

# SINBAD 2008

## Consortium meeting

Felix J. Herrmann

Seismic Laboratory for Imaging &  
Modeling

[slim.eos.ubc.ca](http://slim.eos.ubc.ca)

Vancouver, February 20-21

# Opening



# Team

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## Current team

- 3 Post-docs
- 4 PhD students and 6 MSc students
- 2 scientific programmers
- 2 Summer COOPs

## New team members

- 2 post-docs
- 2 new MSc's



**SLIM**

Seismic Laboratory for  
Imaging and Modeling

# SLIM Group Overview

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Seismic Laboratory for Imaging and Modeling  
Earth & Ocean Sciences  
University of British Columbia

# Faculty

## Felix Herrmann (Ph.D.)



- ◆ M.Sc. & Ph.D., Delft University, Netherlands
- ◆ Seismic imaging and inversion
- ◆ Harmonic analysis (Wavelets)  
in geophysical inverse problem
- ◆ Scaling (Multi-fractal) concepts

# Additional faculty

## Michael Friedlaender (Ph.D.)



- ◆ Fellow Argonne
- ◆ B.A., Cornell, MSc. & Ph.D., Stanford
- ◆ Numerical optimization
- ◆ Numerical linear algebra
- ◆ Design & implementation of constrained optimization
- ◆ Scientific computing

# Additional faculty

## Ozgur Yilmaz (Ph.D.)



- ◆ M.A., Bogazici University, Turkey
- ◆ Ph.D., Princeton
- ◆ Applied harmonic analysis
- ◆ Signal processing
- ◆ Information theory

# Visiting faculty

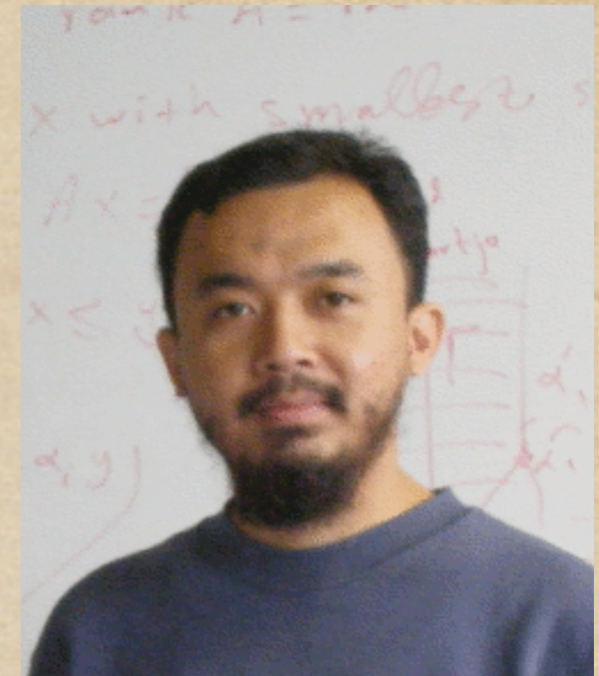
## Deli Wang (Ph.D.)



- ◆ M.Sc., Changchun College of Geology, China
- ◆ Ph.D., Jinlin University ,China
- ◆ Seismic imaging and inversion
- ◆ Seismic anisotropy
- ◆ Forward modeling
- ◆ Multiple attenuation



# Post Doctoral Fellow Yogi Erlangga



- ◆ Joined Slim December 2007
- ◆ Ph.D., Mathematics, Delft University of Technology.
- ◆ Research Interests:
  - ◆ Efficient Solution of the Helmholtz Equation

# Post Doctoral Fellow Reza Shahidi



- ◆ Joined Slim February 2008
- ◆ B. Math., University of Waterloo
- ◆ M. Eng., Ph.D., Memorial University of Newfoundland
- ◆ Research Interests: Variational Methods in Image Processing, Software Engineering/Development

# Additional Faculty

## Henryk Modzelewski (Ph.D.)



- ◆ Ph.D. in Atmospheric Sciences, UBC
- ◆ Scientific programming
  - ◆ High-Performance Computing
  - ◆ Development: MPI and Python
- ◆ System administration

# Scientific Programmer Cody Brown



- ◆ B.Sc., Computer Science, UBC
- ◆ Research Interests:
  - ◆ Artificial Intelligence
  - ◆ Computer Graphics/Photography
  - ◆ Reverse-time Migration
  - ◆ B-Splines

# Ph.D. student Peyman Moghaddam



- ◆ B.Sc. & M.Sc. in Electrical Eng.,  
Tehran Polytechnic, Iran
- ◆ Statistical Signal Processing
- ◆ Imaging Optimization
- ◆ Parallel Programming
- ◆ Migration

# Ph.D. student Gilles Hennenfent



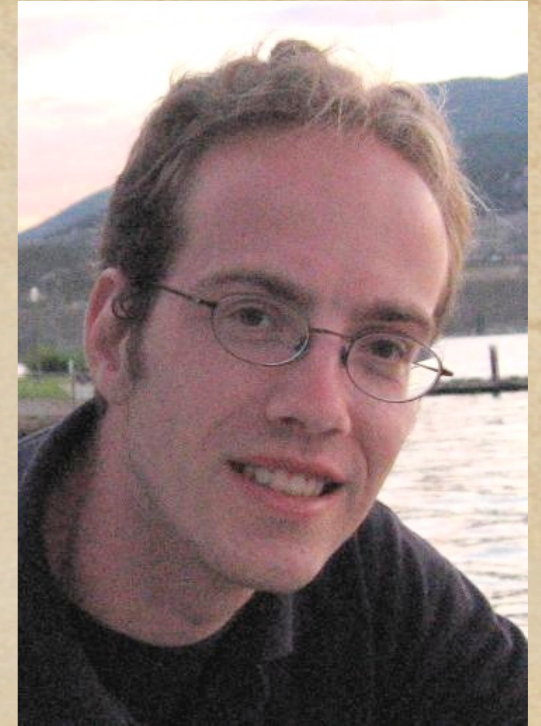
- ♦ DEA (MSc level) in Photonics, Image & Cybernetics, Universite Louis Pasteur, France, 2000
- ♦ Engineer in Applied Physics, Ecole Nationale Supérieure de Physique de Strasbourg, (2000-2003)
- ♦ Data regularization

# Ph.D. Student Rayan Saab



- ◆ M.A.Sc. in Electrical Eng., UBC
- ◆ B.E. in Computer and Communications Eng., American Univ. of Beirut
- ◆ Blind Source Separation
- ◆ Statistical Signal Processing
- ◆ Discrete Optimization
- ◆ Seismic and Biomedical Signal Processing

# Ph.D. Student Ewout Van Den Berg



- ◆ B.Sc., and M.Sc. in Computer Sciences, Delft
- ◆ Ph.D. in Computer Sciences, UBC
- ◆ L1 minimization
- ◆ Sparse signal recovery
- ◆ Seismic signal processing



# M.A.Sc. Student Carson Yarham



- ◆ B.Sc. in Honors Geophysics, UBC
- ◆ Signal Separation
- ◆ Matlab algorithm development
- ◆ Curvelet domain filtering

# M.A.Sc. Student Vishal Kumar



- ◆ M.Sc. in Exploration Geophysics, IIT.
- ◆ Research Interests:
  - ◆ Seismic Inversion
  - ◆ Digital Signal Processing

# M.Sc. Student Evgeniy Lebed



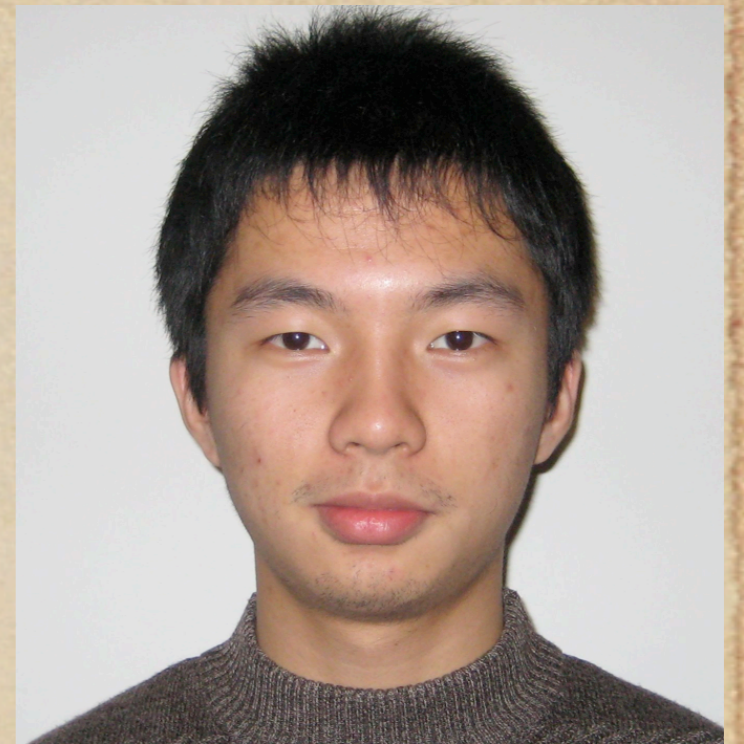
- ◆ B.Sc. in Mathematics (honors) from Simon Fraser University
- ◆ M.Sc. in Math, UBC
- ◆ Multidimensional signal decomposition

# M.Sc. Student James Johnson



- ◆ B. Sc. Honours, Engineering Physics, Queen's University
- ◆ B. Sc. Geology, Queen's University
- ◆ Research Interests:
  - ◆ Data Interpolation with Symmetry
  - ◆ Seismic Data Processing

# M.Sc. Student Jiupeng Yan



- ◆ B. S. in Geophysics, Peking University
- ◆ Research Interests:
  - ◆ Exploration Geophysics
  - ◆ Seismology

# M.Sc. Student Ulas Ayaz



- ◆ B. Sc. Math and B. Sc. Engineering from Bogazici University, Turkey
- ◆ Research Interests:
  - ◆ Applied Harmonic Analysis
  - ◆ Information Theory

# Ph.D. Student Fadhel Alhashim



- ◆ Current job title: Exploration Analyst in Saudi Aramco
- ◆ 2004, BS in Software Engineering, King Fahad University of Petroleum and Minerals
- ◆ On a scholarship from Saudi Aramco.
- ◆ Research Interests:
  - ◆ High Performance Computing
  - ◆ Primary Multiples Separation

