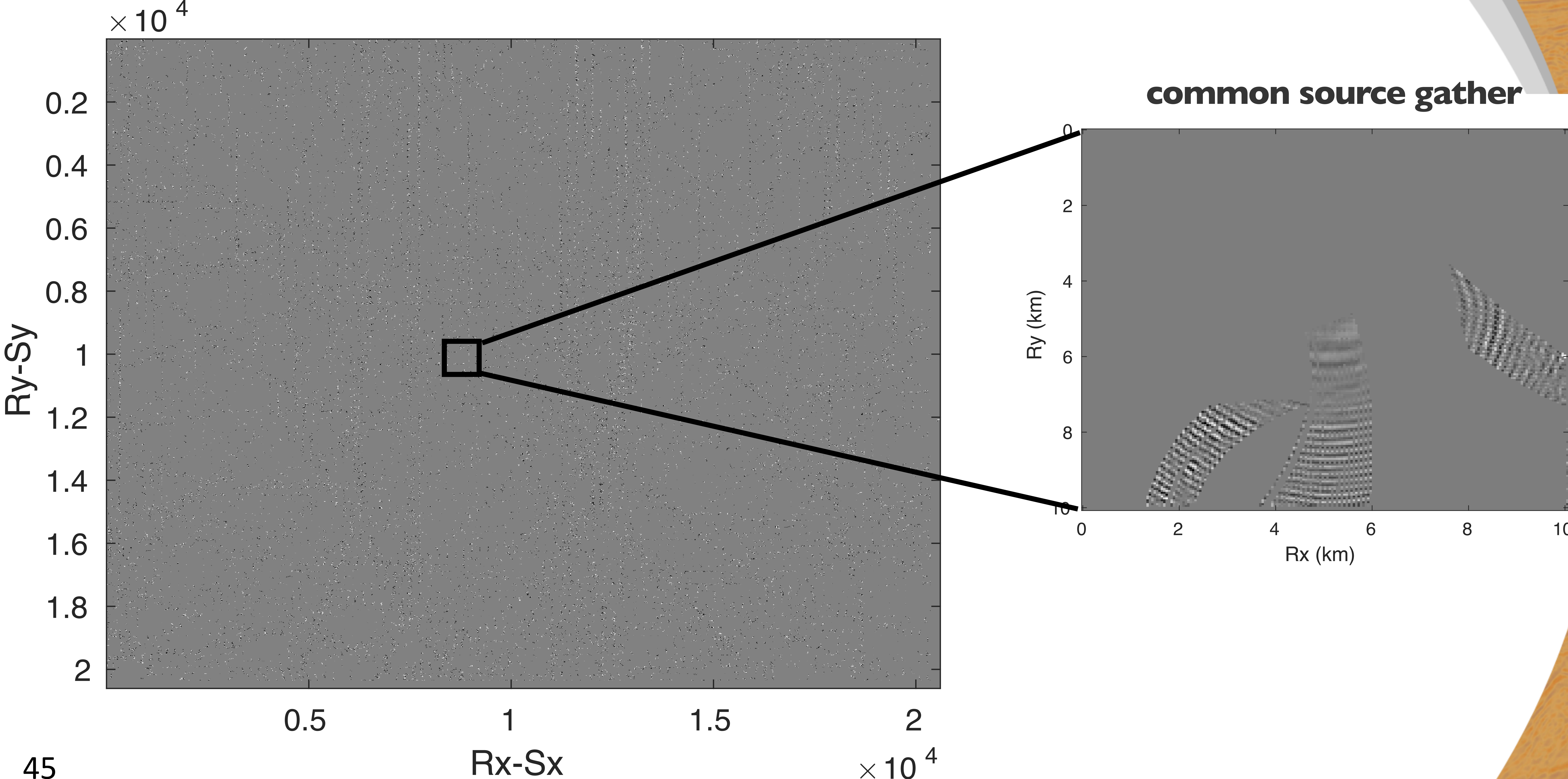
Frequency slice @ 5Hz
interpolated



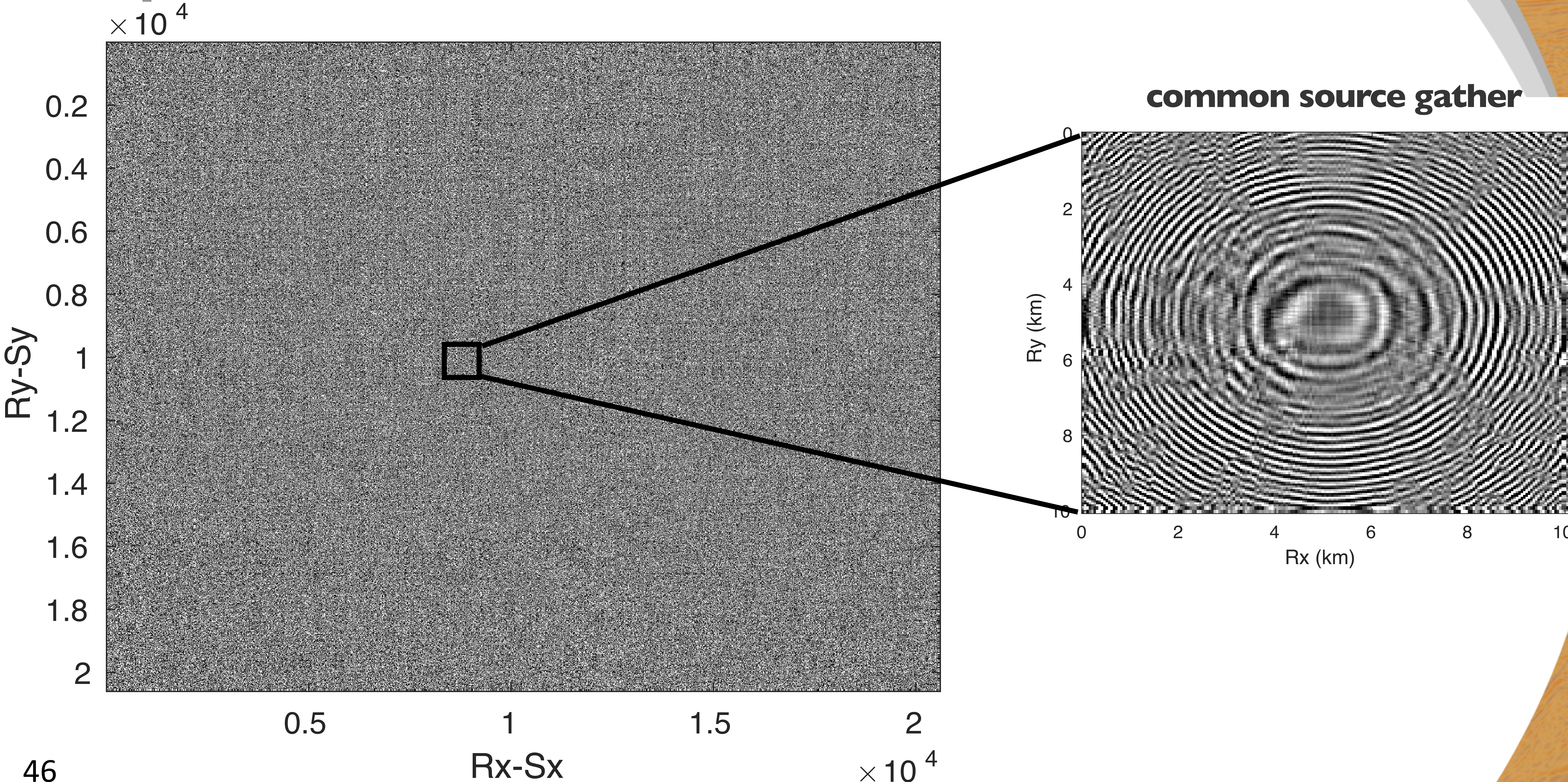
common source gather



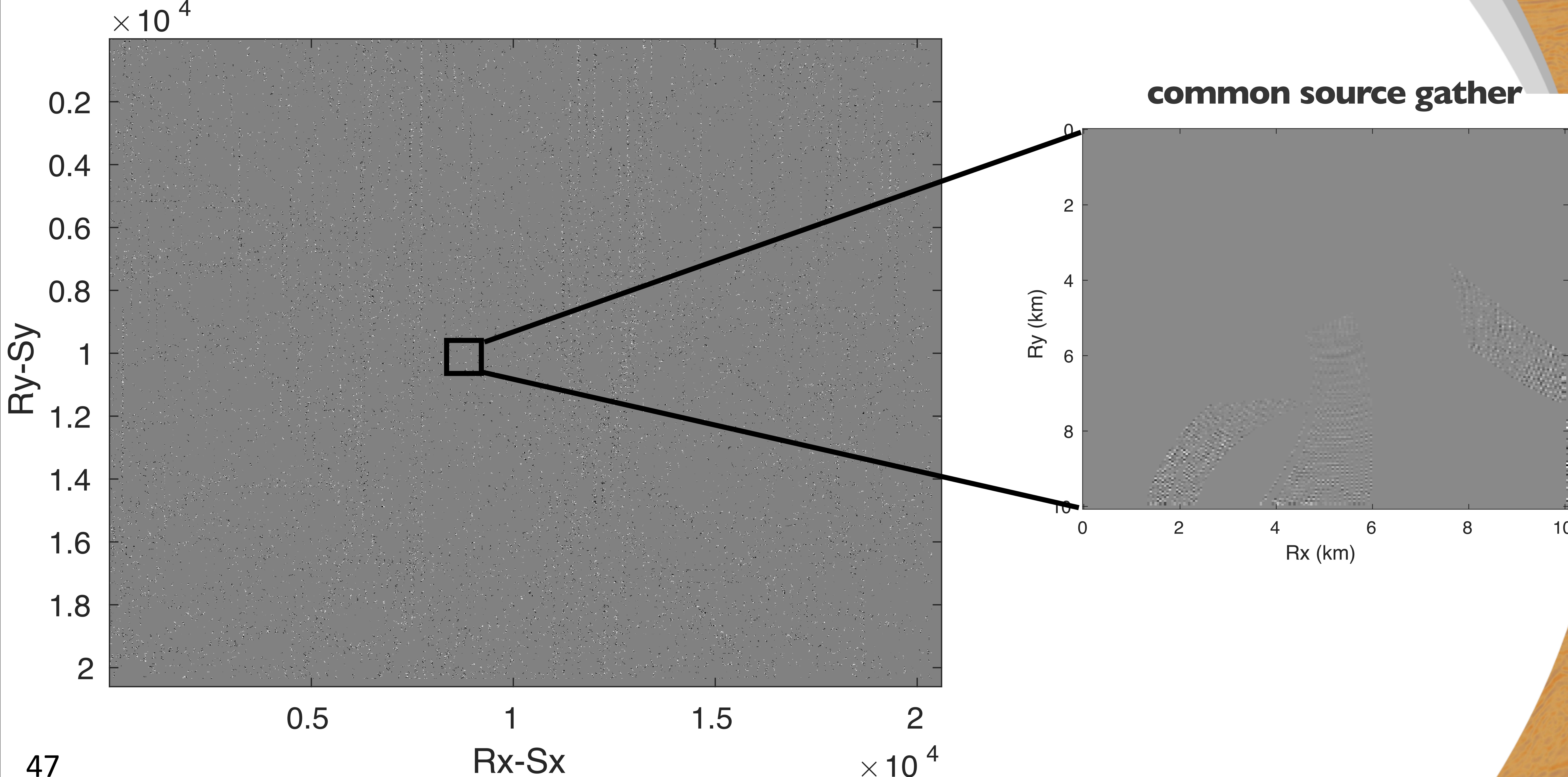
