Affordable omnidirectional image volumes extension to 3D

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Motivation

AVA analysis

- local geological dip estimation

Velocity analysis

Targeted imaging

Creation of subsurface offset image volumes

Motivation

Computation of full-subsurface offset volumes is prohibitively expensive in 3D (storage & computation time)

Can not form full *E* but *action* on (random) vectors allows us to get information from *all* or *subsets* of *subsurface points*

Extended images

Given two-way wave equations, source and receiver wavefields are defined as

$$H(\mathbf{m})U = P_s^T Q$$
$$H(\mathbf{m})^* V = P_r^T D$$

where

$H(\mathbf{m})$: discretization of the Helmoltz operator

Q : source

D : data matrix

P_s, P_r : samples the wavefield at the source and receiver positions

$\mathbf{m}$: slowness

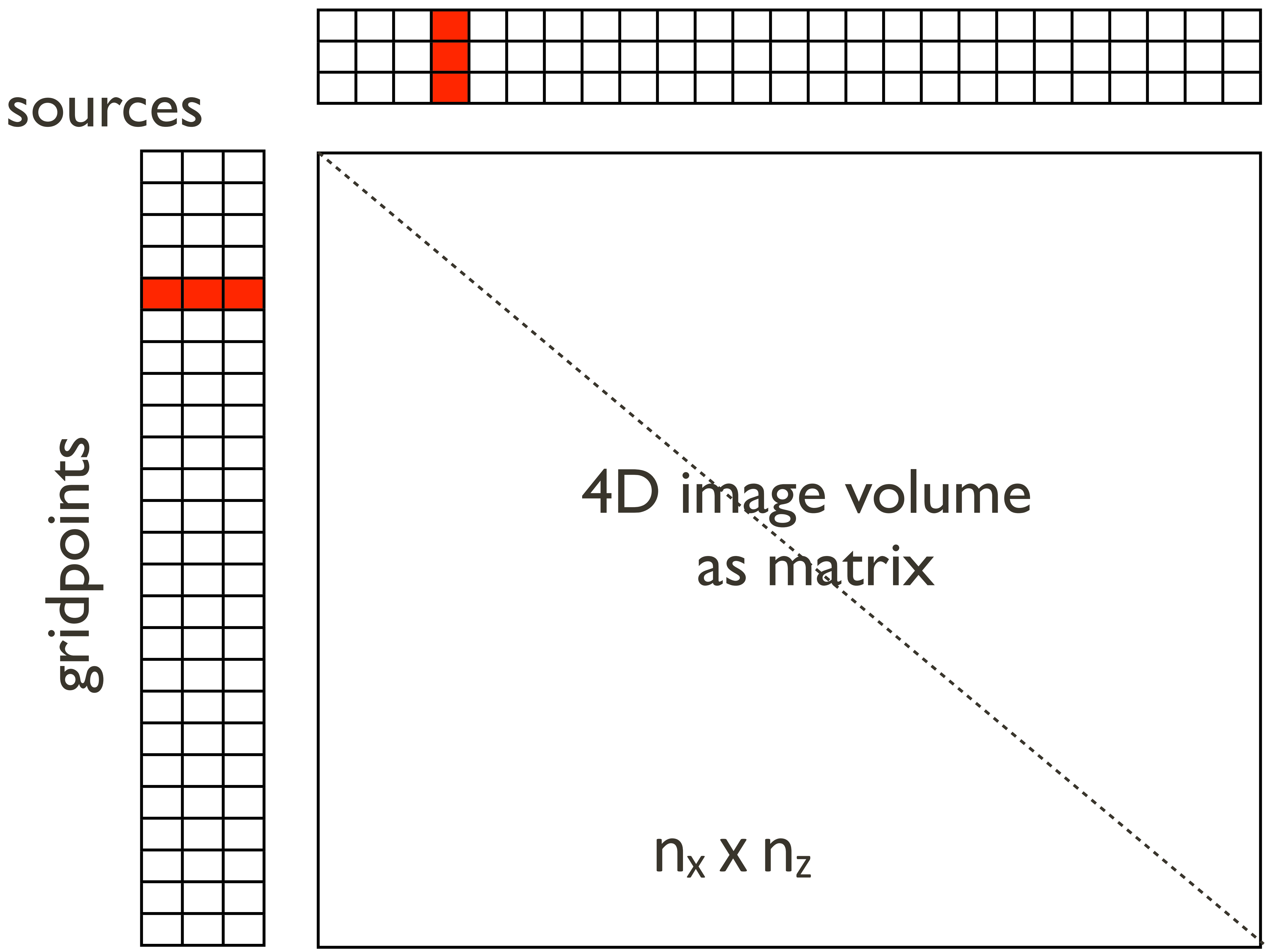
Extended images

Organize wavefields in monochromatic data *matrices* where each *column* represents a *common* shot gather

Express image volume *tensor* for *single* frequency as a *matrix*

$$E = UV^*$$

Extended images



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Extended images

Too expensive to compute *(storage and computational time)*

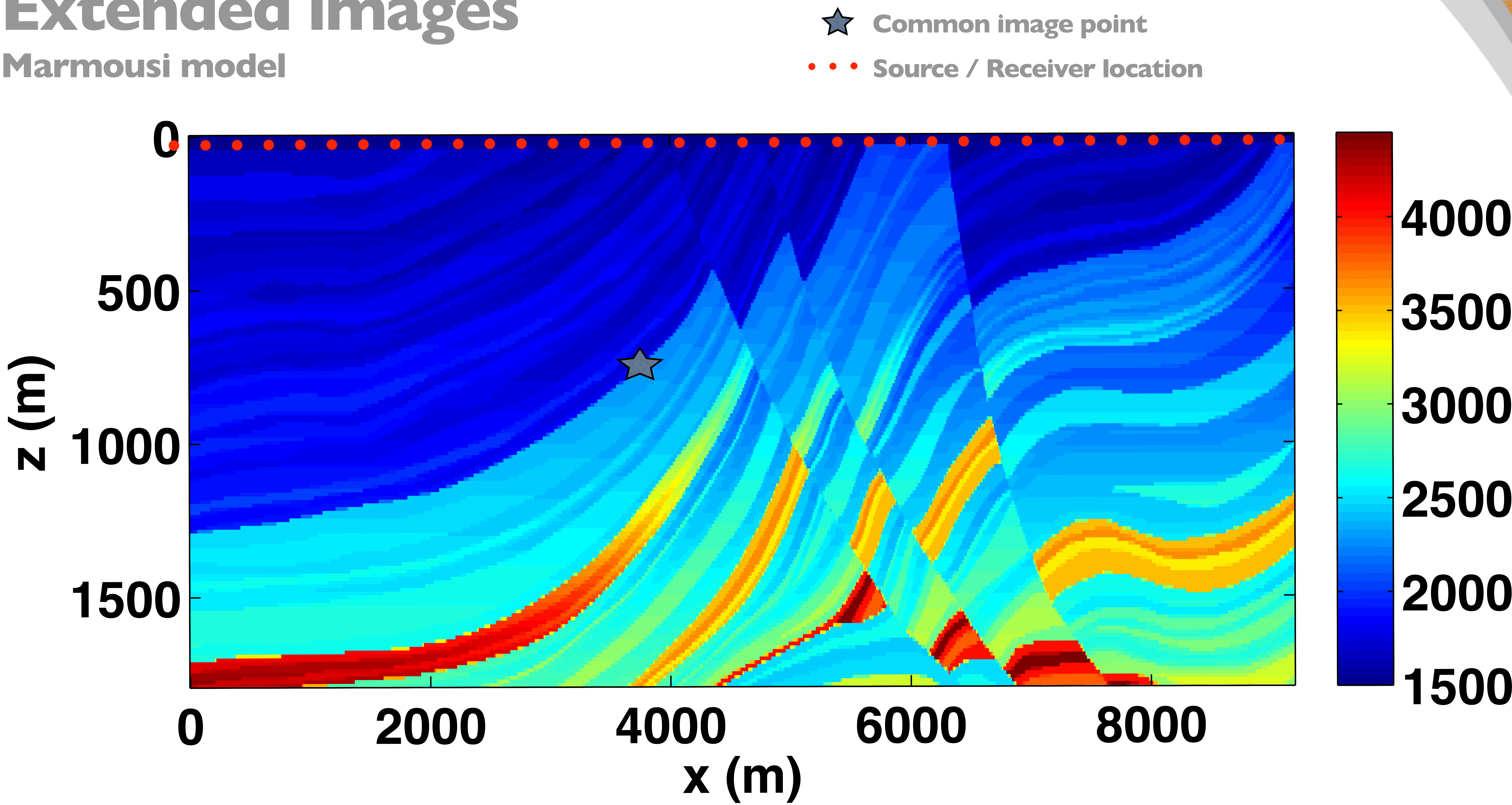
Instead, *probe* volume with *tall* matrix $W = [\mathbf{w}_1, \ldots, \mathbf{w}_l]$