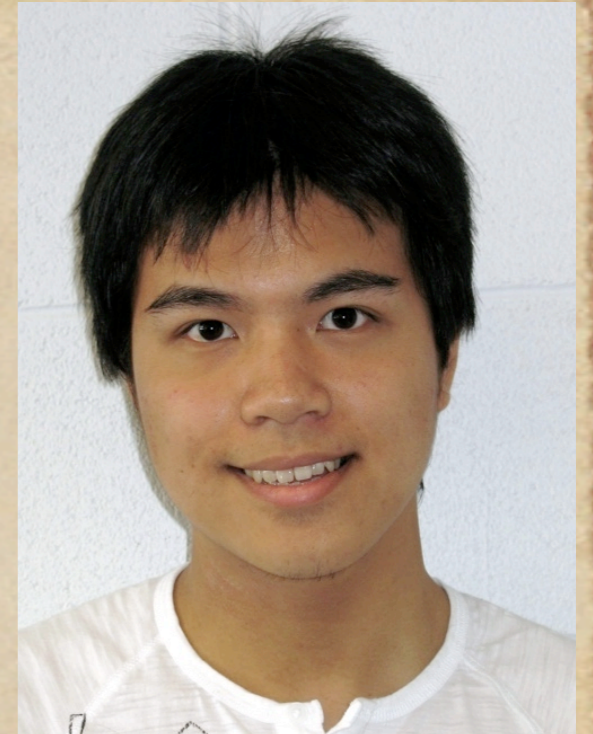
# Summer Co-Op Sean Ross-Ross



- ◆ Undergrad in Computer Science, UBC
- ◆ Joined SLIM in 2006
- ◆ Software Development
- ◆ Development of SLIMpy



# B. Sc. Student Tim Lin



- ◆ 4th year Undergraduate in Hon. Physics, UBC
- ◆ Joined SLIM in 2006 as summer co-op student
- ◆ Compressive Wavefield Modeling and Migration

# SINBAD project

*“from seismic data to reflectivity ...”*

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## Stable wavefield & image reconstruction using compressive sensing (CS)

- development of sampling theory for wavefields
- adaptation of transforms to sparsify wavefronts
- development & adaptation of sparsity-promoting large-scale solvers
- reflectors in the subsurface

## Mitigation of surface related effects:

- removal of acquisition imprints
- coherent wavefield separation

## Imaging:

- amplitude-recovery with phase-space matched filters
- WE-based wavefield reconstruction

# SINBAD II

*“an outlook”*

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Shift towards “wave-equation” based seismic processing

- extension of wavefield recovery & separation to 3-D seismic
- wavefield prediction with interferometric and “anti-interferometric” methods, e.g. ground-roll & multiple prediction
- extension of phase-space method to 3-D seismic
- compression of wavefield extrapolation & imaging operators
- target-oriented imaging & inversion
- linkages to rock physics

# Co-workers

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Imaging: Dr. Chris Stolk (TUT)

Primary-multiple separation: Dr. Eric Verschuur (TUD)

Singularity detection and characterization: Dr. Stephane Jaffard (Paris XII) and Dr. Beatrice Vedel (Orsay)

Singularity modeling: Dr. Yves Bernabe (MIT)

# SINBAD's main themes

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New **nonlinear** *sampling theory* for wavefields ....  
exploiting wavefield *sparsity*!

New **nonlinear** *wavefield separation* with phase-  
space *matched filtering & sparsity* promotion

New **nonlinear** *image-amplitude* recovery

Proposals for *compressed wavefield* computations  
and **nonlinear** *imaging* with *sparsity* promotion

***Leveraging our ability to adapt and extend  
techniques from Applied & Computational  
Harmonic Analysis, Compressive sensing and  
scientific computing ...***

# New themes

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Exploit the **structure** of *phase space*

- add ability to handle conflicting dips

For zero-order *pseudodifferential* operators (read space-& dip-dependent amplitude scaling) this

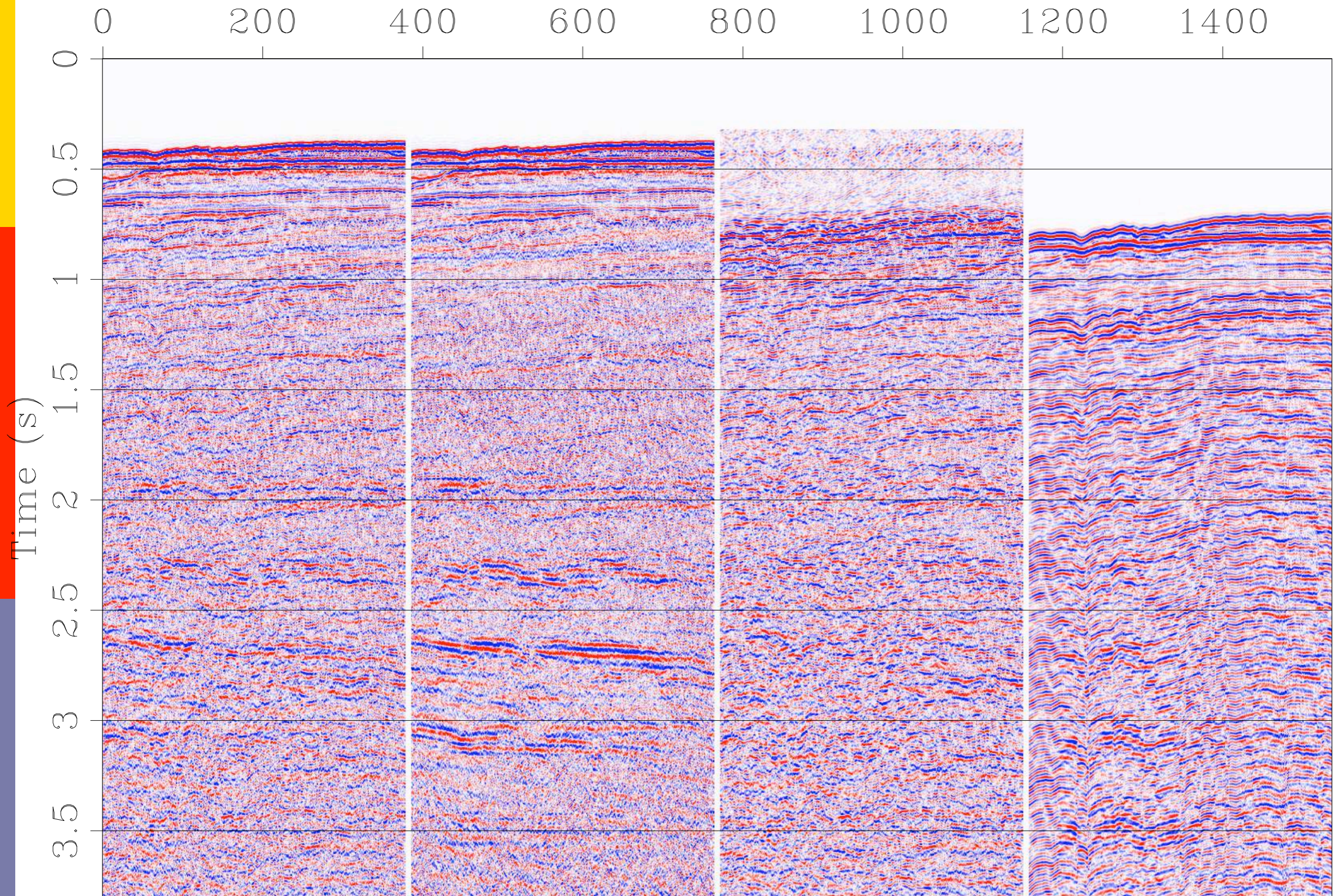
- corresponds to promoting *smoothness* of the symbol
- equivalent to smoothness amongst neighboring (in position and angle) curvelet coefficients

Blends in with recent work on *scaling* for migration amplitude recovery.

Extend these ideas to curvelet-domain matched filtering ...

# Example

Trace number



# New themes cont'd

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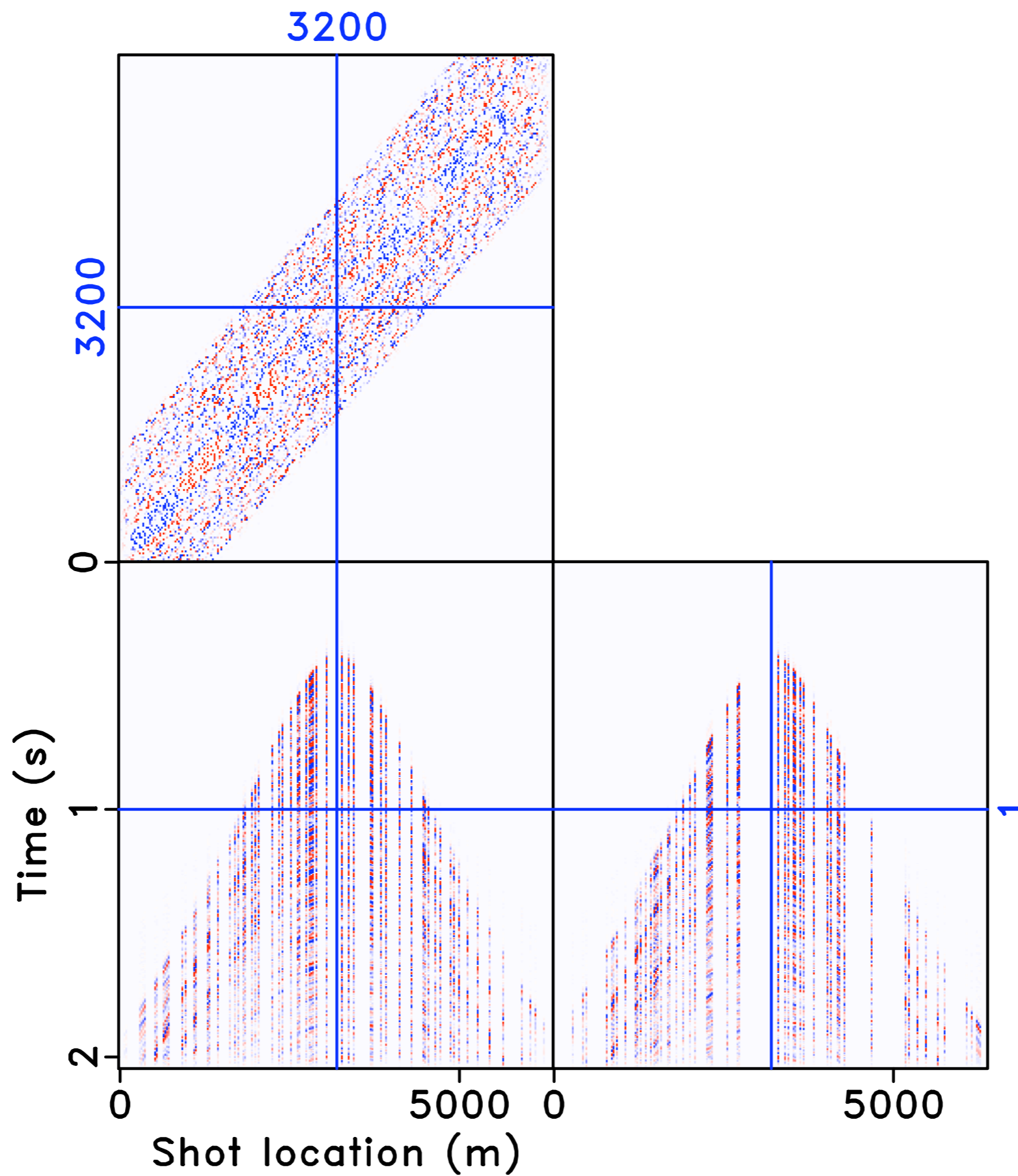
Use *prior* information on the wavefield (e.g. SRME estimated primaries or Born modeling operator)