Frequency slice @ 10Hz
subsampled



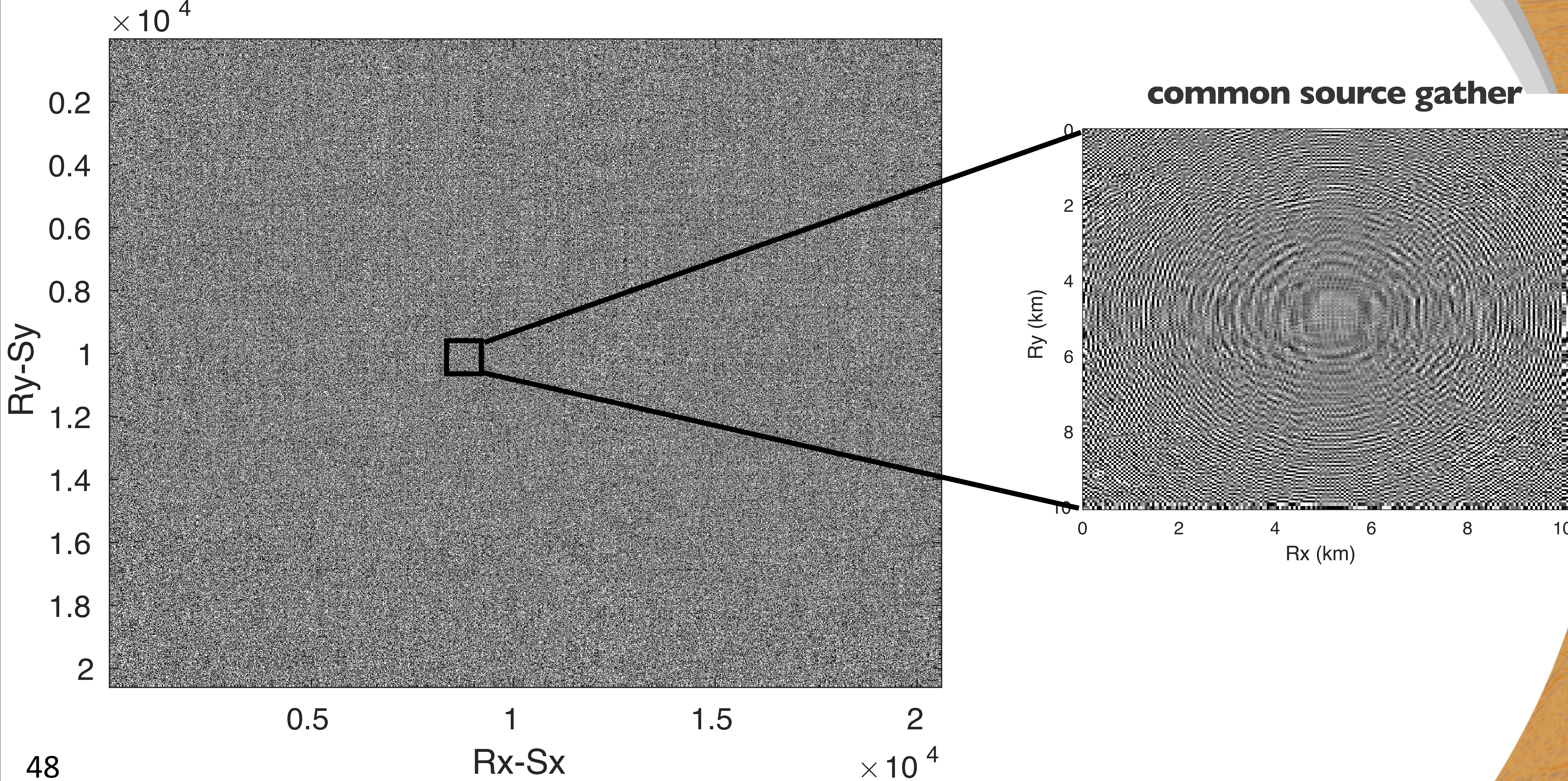
Frequency slice @ 10Hz
interpolated



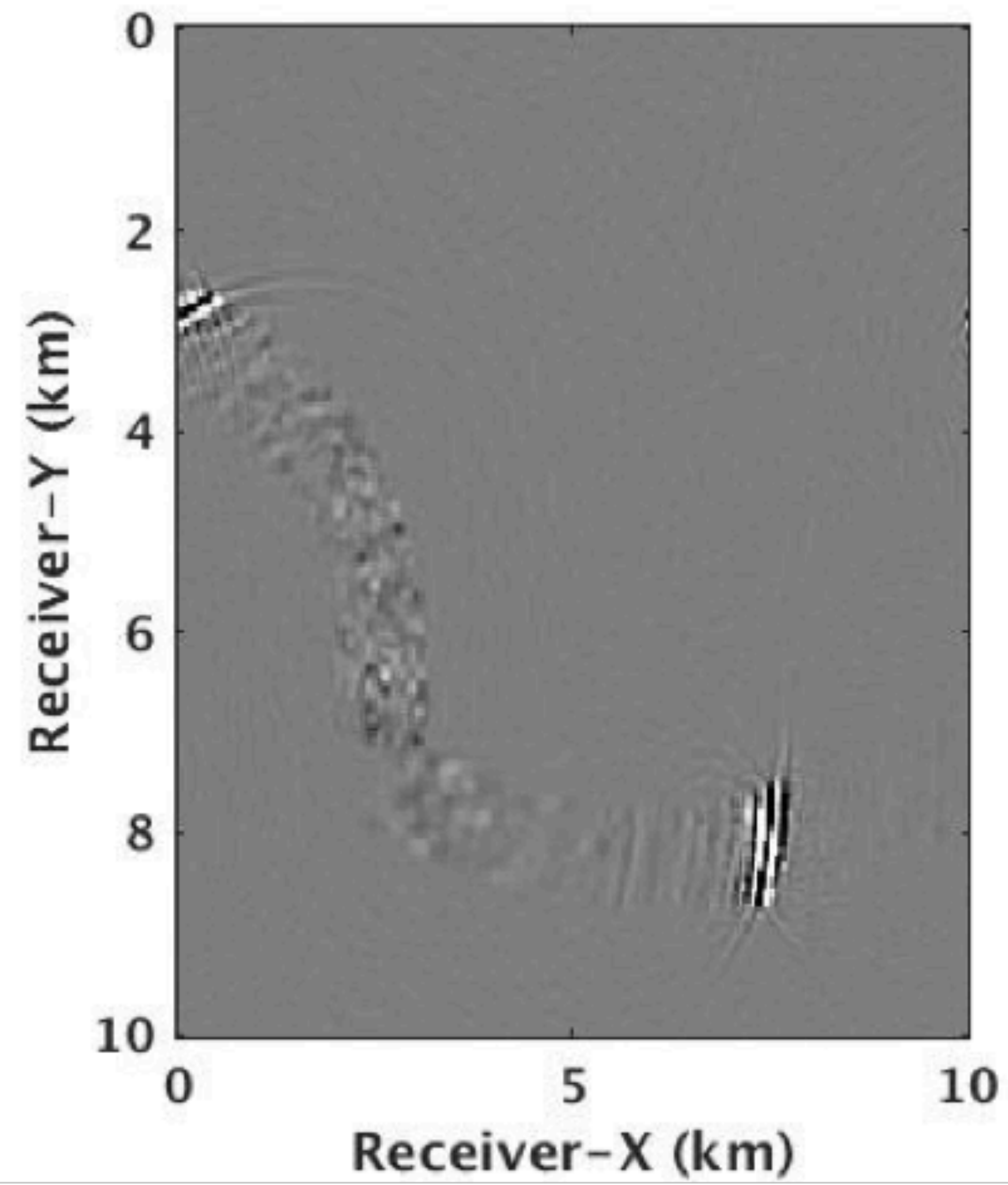