$$\widetilde{E} = EW = H^{-1} P_s^T Q D^* P_r H^{-1} W$$

where $\mathbf{w}_i = [0, \ldots, 0, 1, 0, \ldots, 0]$ represents *single* scattering points

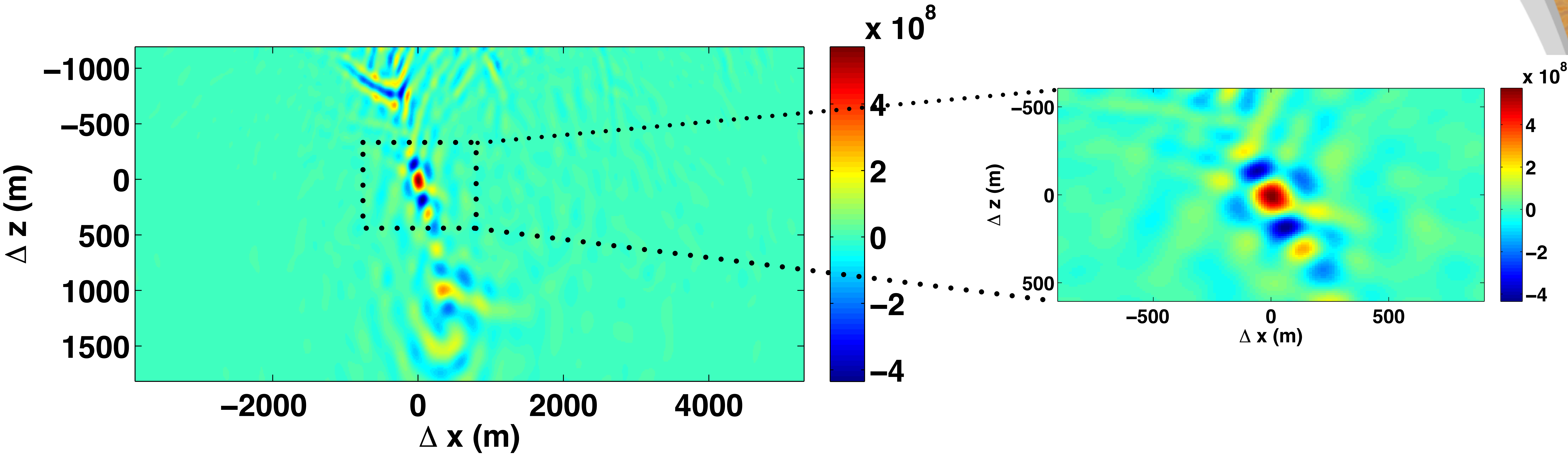
Extended images

Marmousi model



Extended images

common image point gather, 3- 30 Hz



Δ x : **Horizontal offset**

Δ z : **Vertical offset**

Take-away message

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Computational costs

Full subsurface offset extended images:

	# of PDE solves	"flops for correlations"
conventional	$2N_s$	$N_s \times N_h$
mat-vecs	$2N_x$	$N_s \times N_r$

N_s – # of sources
N_r – # of receivers
N_h – # of subsurface offsets
N_x – # of sample points

Take-away message

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N_r – # of receivers
N_h – # of subsurface offsets
N_x – # of sample points

We win when $N_x < N_s$!