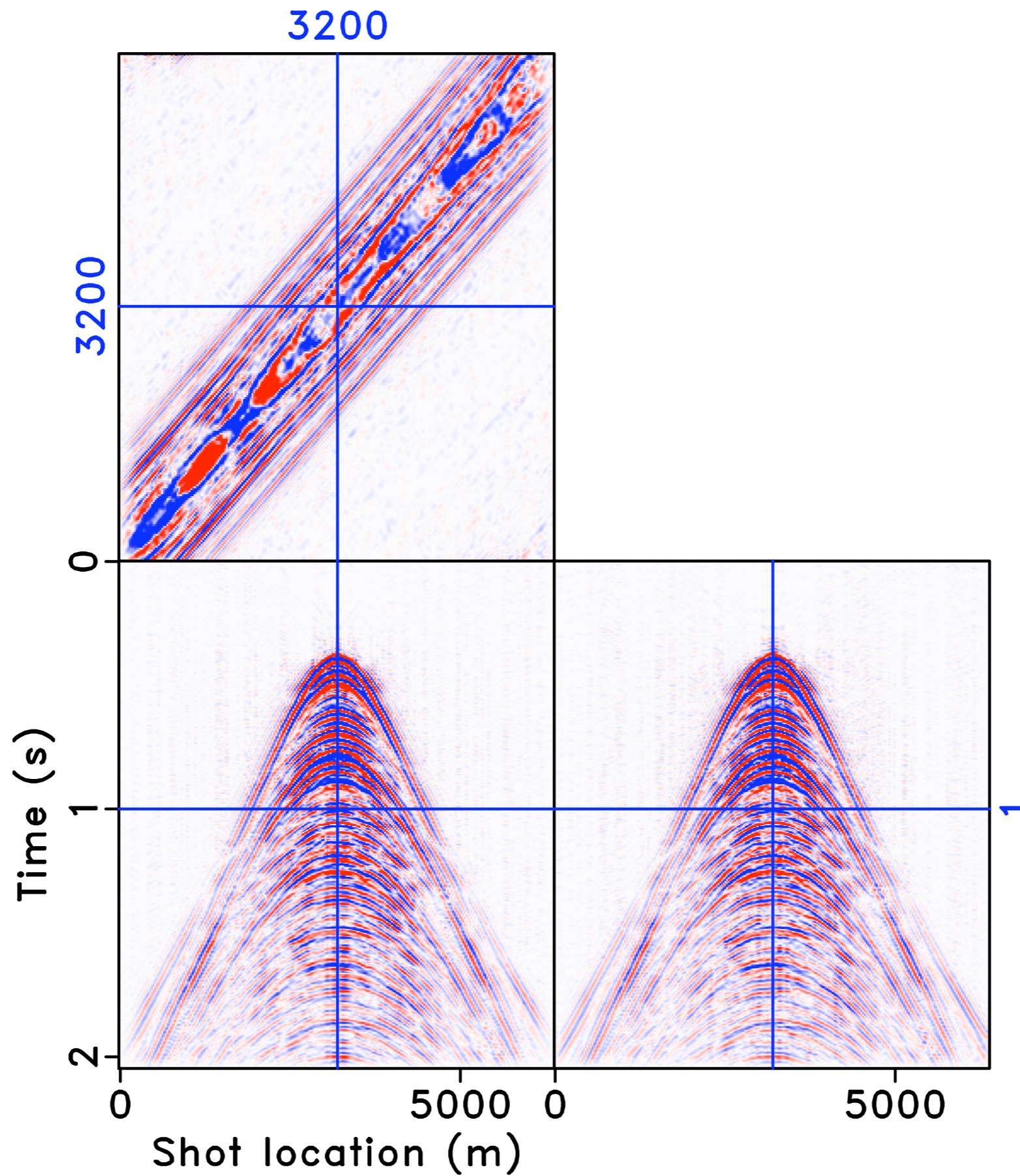
- to *focus* data and therefore
- aid the recovery

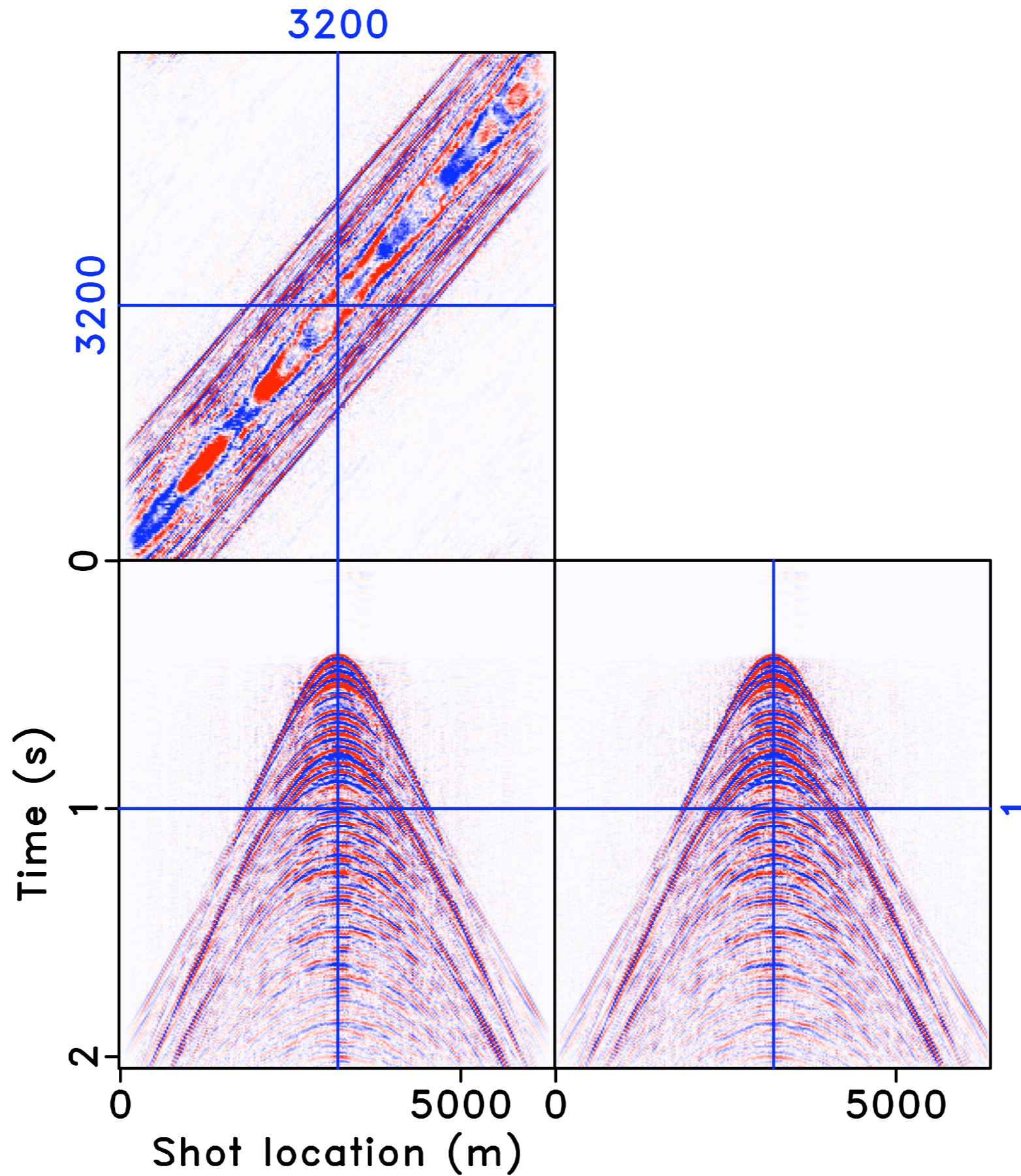
Use the **nonlinear** sampling theory to *compress* wavefield *extrapolation* & *imaging* operators