Frequency slice @ 18Hz
subsampled

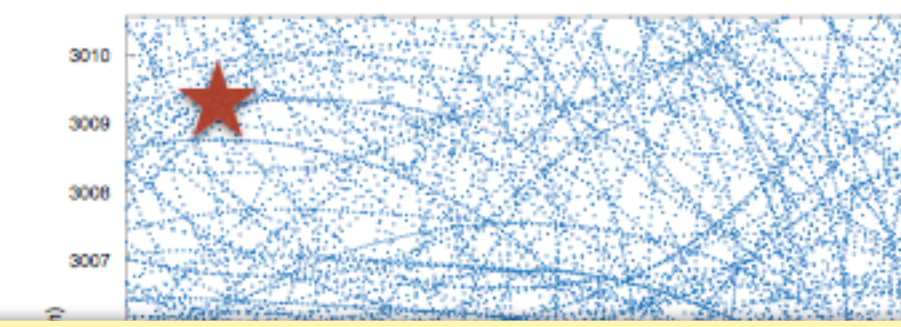


Frequency slice @ 18Hz
interpolated



Common source gather
observed

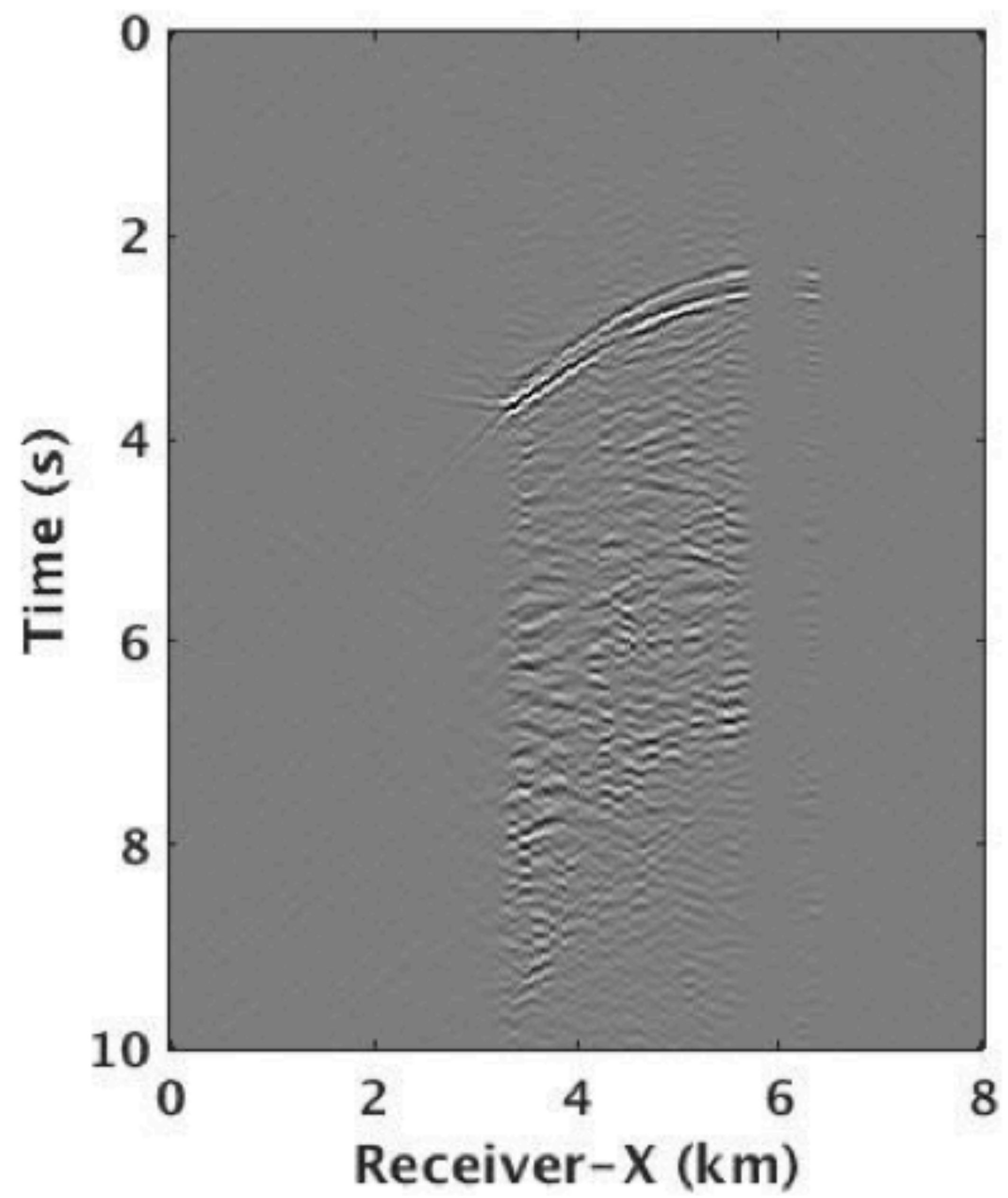