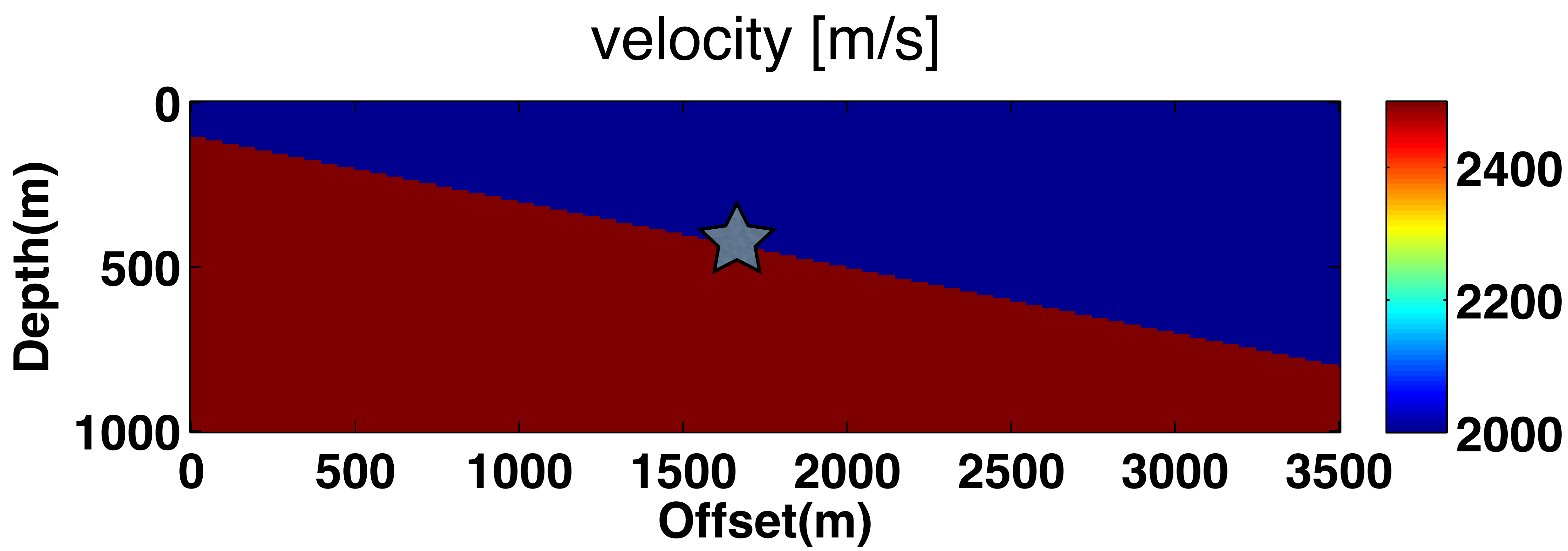
Applications in 2D

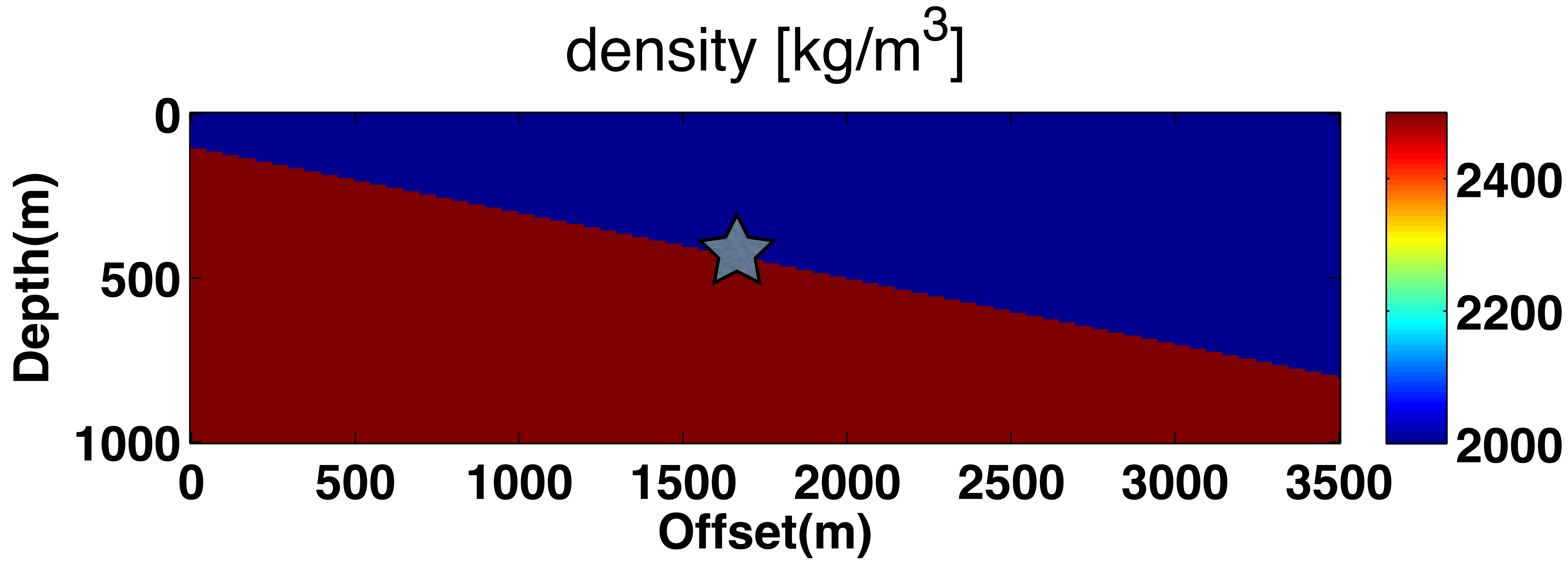
AVA analysis

Reservoir characterization

Local geological dip estimation