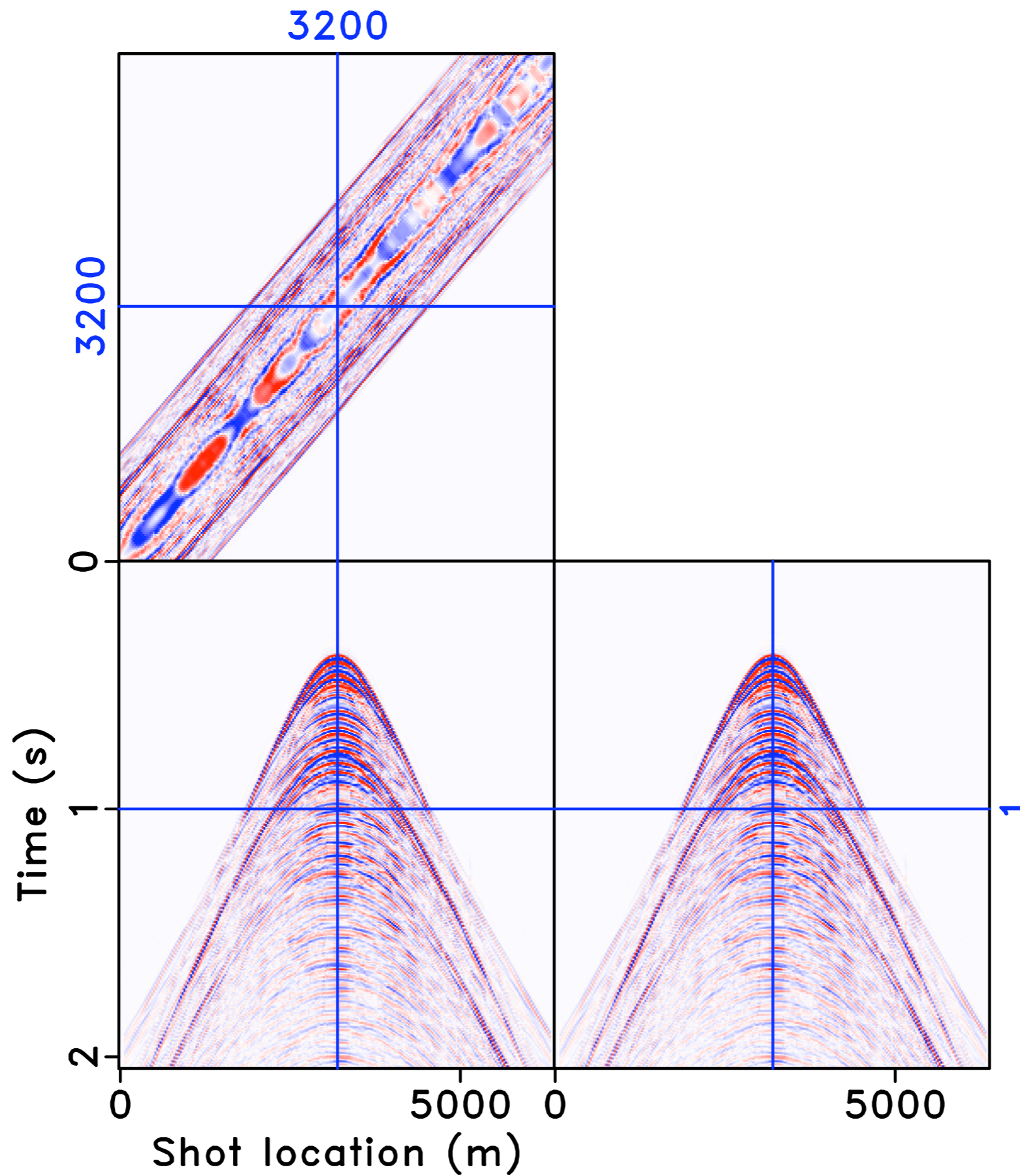
- removal of shots
- subsets of temporal frequencies
- subsets of eigenvalues
- etc.











# Publications

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## Accepted journal publications:

1. **Herrmann, F. J.**, Wang, D and Verschuur, D. J. Adaptive curvelet-domain primary-multiple separation. 2007. 18 pages, 3 figures (12 plots). Accepted for publication in *Geophysics*.
2. **Herrmann, F. J.** and *Hennenfent, G.* Non-parametric seismic data recovery with curvelet frames, 2007. 55 pages, 13 figures (37 plots). Accepted for publication in *Geophysical Journal International*.
3. *Hennefent, G.* and **Herrmann, F. J.** Simply denoise: wavefield reconstruction via jittered under-sampling. 44 pages. 11 figures (43 plots). To appear in *Geophysics*.
4. **Herrmann, F. J.**, Wang, D., *Hennenfent, G.* and *Moghaddam, P.* Curvelet-based seismic data processing: a multiscale and nonlinear approach. *Geophysics*, Vol. 73, No. 1, pp. A1–A5, January-February 2008.\*
5. **Herrmann, F. J.**, *Moghaddam, P.* and Stolk, C. Sparsity- and continuity-promoting seismic image recovery with curvelet frames. *Appl. Comput. Harmon. Anal.*, doi:10.1016/j.acha.2007.06.007, in press, 2007. \*
6. **Herrmann, F. J.**, and *Boeniger, U* and Verschuur, D.J. Nonlinear primary-multiple separation with directional curvelet frames. *Geophysical Journal International*, 170, 781–799. 2007. \*
7. *Lin, T.* and **Herrmann, F. J.**, Compressed extrapolation. *Geophysics*, vol. 72, issue 5, SM77-SM93, (17 figures (54 plots)). 2007. \*
8. *Hennenfent, G* and **Herrmann, F. J.**, "Seismic Denoising with Nonuniformly Sampled Curvelets" *Computing in Science and Engineering*, vol. 8, no. 3, pp. 16-25, May/June, (8 figs). 2006.

# Publications

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## Submitted journal publications

1. E. van den Berg, M. P. Friedlander, *G. Hennenfent*, **F. J. Herrmann**, R. Saab, O. Yilmaz. Department of Computer Science Technical Report TR-2007-20: Sparco: A Testing Framework for Sparse Reconstruction. 2007. 20 pages.
2. *G. Hennenfent*, E. van den Berg, M. P. Friedlander, and **F J. Herrmann**. TR-2007-7: New insights into one-norm solvers from the Pareto curve. 2007. 16 pages and 4 figures.
3. D. Wang, R. Saab, O. Yilmaz and **F J. Herrmann**. Seismic Laboratory for Imaging and Modeling. The university of British Columbia Technical Report. TR-2008-1 Bayesian wavefield separation by transform-domain sparsity promotion. 2008. 18 pages and 10 figures.

# Publications

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1. *Hennenfent, G.* and **Herrmann, F. J.** Random sampling: new insights into the reconstruction of coarsely-sampled wavefields. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
2. **Herrmann, F. J.**, *Wang, D.*, *Hennenfent, G.* and *Moghaddam, P.* Seismic data processing with curvelets: a multiscale and nonlinear approach. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
3. **Herrmann, F. J.**, *Wang, D.* and *Gilles Hennenfent, G.* Multiple prediction from incomplete data with the focused curvelet transform. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
4. *Saab, R.*, *Wang, D.*, *Yilmaz, O.* and **Herrmann, F. J.** Curvelet-based primary-multiple separation from a Bayesian perspective. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
5. *Verschuur, D. J.*, *Wang, D.* and **Herrmann, F. J.** Multi-term multiple prediction using separated reflections and diffractions combined with curvelet-based subtraction. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
6. *Wang, D.*, *Saab, R.*, *Yilmaz, O.*, **Herrmann, F. J.** Recent results in curvelet-based primary-multiple separation: application to real data. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
7. *Lin, T.* and **Herrmann, F. J.** Compressed wavefield extrapolation with curvelets. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
8. *Moghaddam, P.*, **Herrmann, F. J.** and *Stolk, C. C.* Robust seismic amplitude recovery using curvelets. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2007.
9. *Moghaddam, P.*, **Herrmann, F. J.** and *Stolk, C.* Seismic amplitude recovery with curvelets. In the proceedings of the Canadian Society of Exploration Geophysicists (CSEG), 2007.
10. *Hennenfent, G.* and **Herrmann, F. J.** Irregular sampling: from aliasing to noise. In the proceedings of the European Association of Geoscientists and Engineers (EAGE), 2007.
11. *Challa, S.*, *Hennenfent, G.* and **Herrmann, F. J.** Signal reconstruction from incomplete and misplaced measurements. In the proceedings of the European Association of Geoscientists and Engineers (EAGE), 2007.
12. **Herrmann, F. J.** Surface related multiple prediction from incomplete data. In the proceedings of the European Association of Geoscientists and Engineers (EAGE), 2007.
13. **Herrmann, F. J.**, *G. Hennenfent, G.* and *Moghaddam, P.* Seismic imaging and processing with curvelets. In the proceedings of the European Association of Geoscientists and Engineers (EAGE), 2007.
14. *Maysami, M.* and **Herrmann, F. J.** Seismic reflector characterization by a multiscale detection-estimation method. In the proceedings of the European Association of Geoscientists and Engineers (EAGE), 2007.
15. *Moghaddam, P.* and *Stolk, C. C.* and **Herrmann, F. J.** Sparsity and Continuity Enhancing Seismic Imaging. In the proceedings of the European Association of Geoscientists and Engineers (EAGE), 2007.
16. *Hennenfent, G.* and **Herrmann, F. J.**, Curvelet reconstruction with sparsity-promoting inversion: successes and challenges. In the proceedings of the European Association of Geoscientists and Engineers (EAGE), 2007.
17. *Hennenfent, G.* and **Herrmann, F. J.** Application of stable signal recovery to seismic data interpolation. In Expanded Abstracts, In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2006.
18. *Carson, Y.*, *Boeniger B.* and **Herrmann, F. J.** Curvelet-based ground roll removal In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2006
19. *Thomson, D.*, *Hennenfent, G.*, *Modzelewski H.* and **Herrmann, F. J.** A parallel windowed fast discrete curvelet transform applied to seismic processing. In the proceedings of the Society of Exploration Geophysicists International Exposition and Annual Meeting (SEG), 2006.

# Program

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<http://slim.eos.ubc.ca/SINBAD2006/SINBAD2008/Program.html>

Confirm diner tonight!