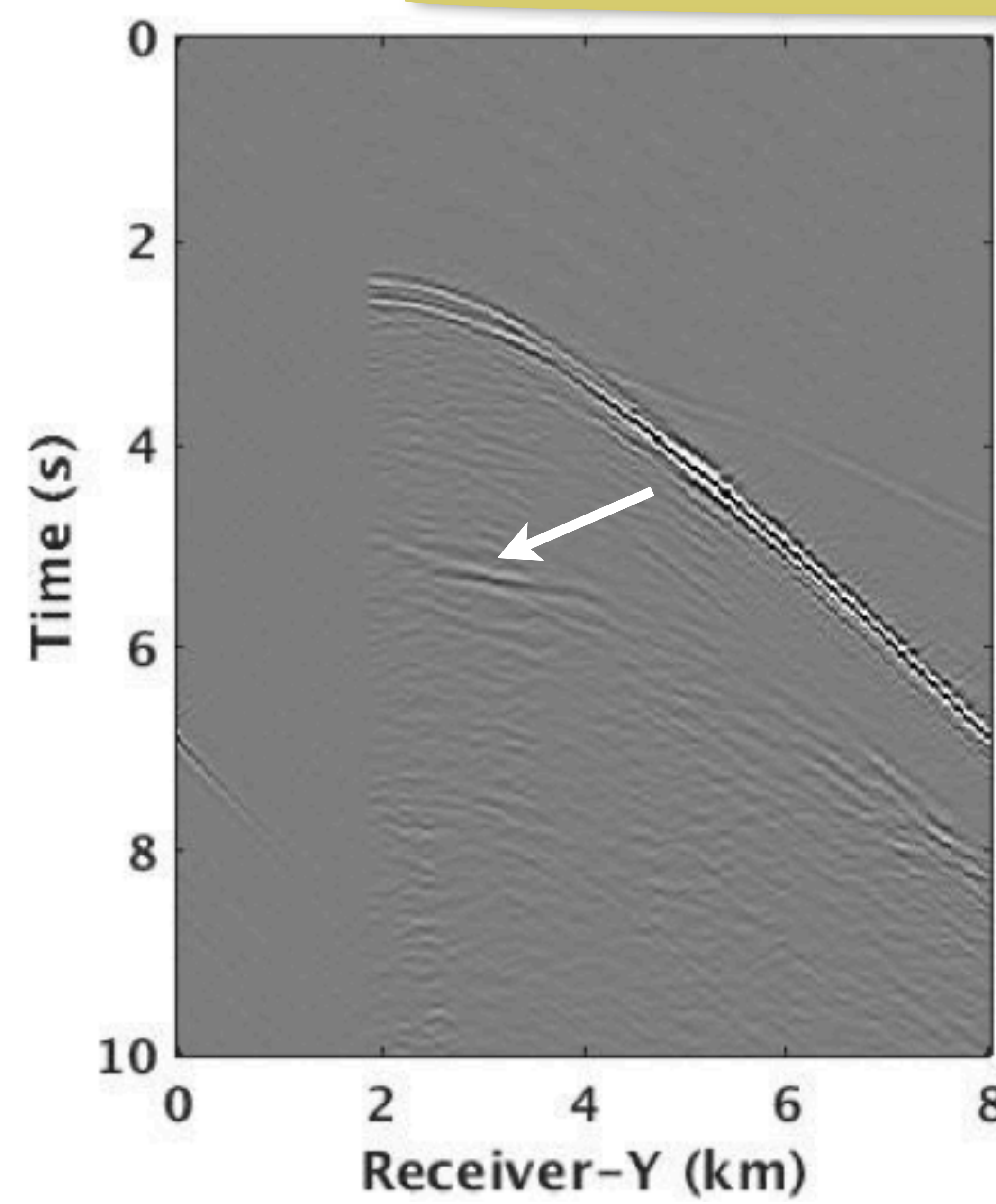


I would first show freq slices and start with best

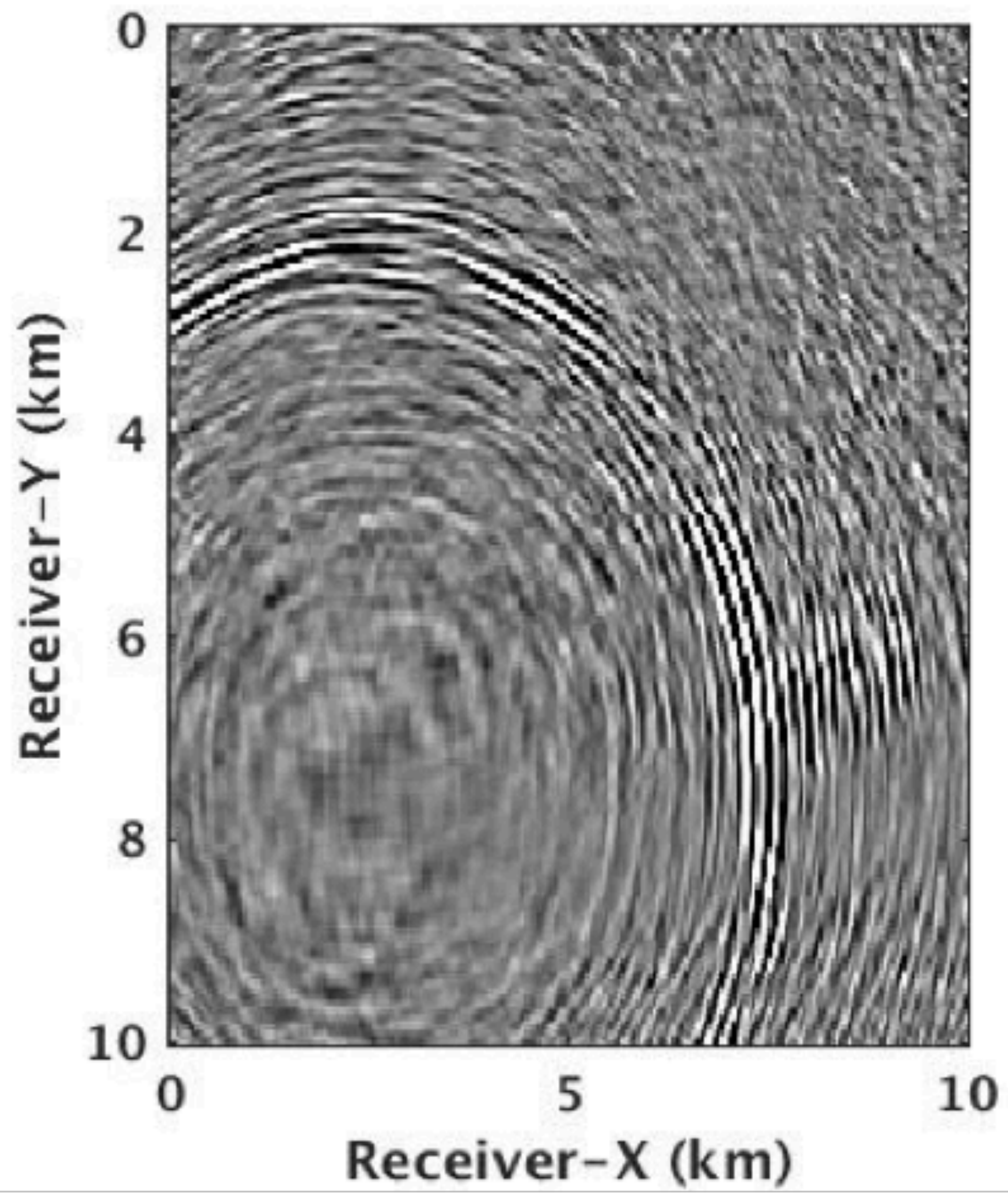
Again things are very noisy.