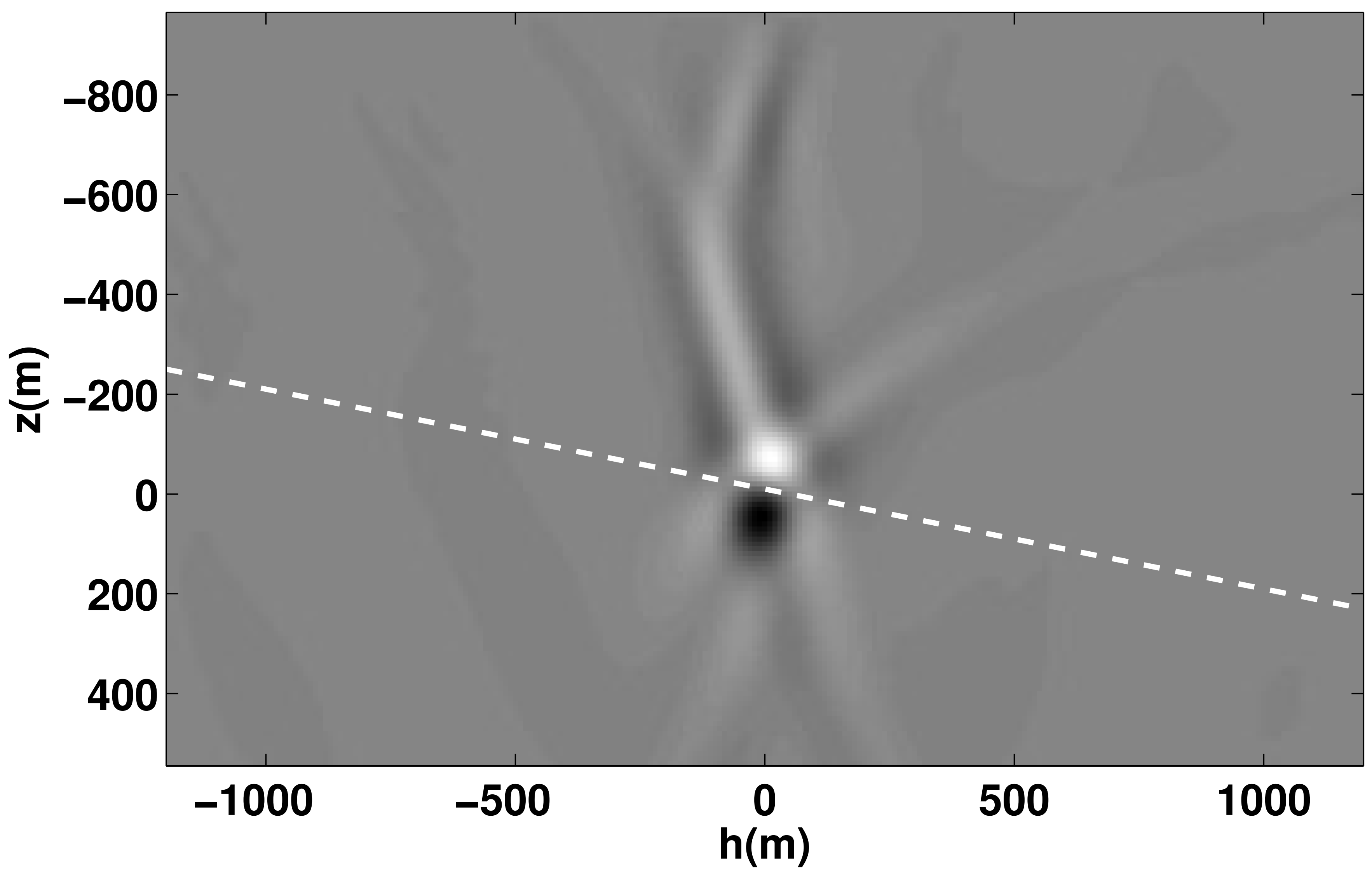
Dip-angle gathers
dipping layer model





Dip angle gathers

Dip can be detected by measuring the *stack-power* normal to the dip