# Highlights

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## Day one:

- One-norm solvers, non-convex optimization & the Pareto curve
- Bayesian coherent wavefield separation & adaptive phase-space matching
- Wavefield reconstruction, jittered sampling, wavefield reciprocity & comparison different transforms
- Noise attenuation & deconvolution

# Highlights

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## Day two:

- WE methods, phase-space matching, preconditioning, amplitude recovery, (de)focussed wavefield reconstructions & migration wavefield reconstruction
- Compressive wavefield computations, Helmholtz preconditioning & compressive sampling
- SPARCO, SLIMPy & software releases

# The curvelet transform

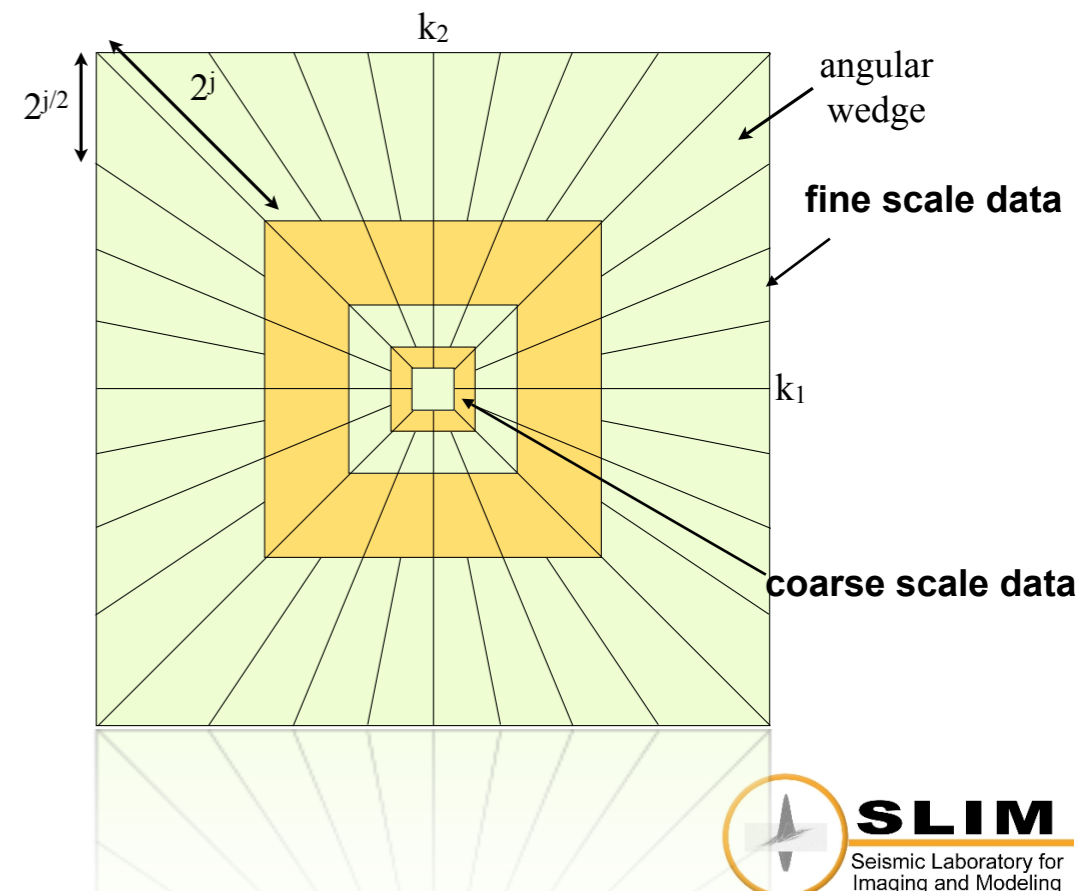


# Representations for seismic data

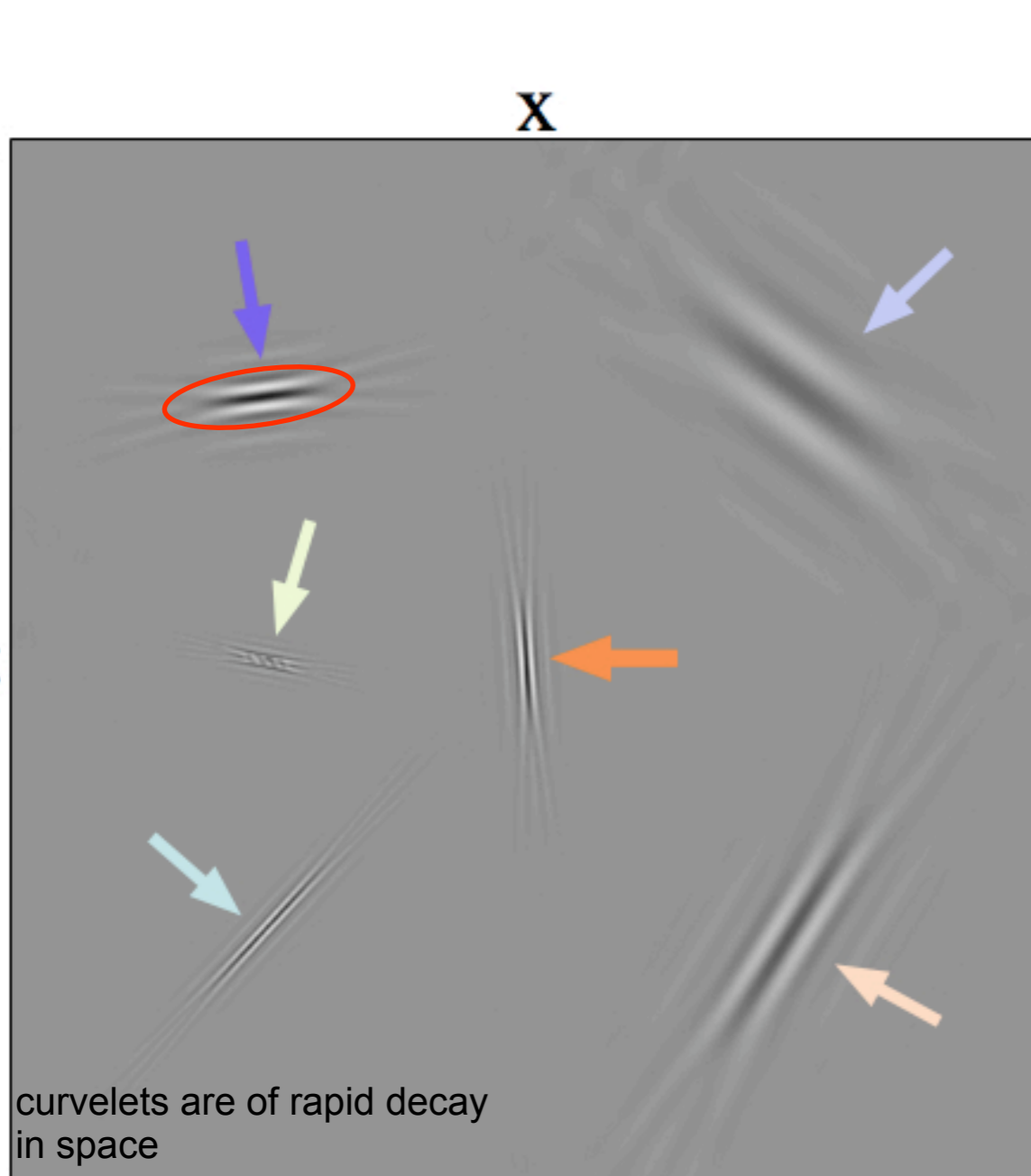
| Transform                        | Underlying assumption                       |
|----------------------------------|---|
| FK                               | plane waves                                 |
| linear/parabolic Radon transform | linear/parabolic events                     |
| wavelet transform                | point-like events (1D singularities)        |
| <b>curvelet transform</b>        | <b>curve-like events (2D singularities)</b> |

## Properties curvelet transform:

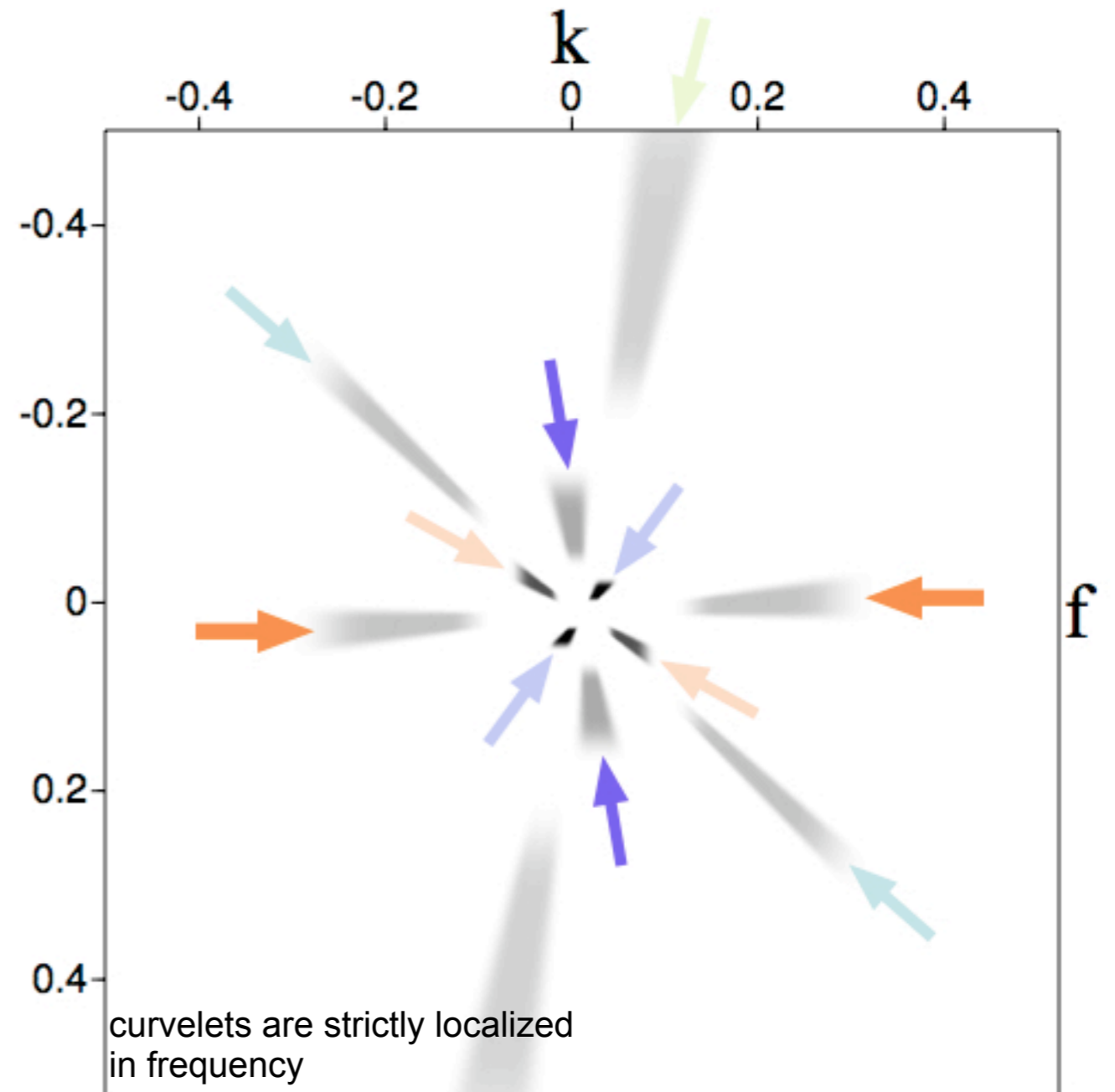
- **multiscale:** tiling of the FK domain into dyadic coronae
- **multi-directional:** coronae sub-partitioned into angular wedges, # of angle doubles every other scale
- **anisotropic:** parabolic scaling principle
- **Rapid decay space**
- **Strictly localized in Fourier**
- **Frame with moderate redundancy (8 X in 2-D and 24 X in 3-D)**