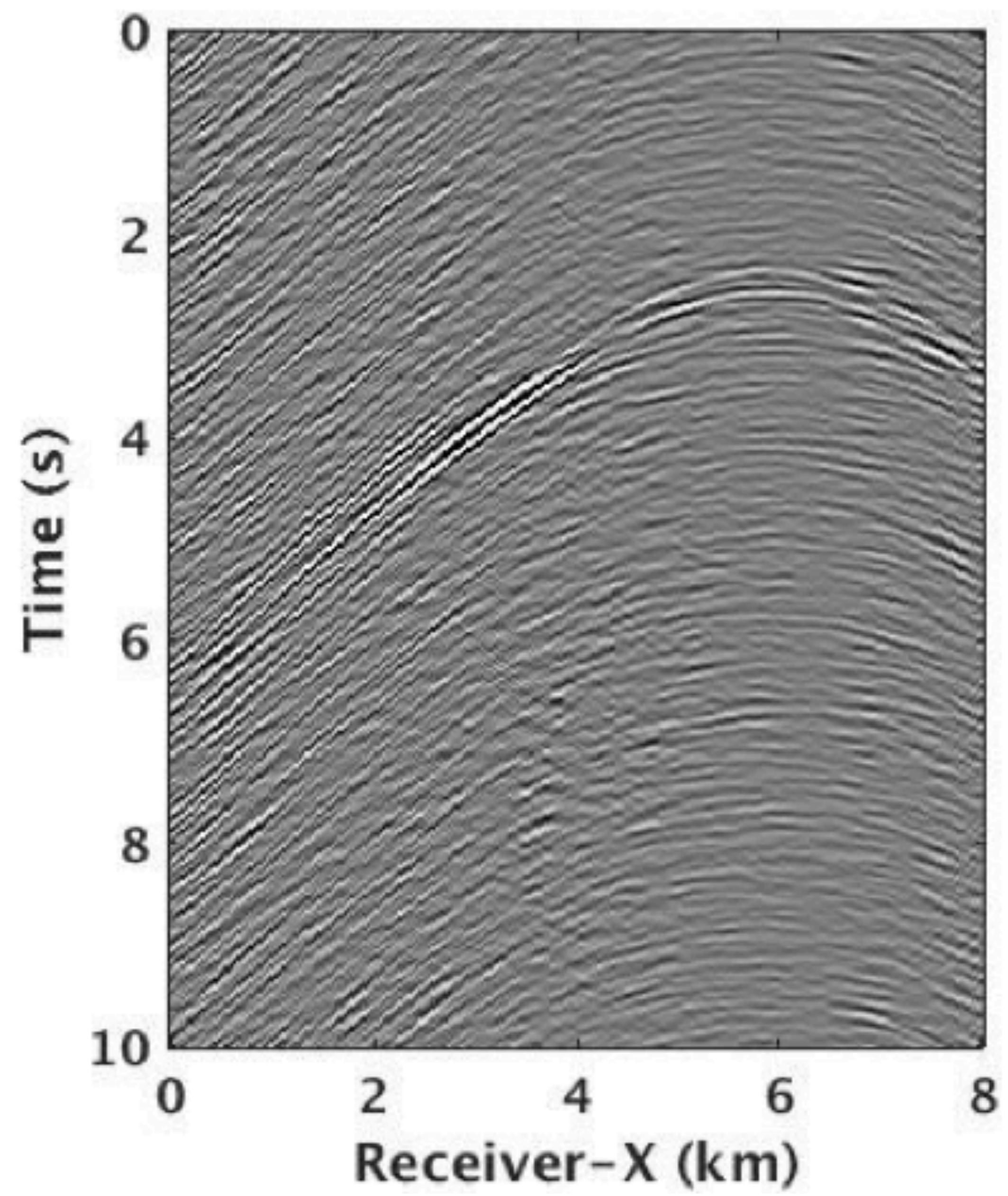
Rajiv : Yeah I really wanted to investigate the cause of it. I see this in the synthetic examples also.