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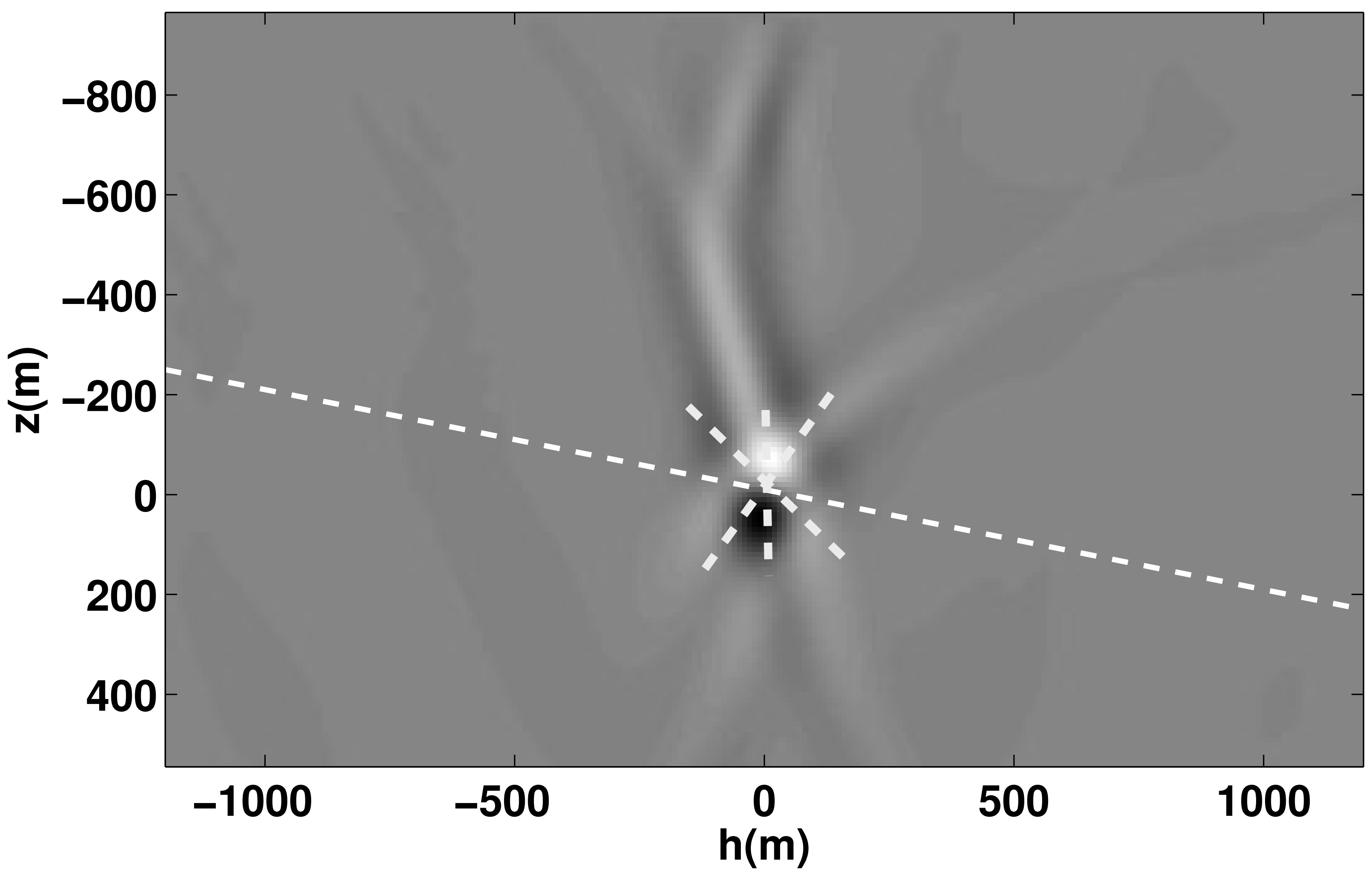
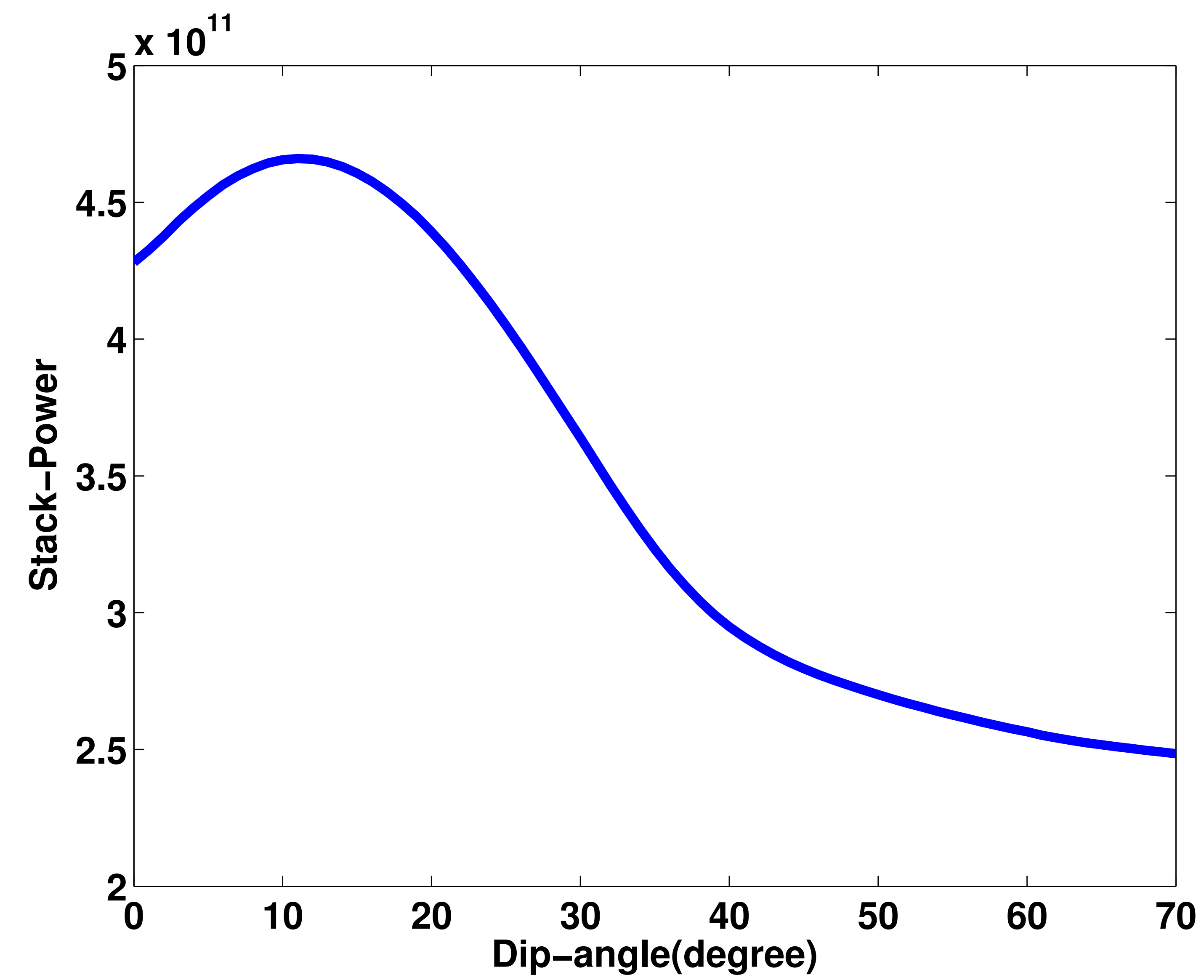
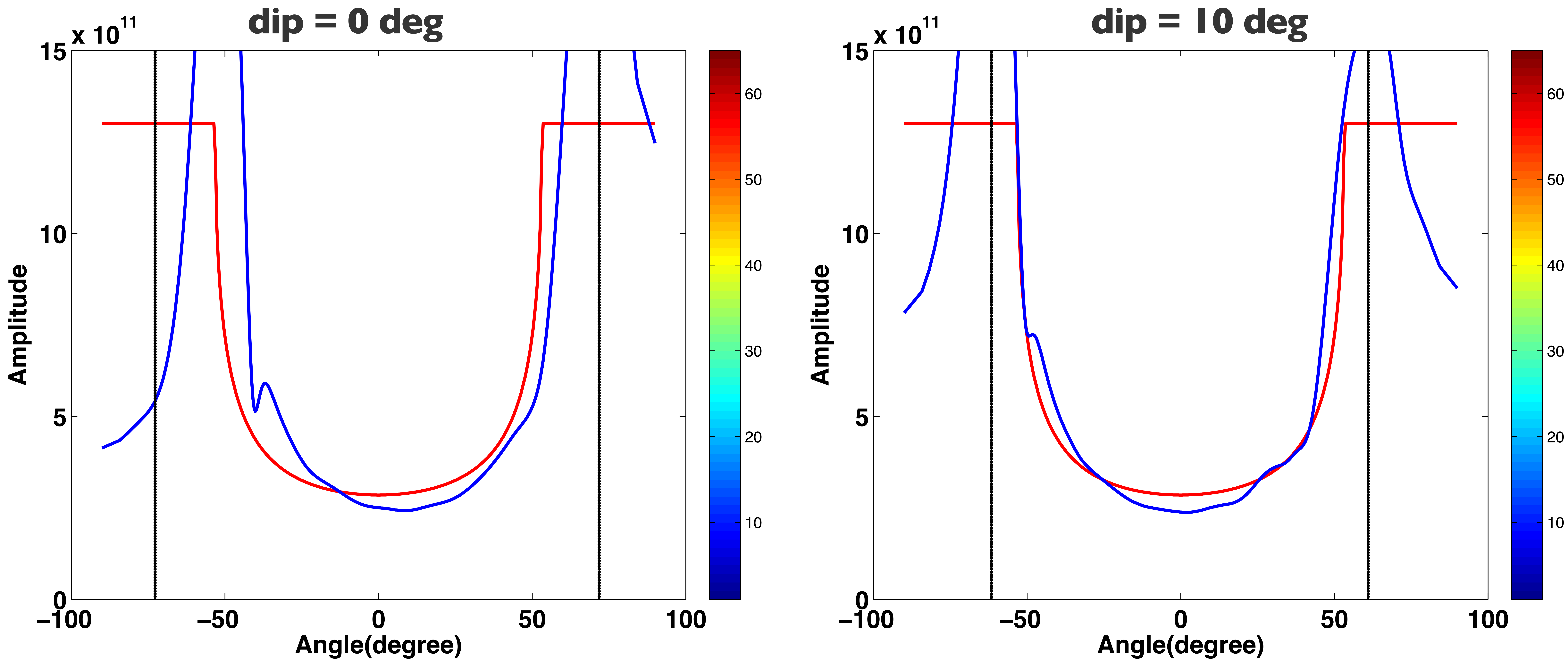