# 2-D curvelets



$x-t$

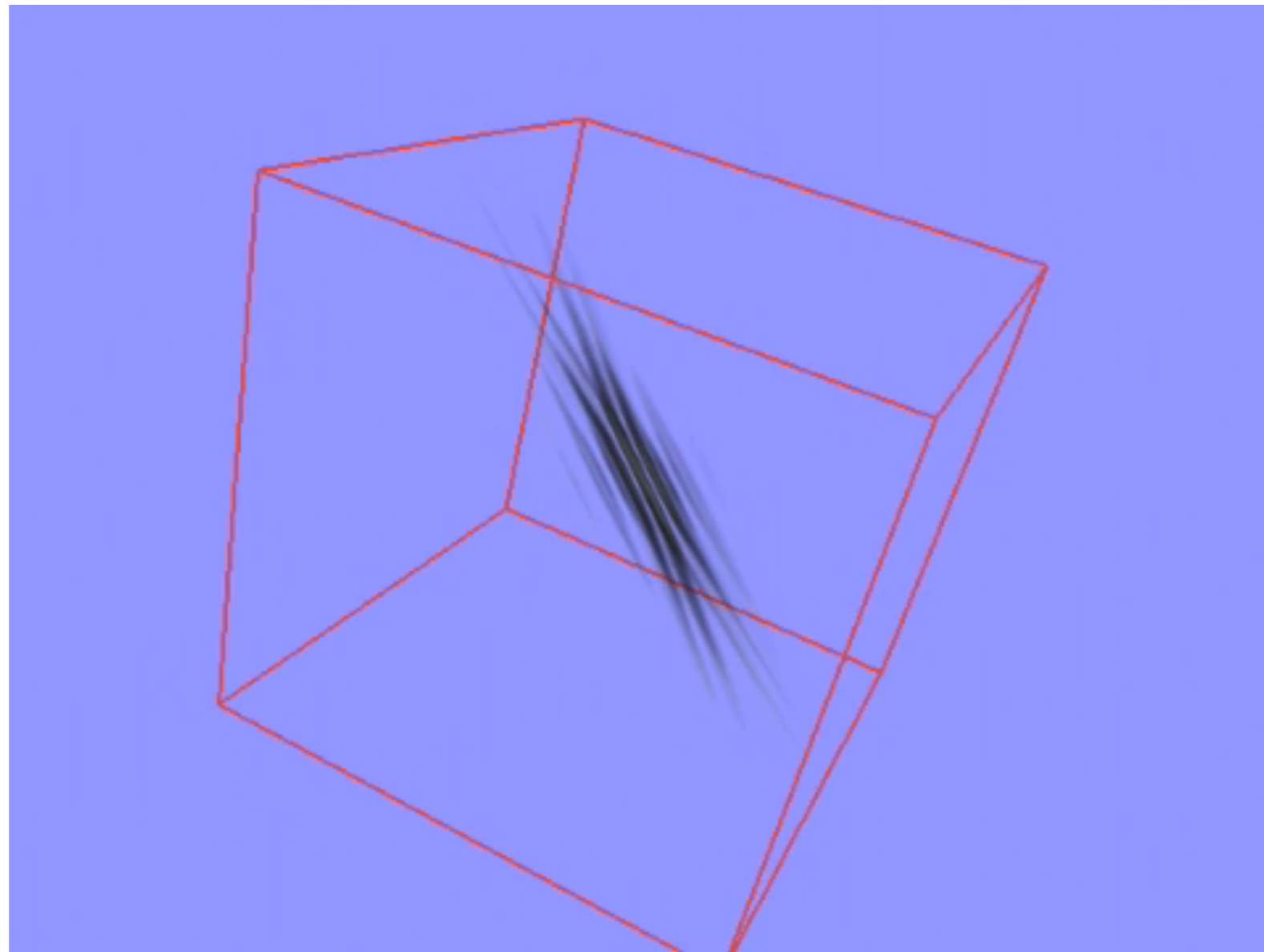


$f-k$

**Oscillatory in one direction and smooth in the others!**

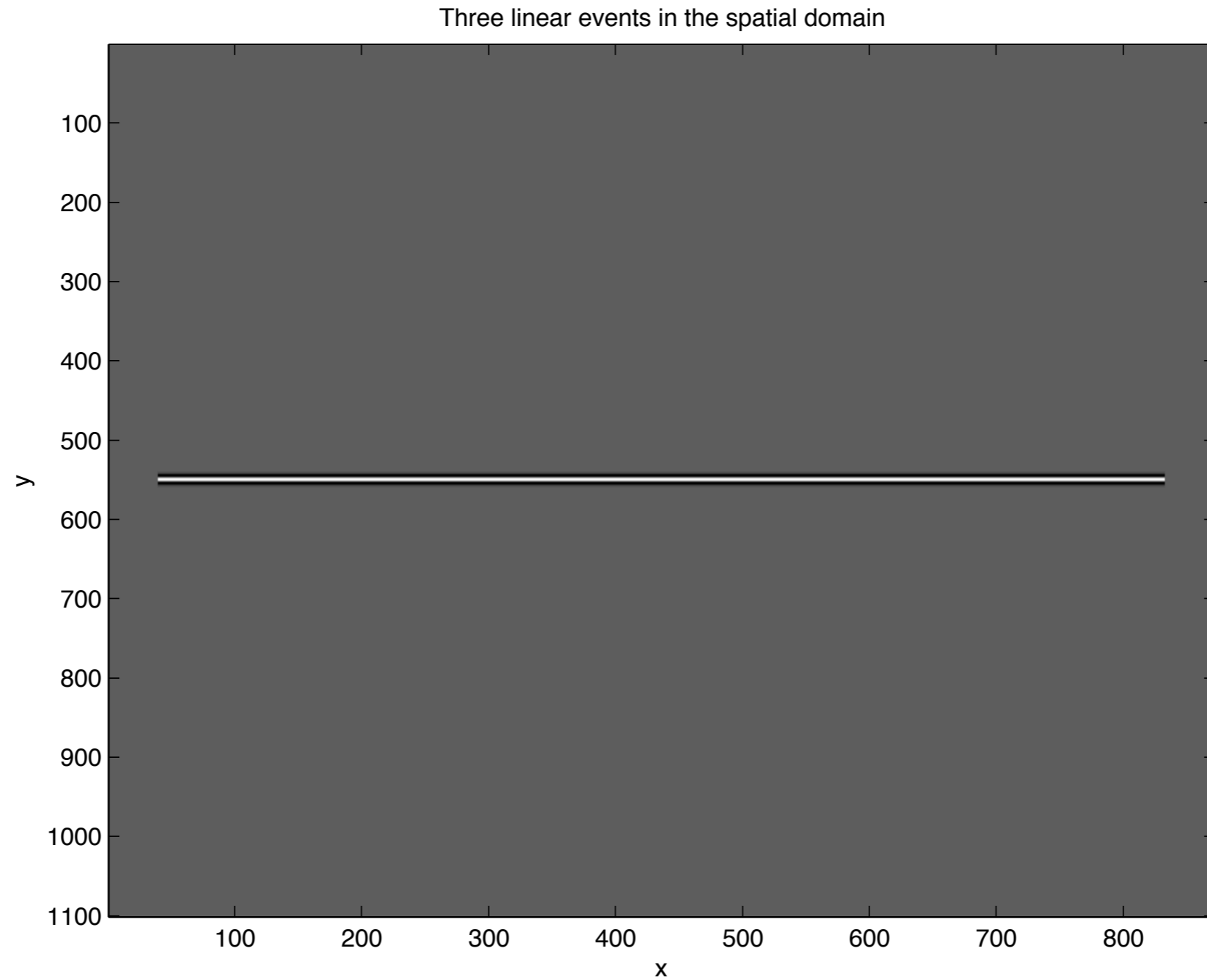
**Obey *parabolic* scaling relation  $\text{length} \approx \text{width}^2$**