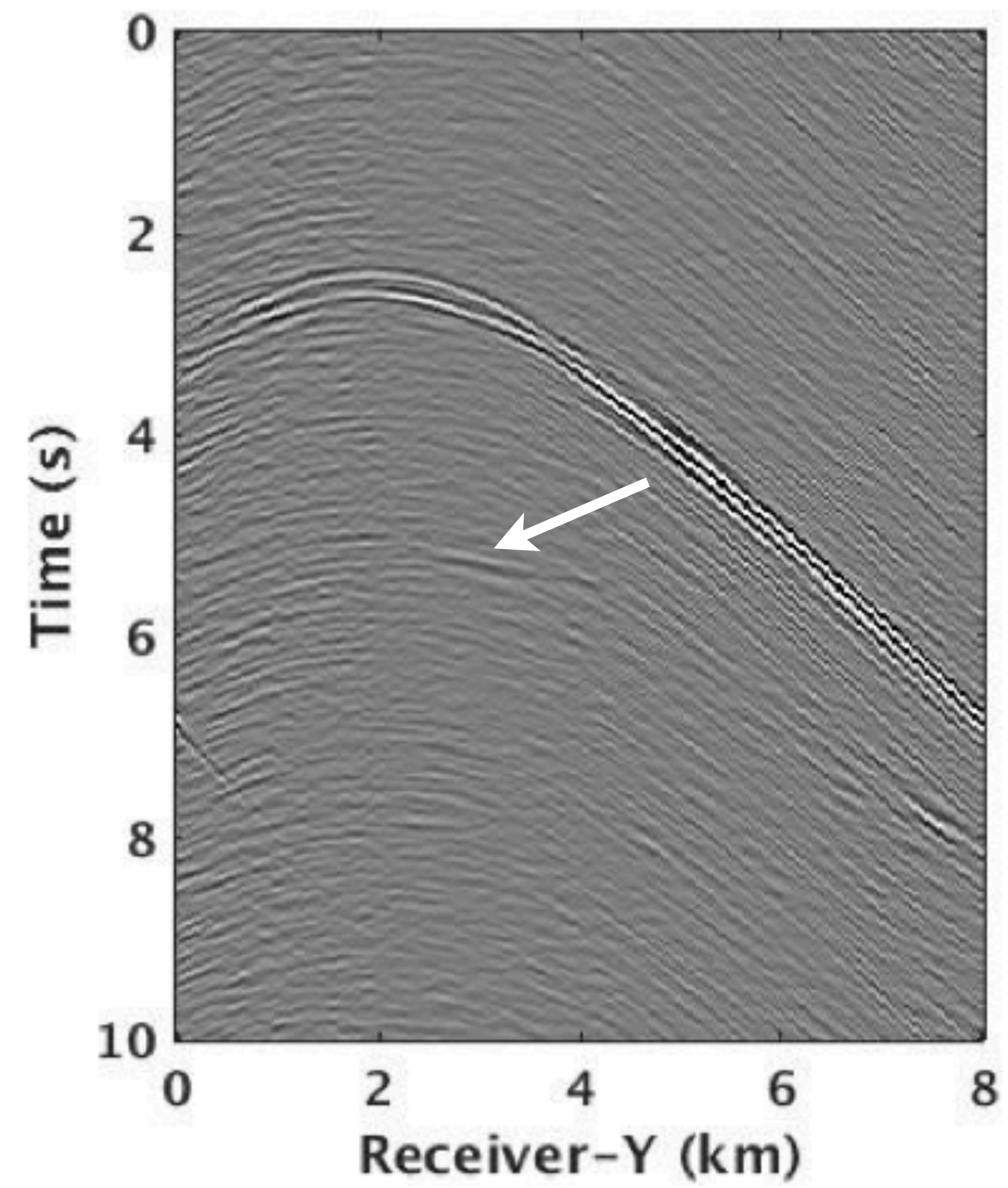




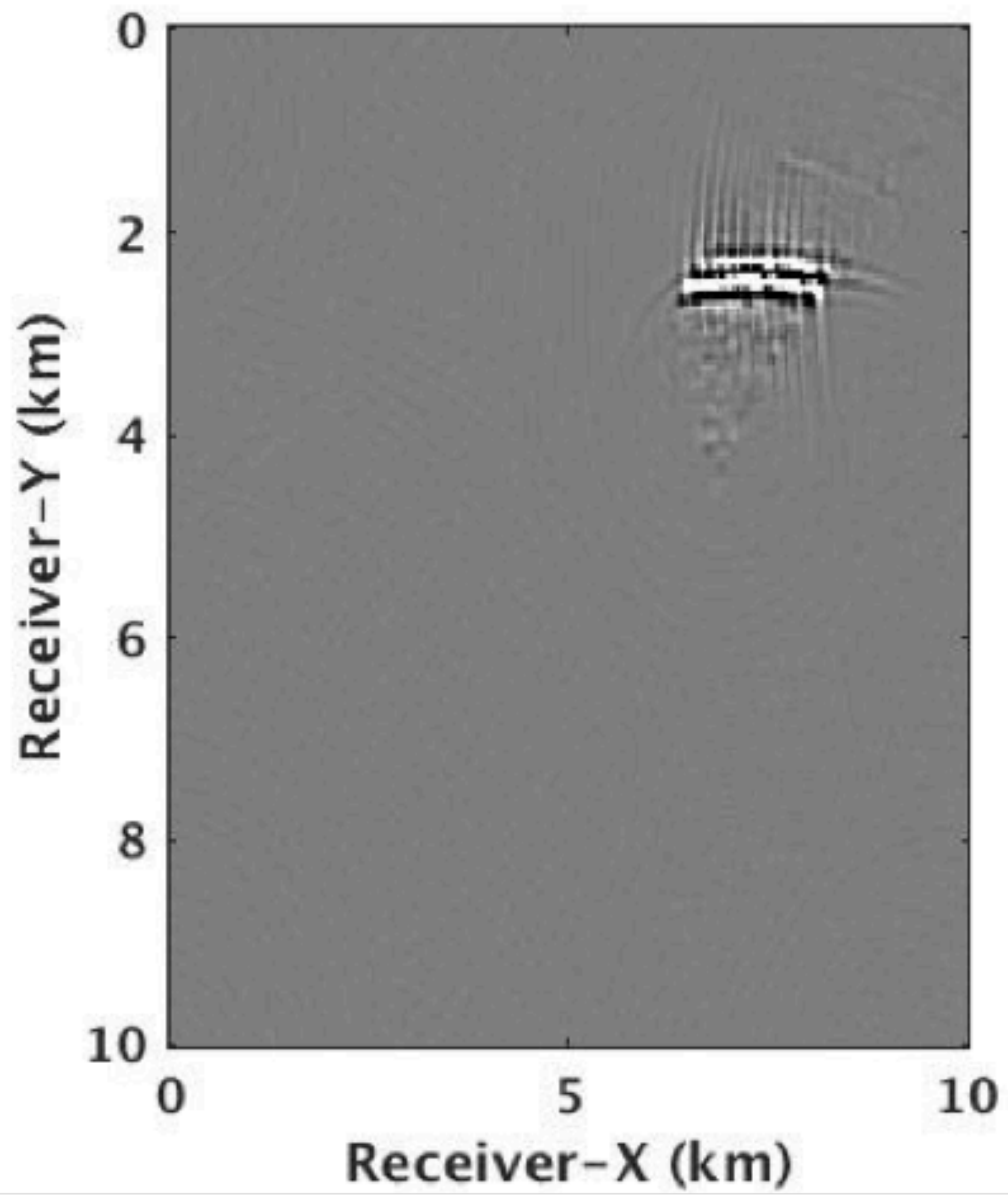
Common source gather
interpolated

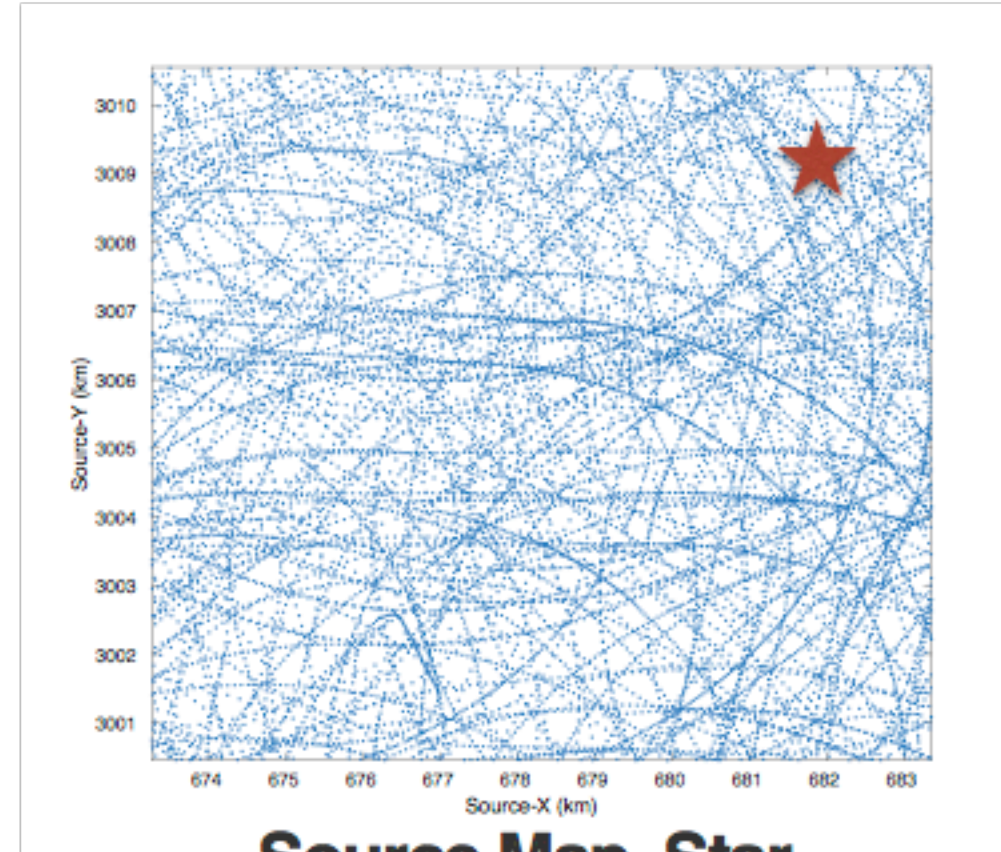




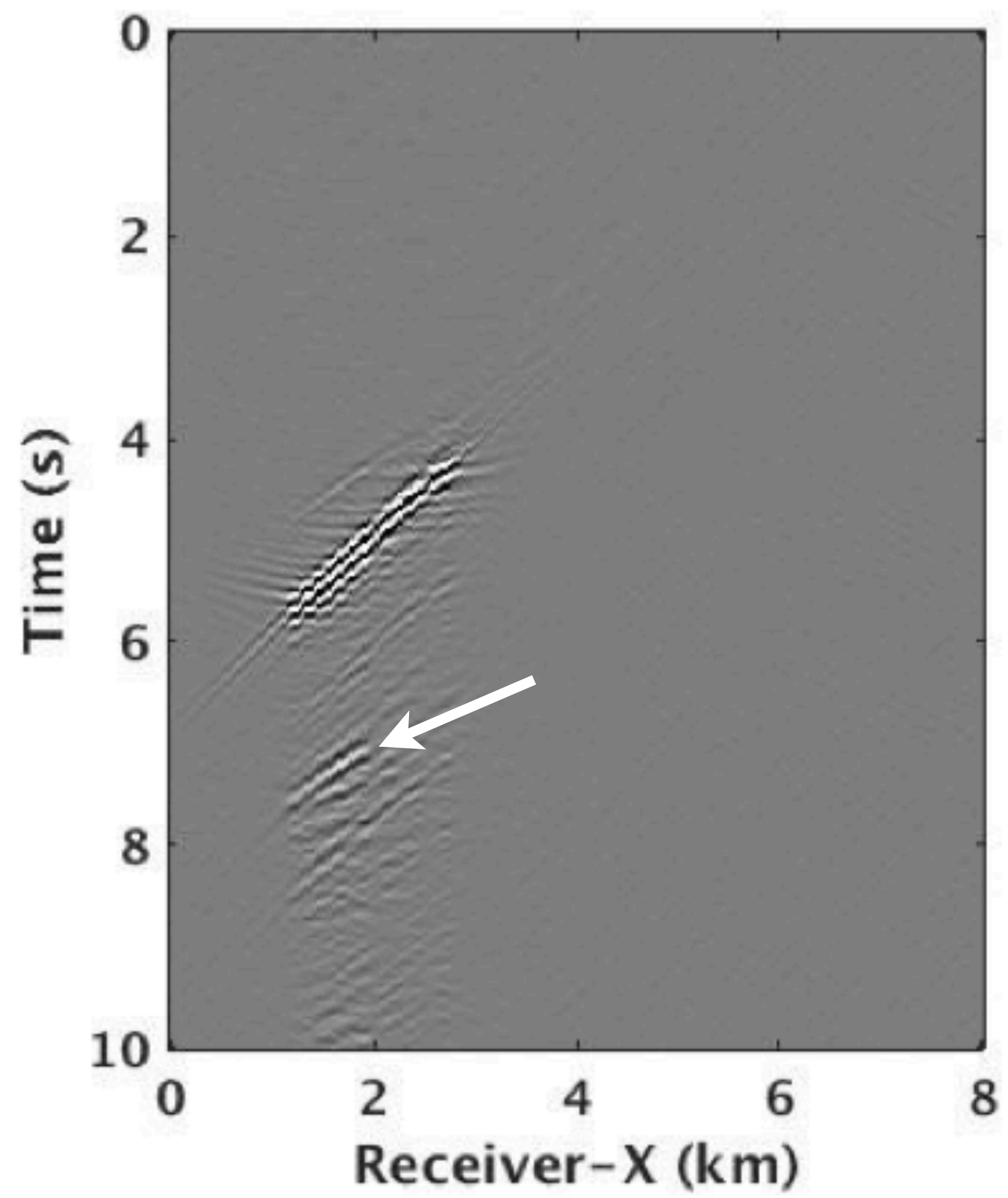


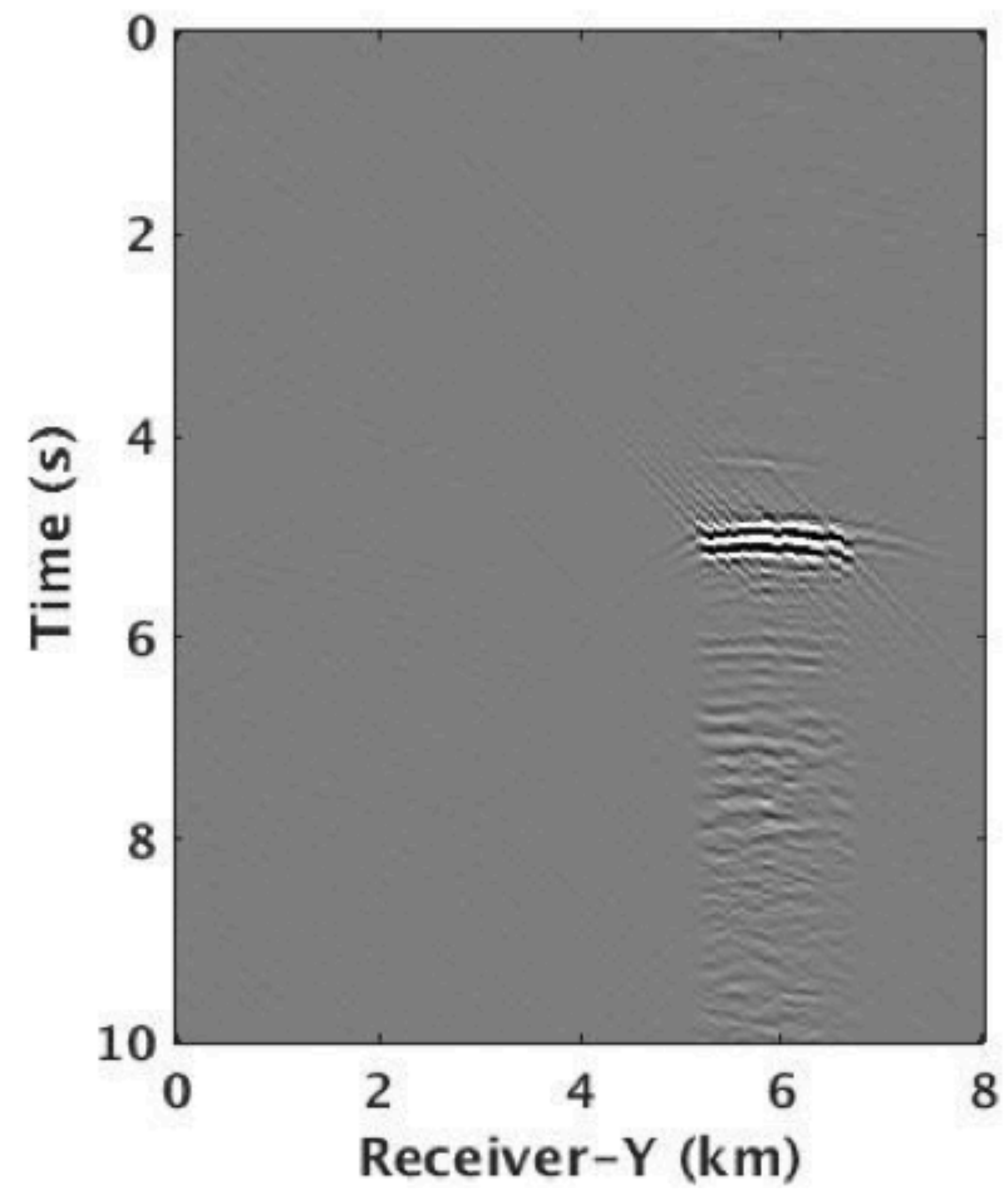
Common source gather
observed



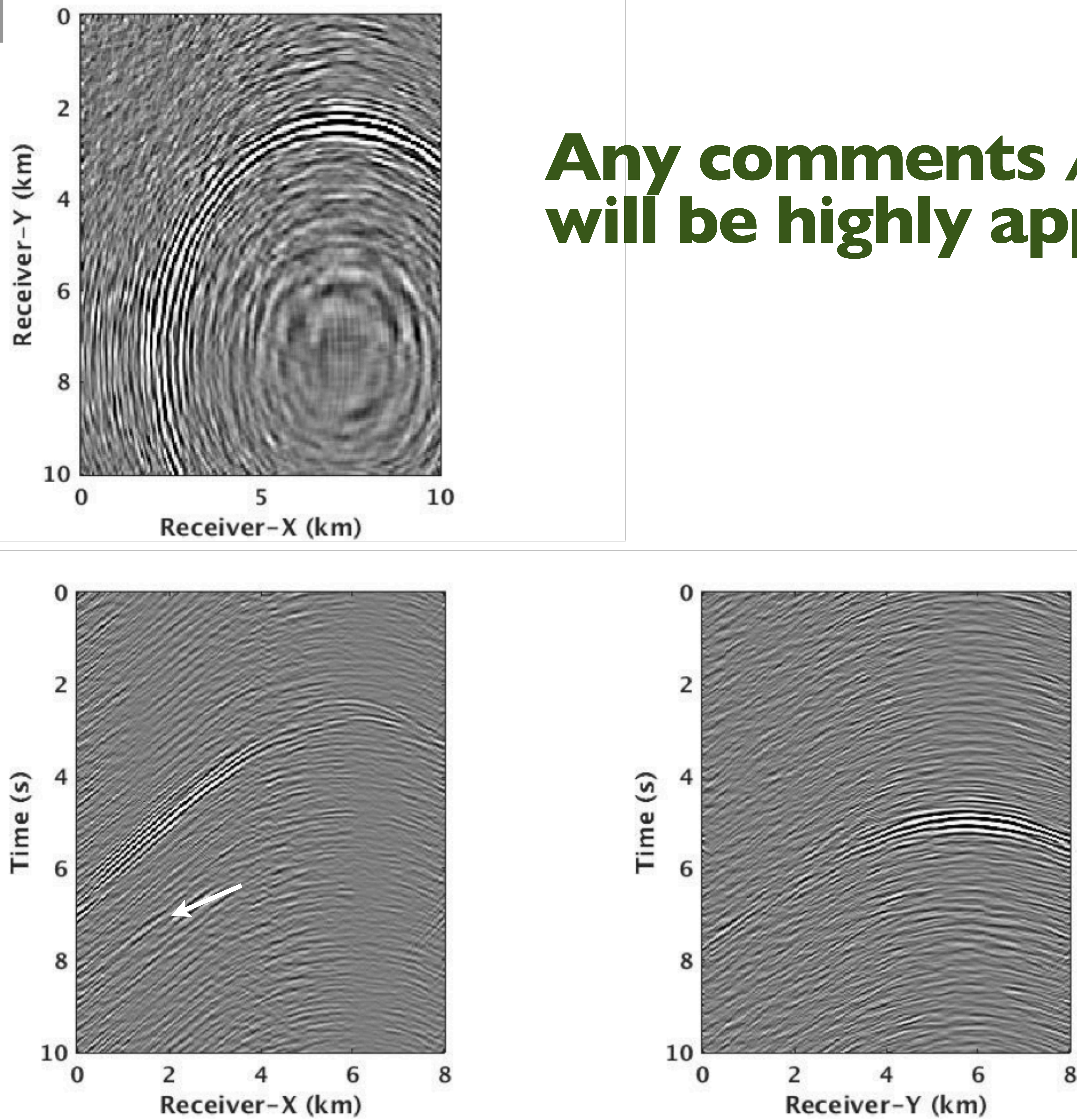


Source Map. Star represents the common shot gather location





Common source gather
interpolated



Any comments / suggestions will be highly appreciated

Computational / memory advantages

Size of fully sampled interpolated volume : 2.5 TB

Save low-rank factors

- compression rate: **99.5%**
- size of final compressed 5D seismic volume : **15GB**