AVA

dipping layer model

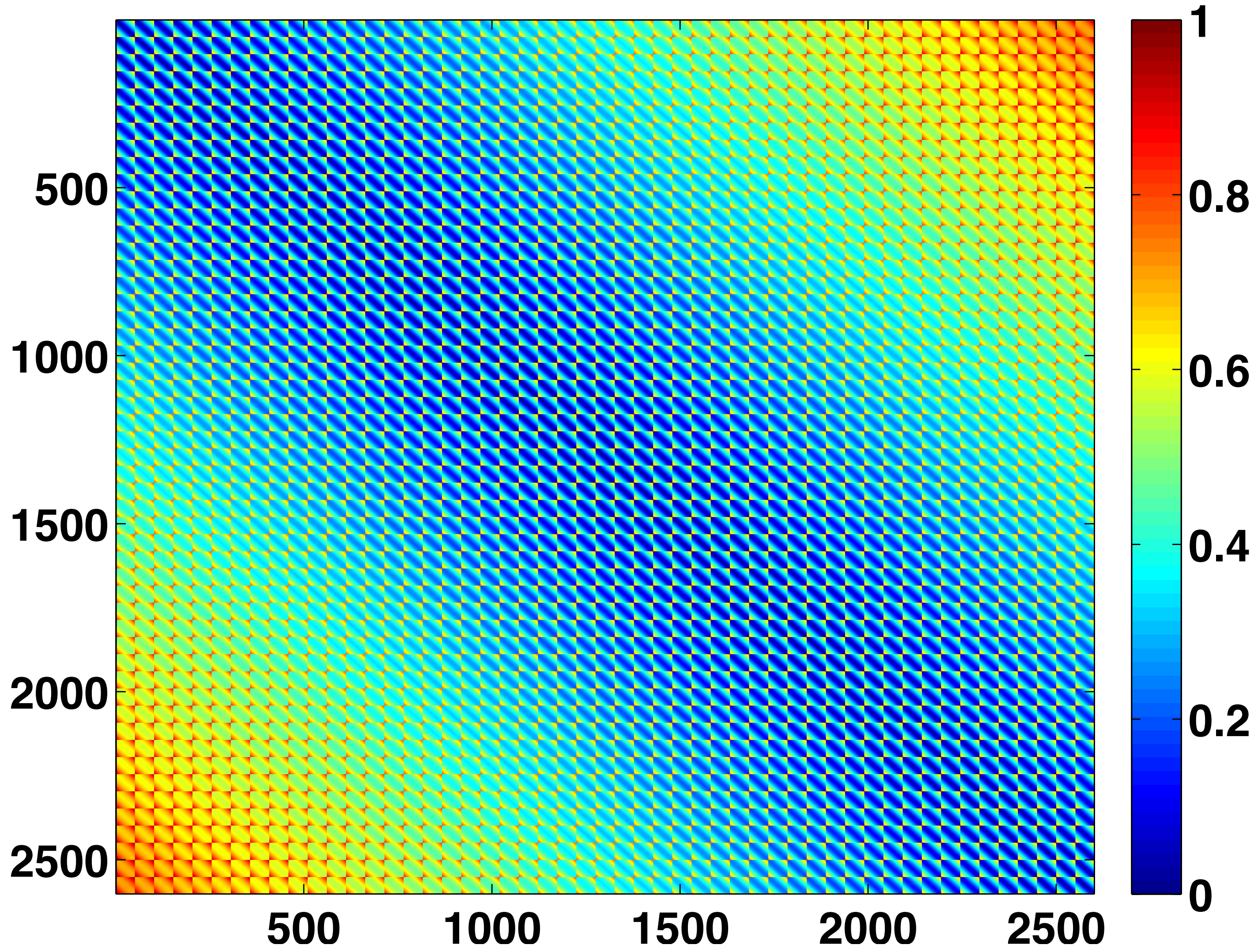
- **Zoeppritz equation**
- **Predicted response**