# 3-D curvelets

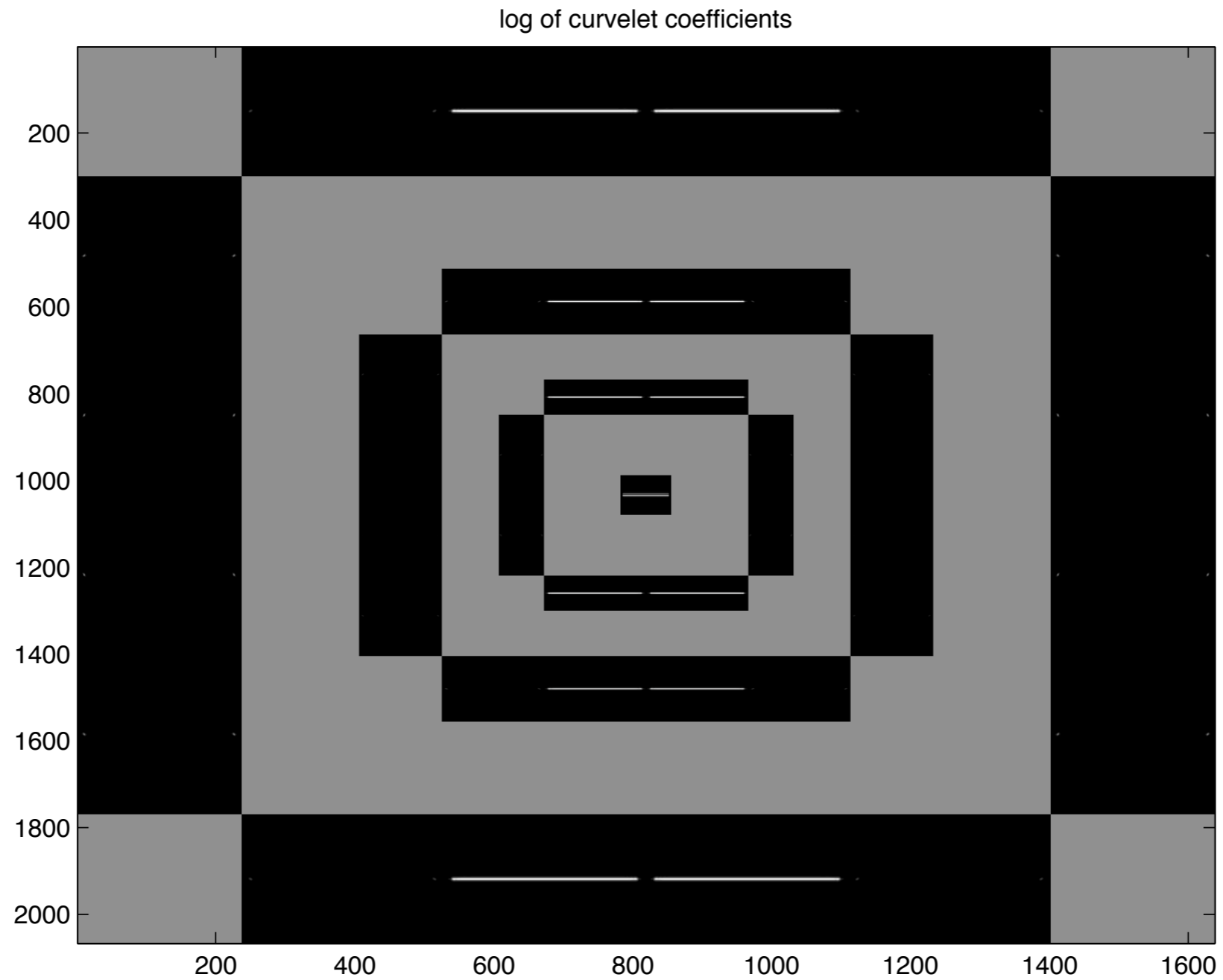


Curvelets are oscillatory in one direction and smooth in the others.