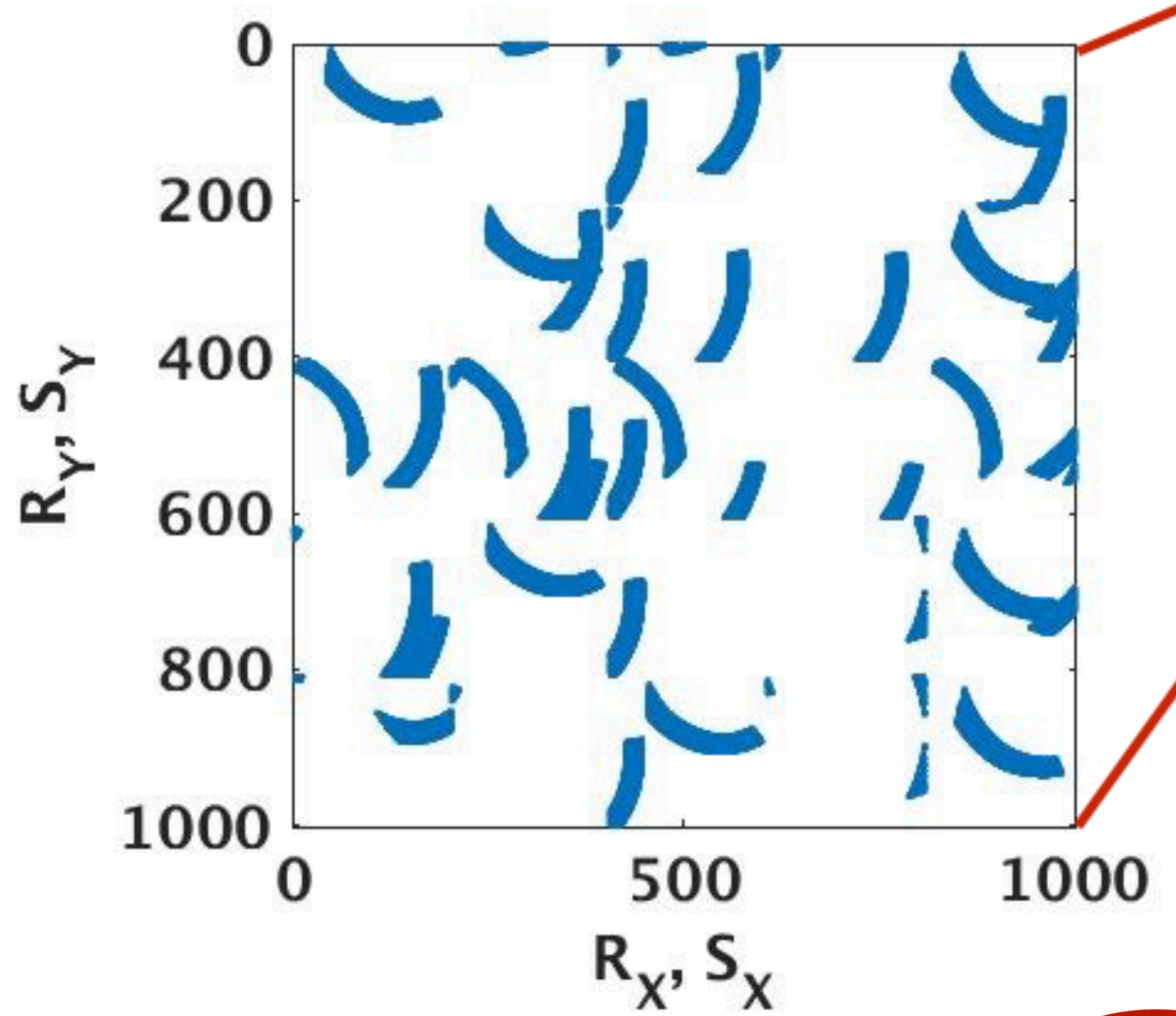
Future work

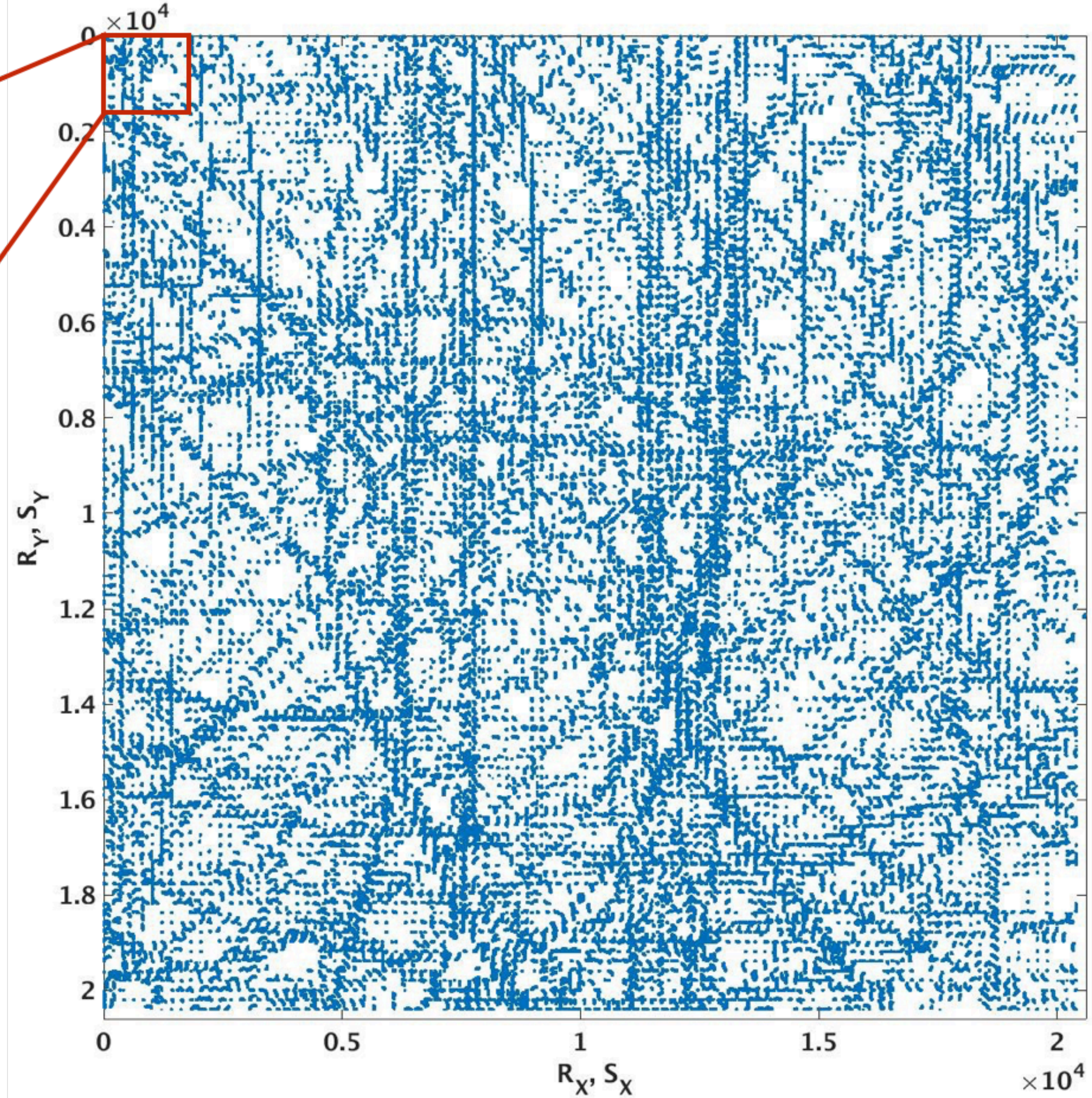
Investigate the causes of high frequency artifacts in interpolation

Validate the interpolation results using FWI/Migration

- extract sequential/simultaneous sources from low-rank factors

Redesign acquisition mask





Observed sampling = 16%
Effective sampling = 4%
Spectral Gap = 0.4

Acknowledgements

This research was carried out as part of the SINBAD project with the support of the member organizations of the SINBAD Consortium.

SINBAD