Biondo & Symes, ’04 , Symes 2008, Sava & Vasconcelos, ’11

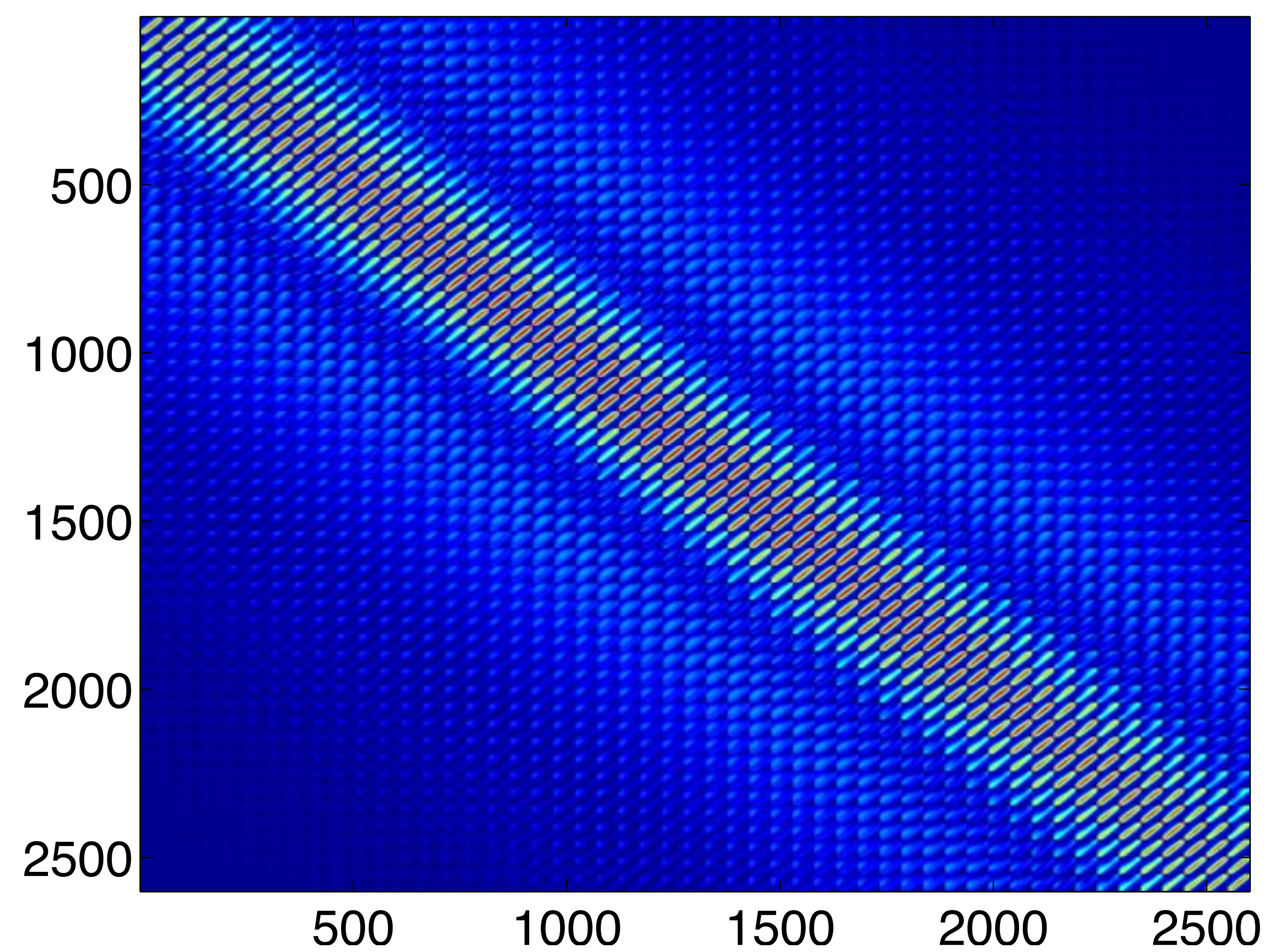
WEMVA

conventional approach



h

$.*$



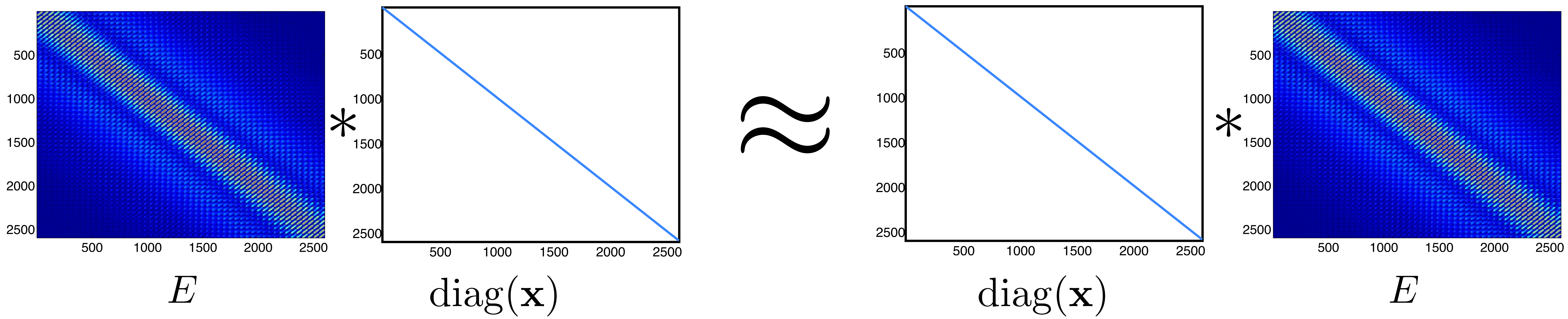
E

$.*$ stand for element-wise multiplication

Focusing

propose method approach

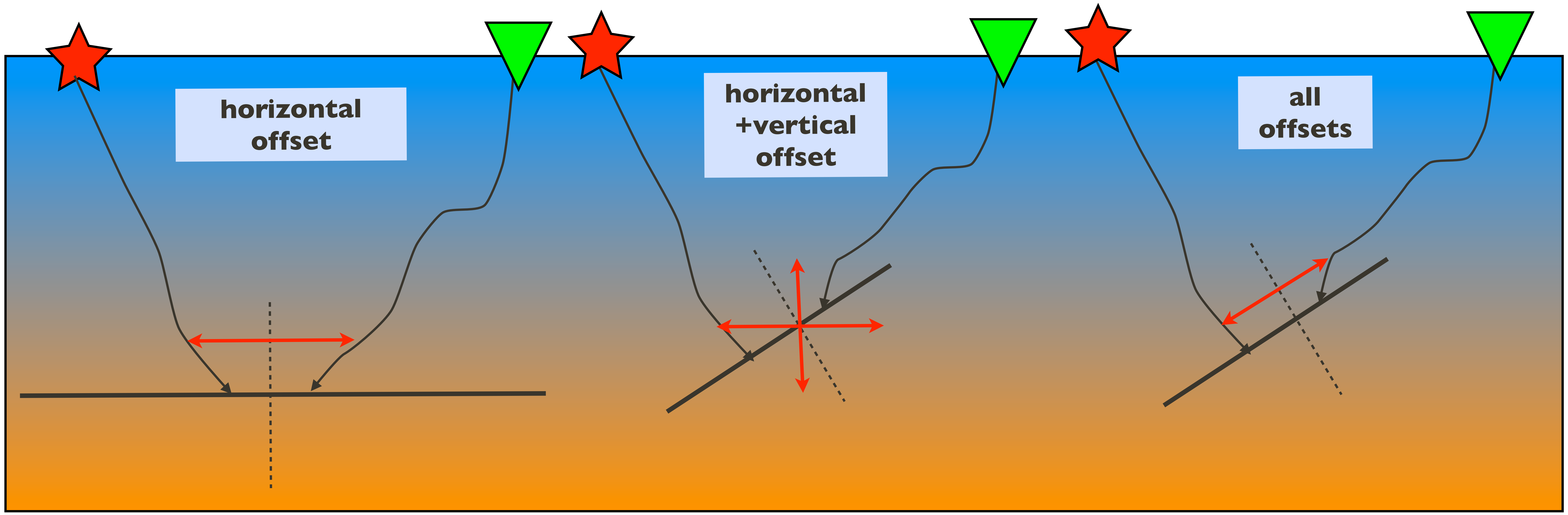
$$E\mathrm{diag}(\mathbf{x}) \approx \mathrm{diag}(\mathbf{x})E$$



$*$ **matrix-matrix multiplication**

Focusing

where $\mathbf{x}$ represents horizontal, vertical or all offset.



Fast WEMVA w/ *randomized* probing

Measure the error in some norm

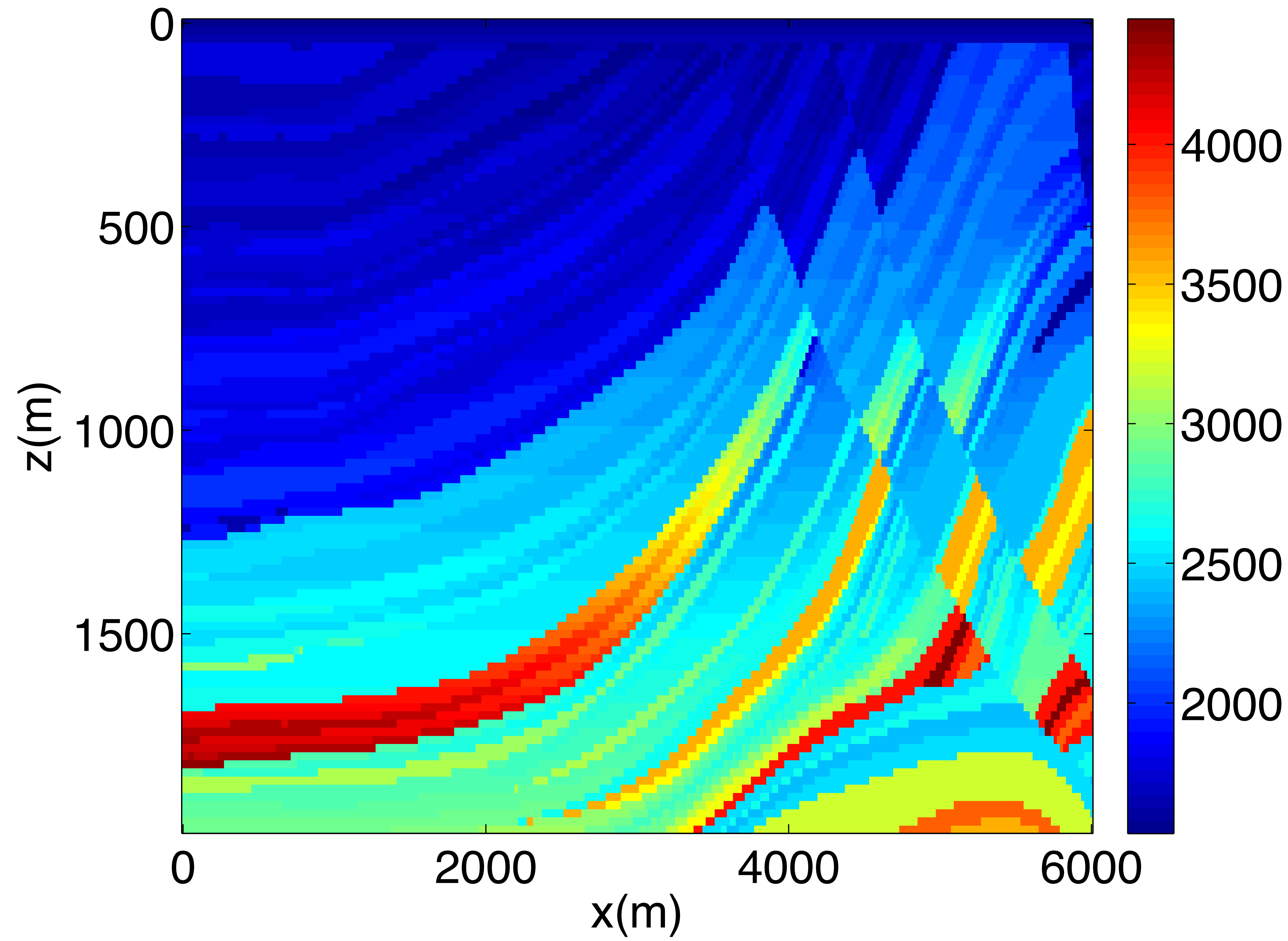
$$\min_{\mathbf{m}} ||E(\mathbf{m})\text{diag}(\mathbf{x}) - \text{diag}(\mathbf{x})E(\mathbf{m})||_?^2$$

The *Frobenius* norm can be estimated via randomized trace estimation : **Avron and Toledo, 2011**