# Horizontal line



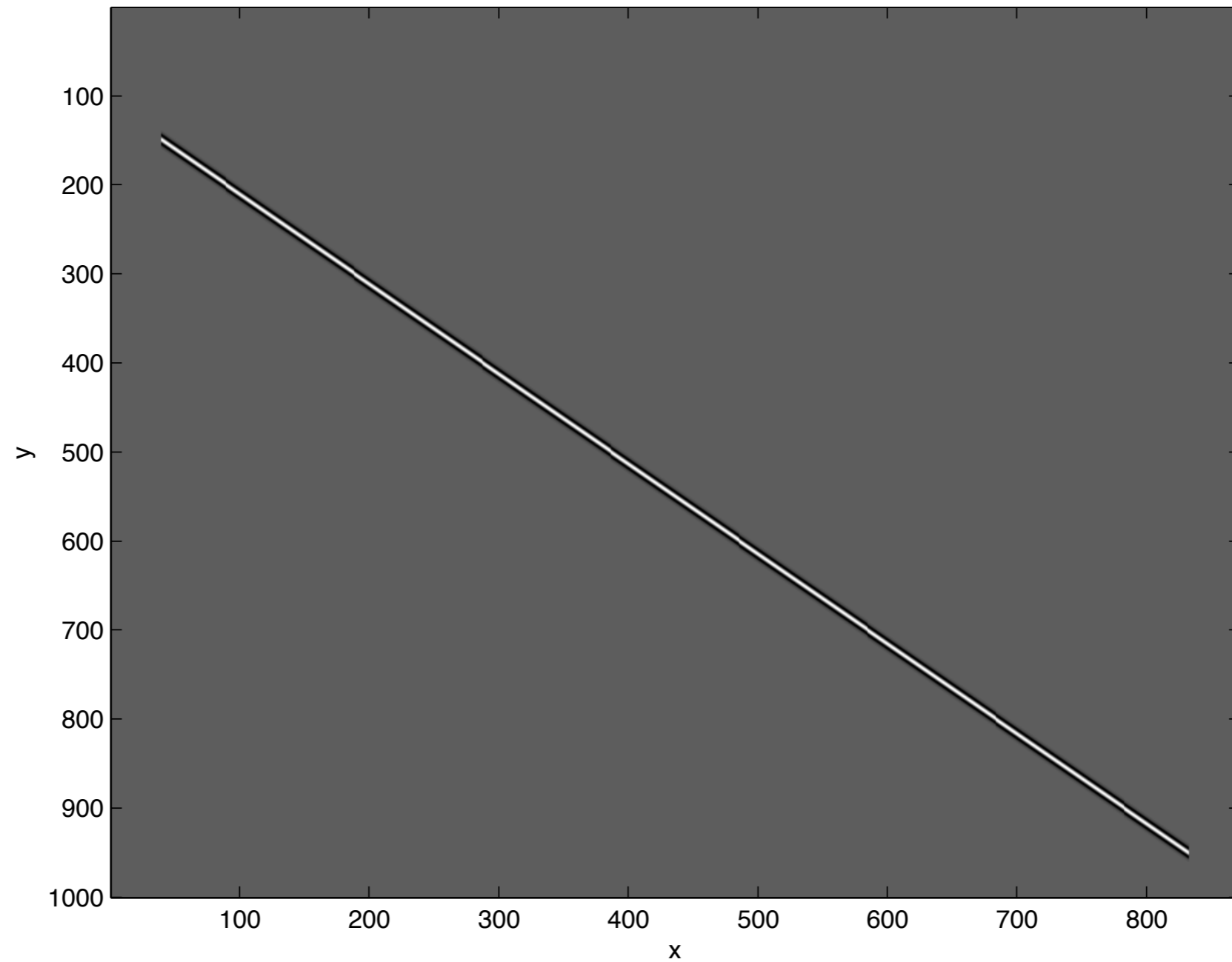
# Horizontal line in curvelet domain



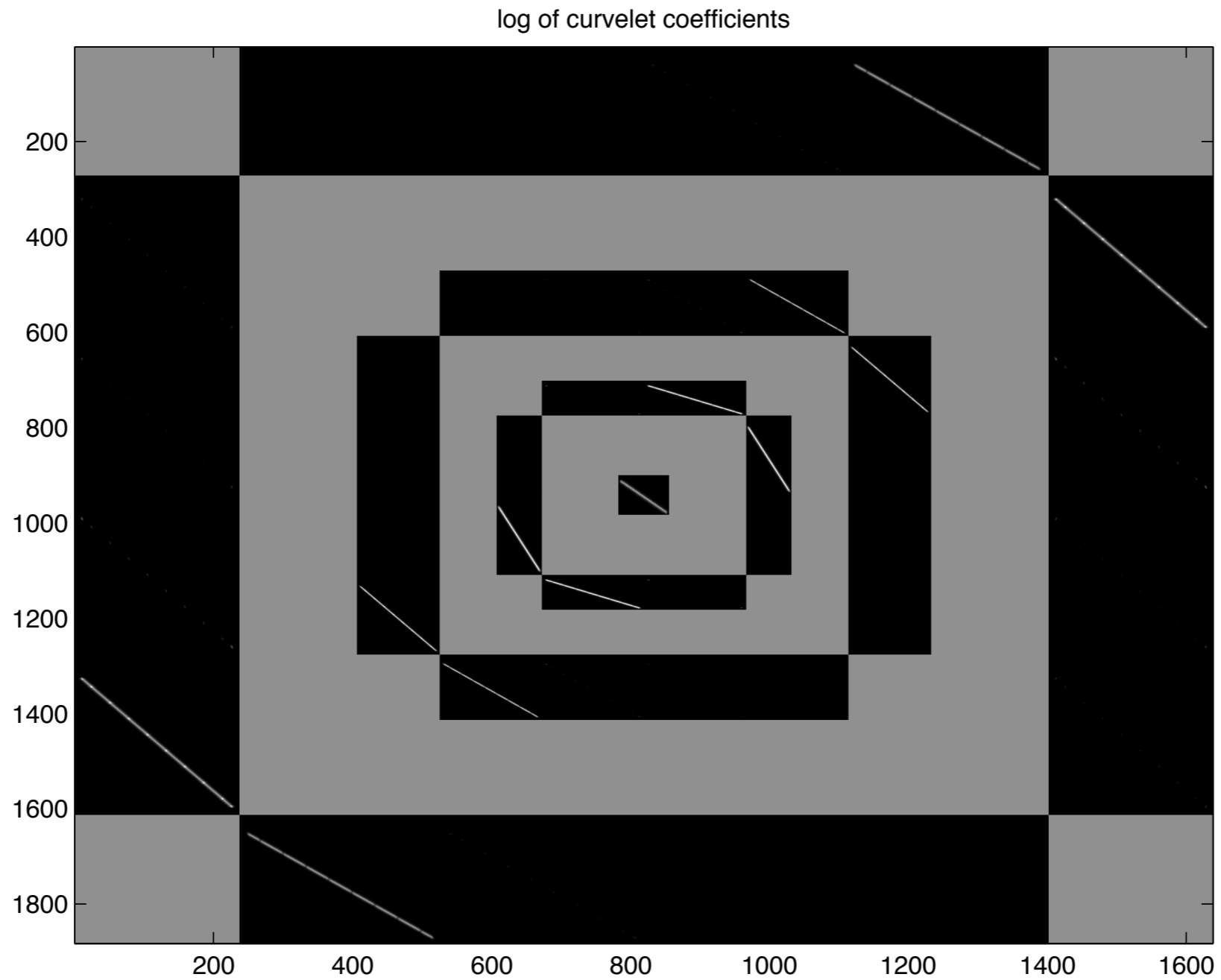


# Slant line

One linear event in the spatial domain

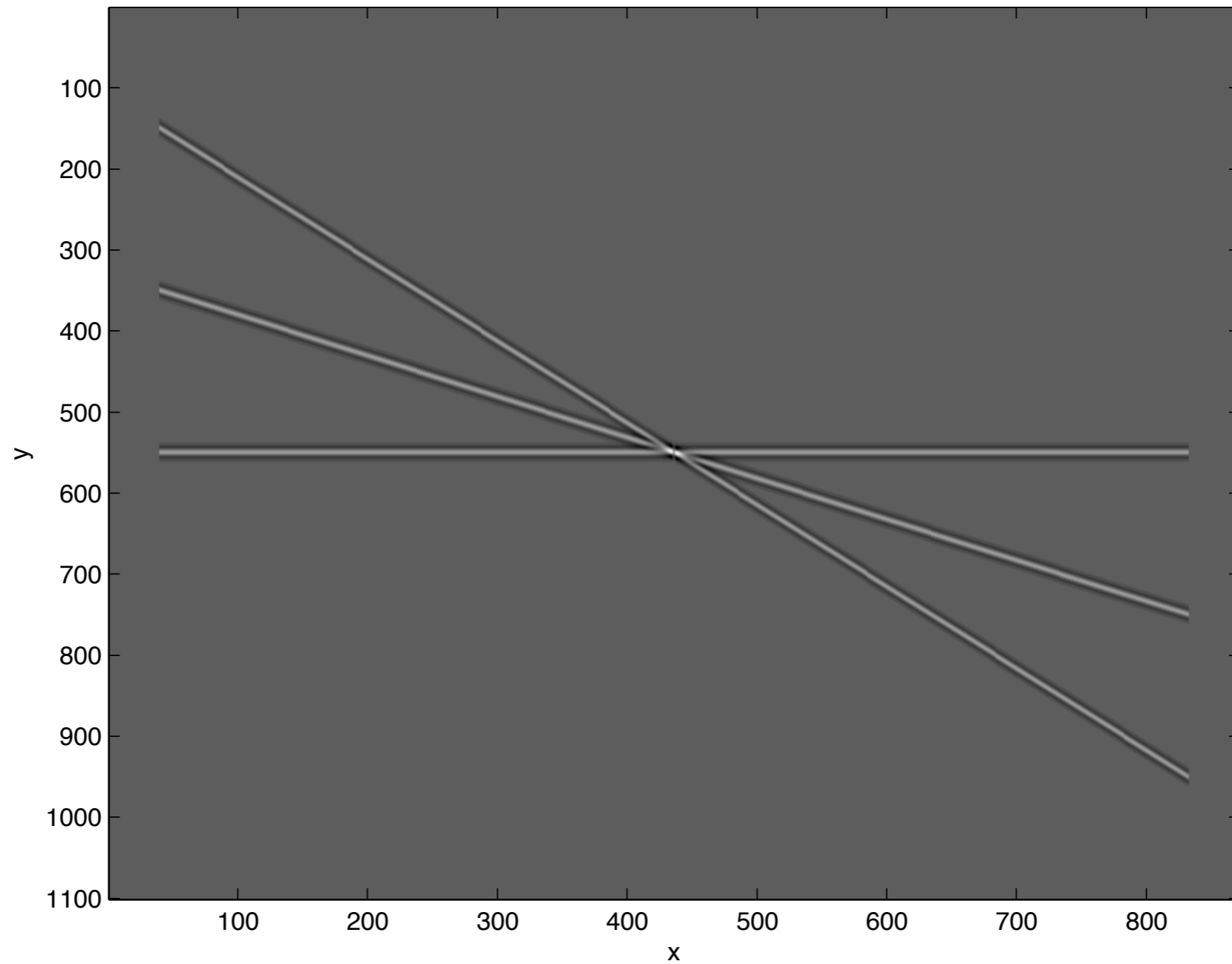


# Slant line curvelet domain

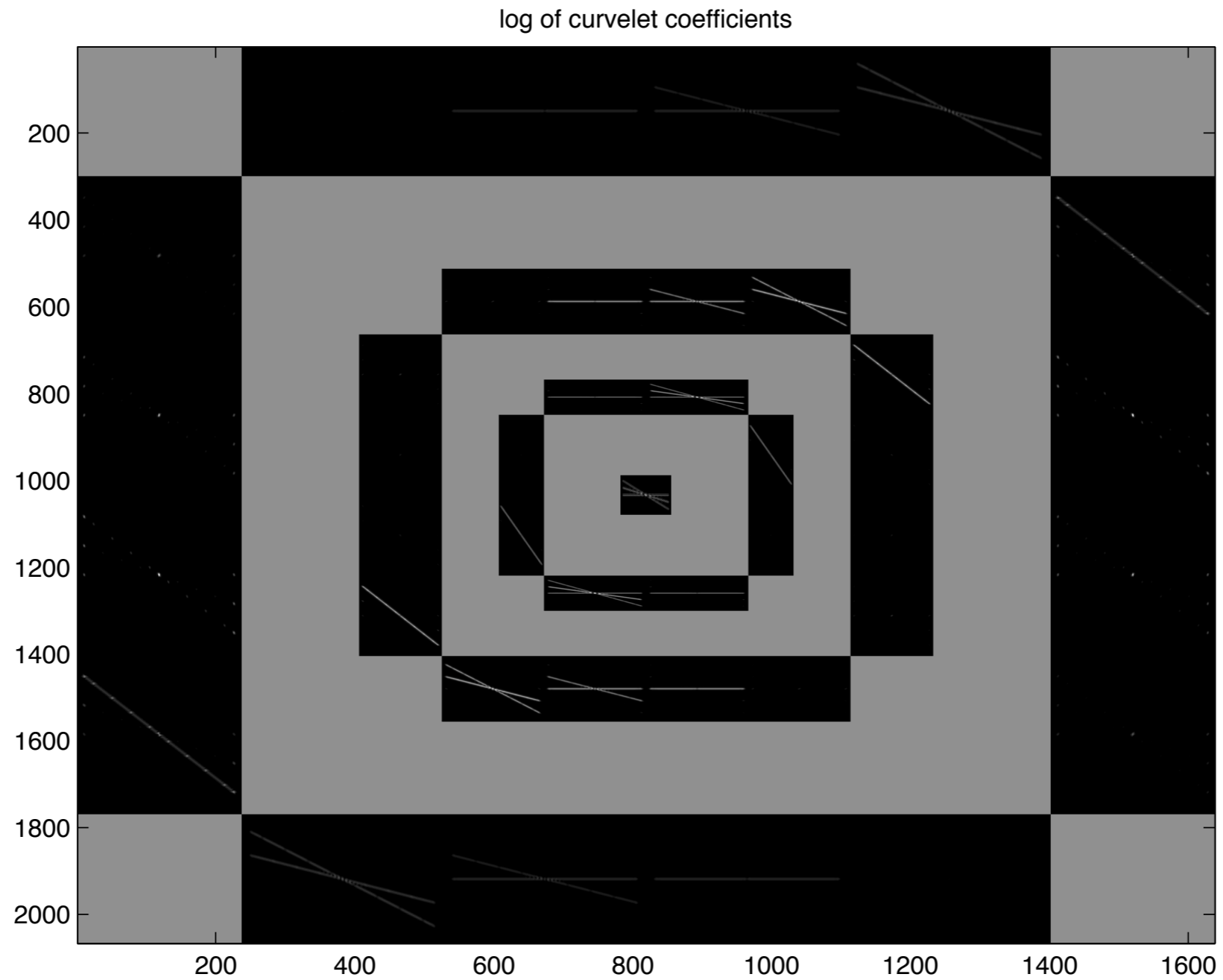


# 3 lines

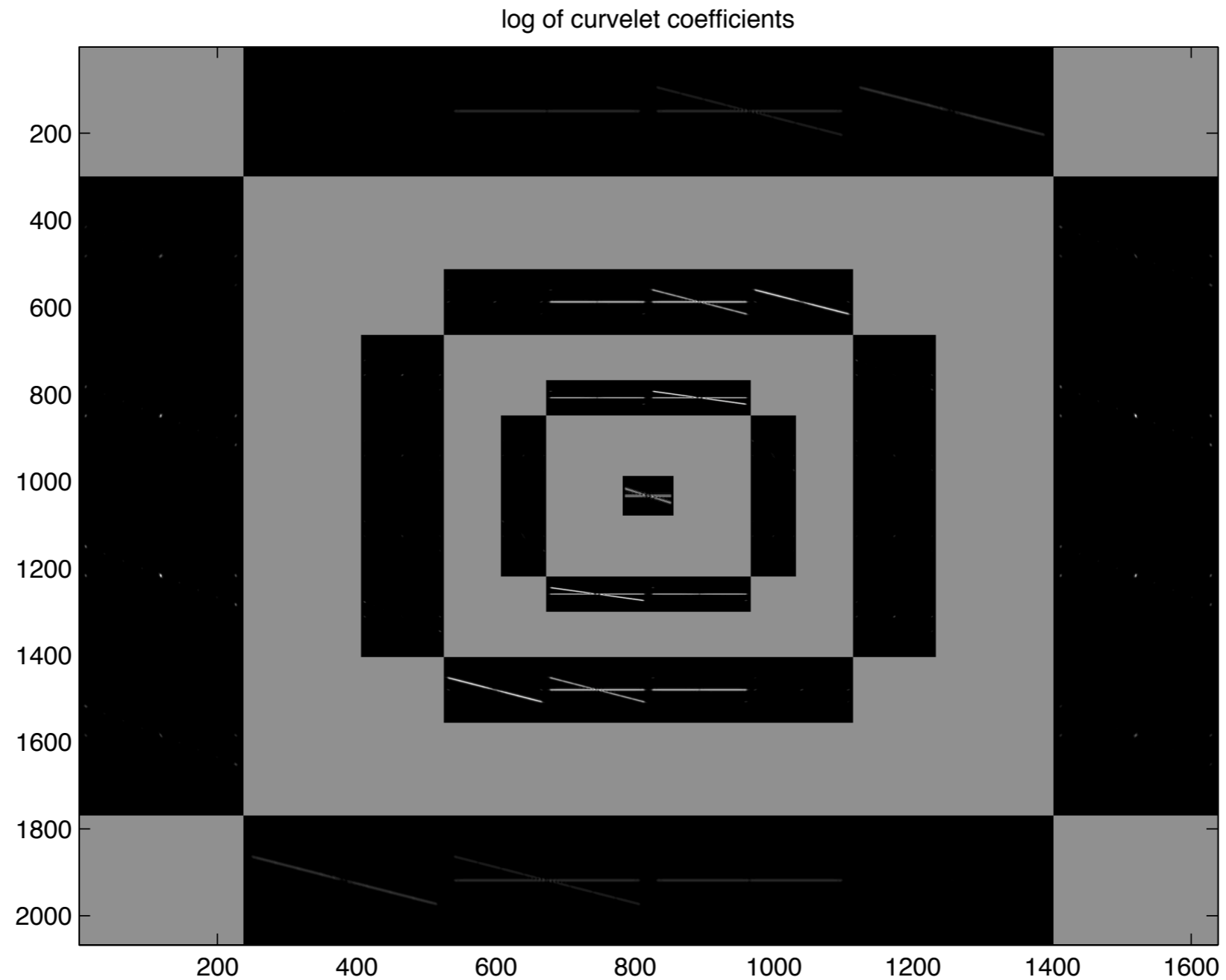
Three linear events in the spatial domain



# 3 lines curvelet domain



# Filtered steepest event by thresholding



# Filtered result