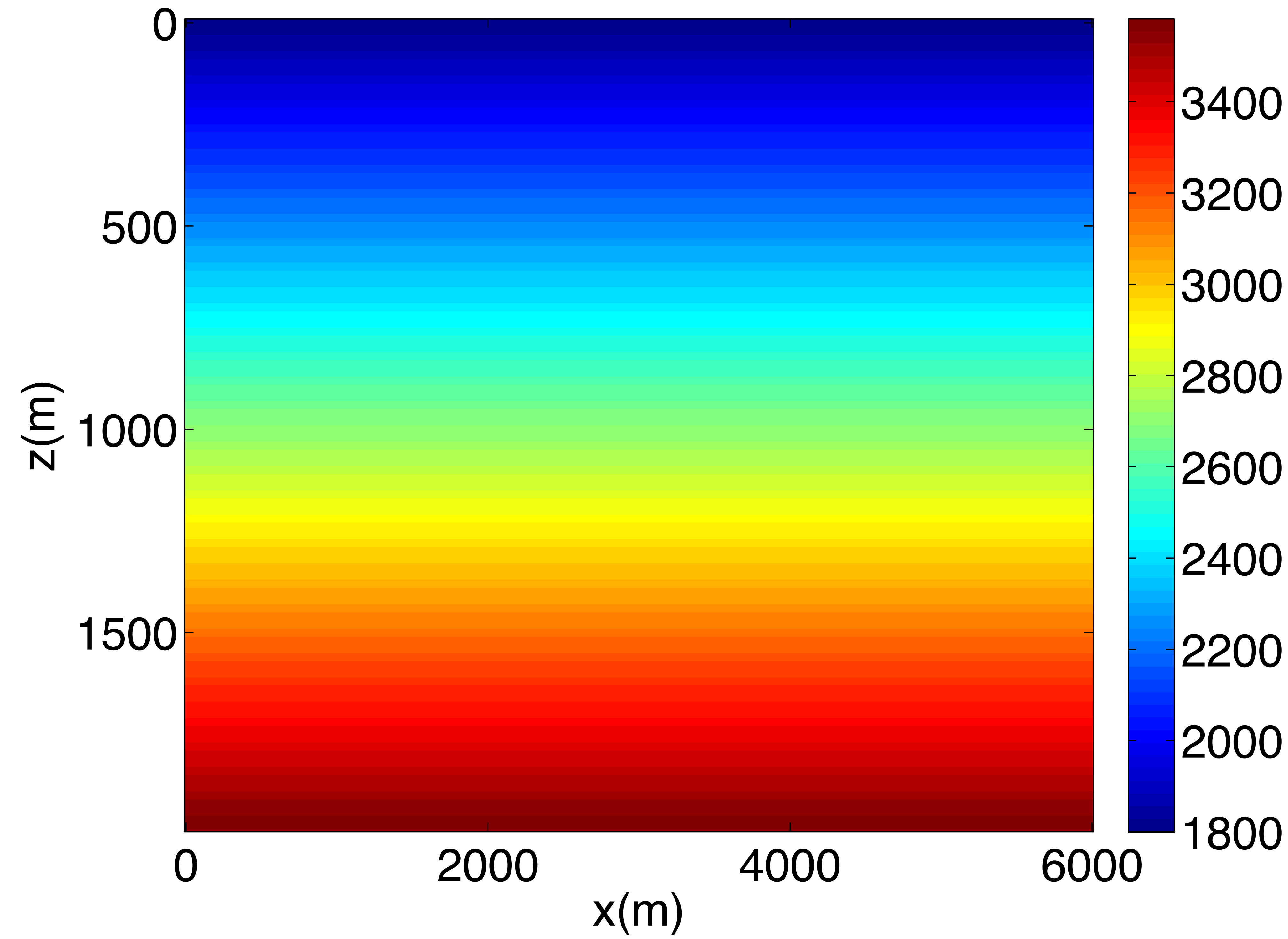
$$||A||_F^2 = \text{trace}(A^T A)$$
$$\approx \sum_{i=1}^{K} \mathbf{w}_i^T A^T A \mathbf{w}_i = \sum_{i=1}^{K} ||A\mathbf{w}_i||_2^2$$

where $\sum_{i=1}^{K} \mathbf{w}_i \mathbf{w}_i^T \approx I$

Randomized probing
reflection data



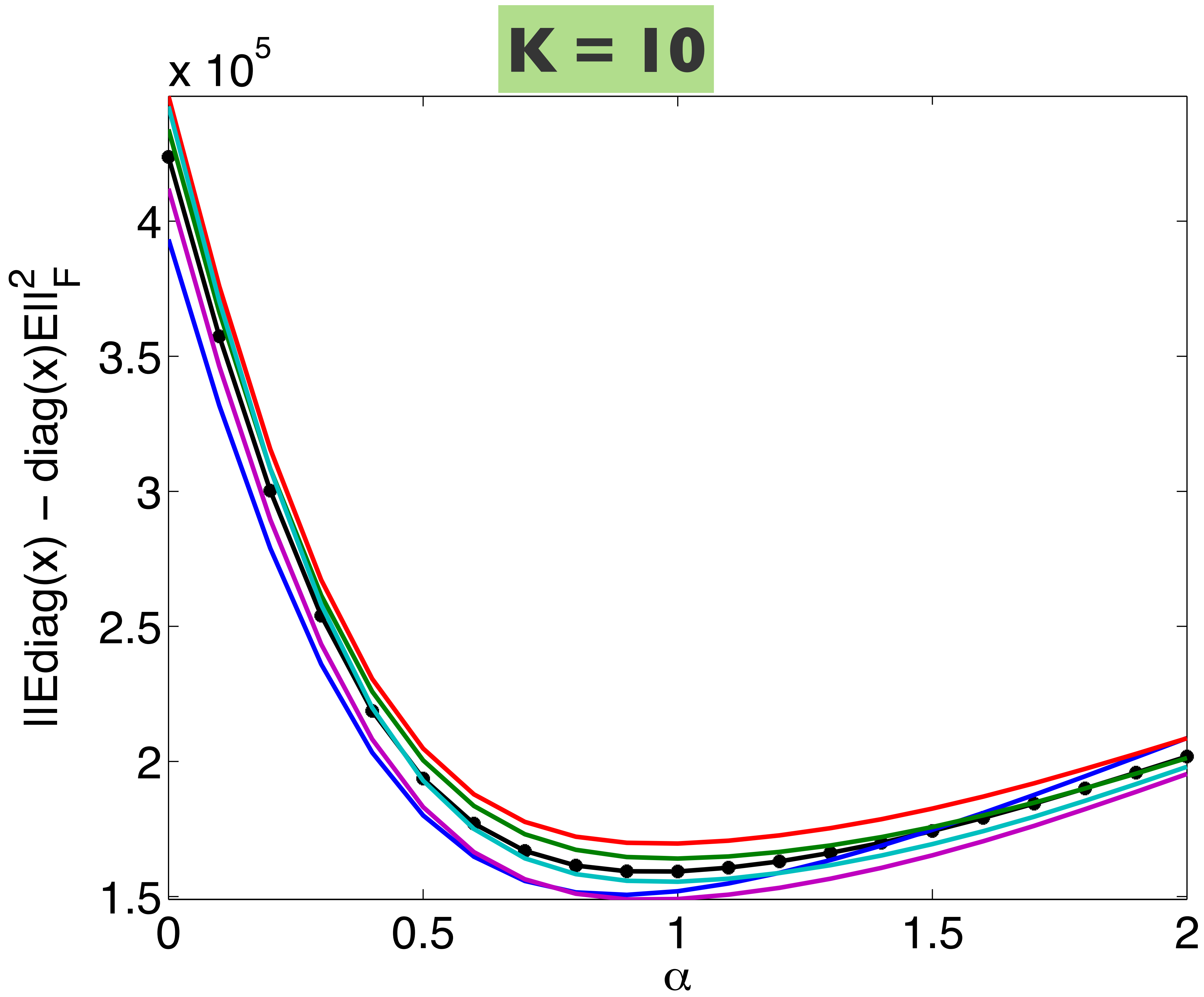
true model

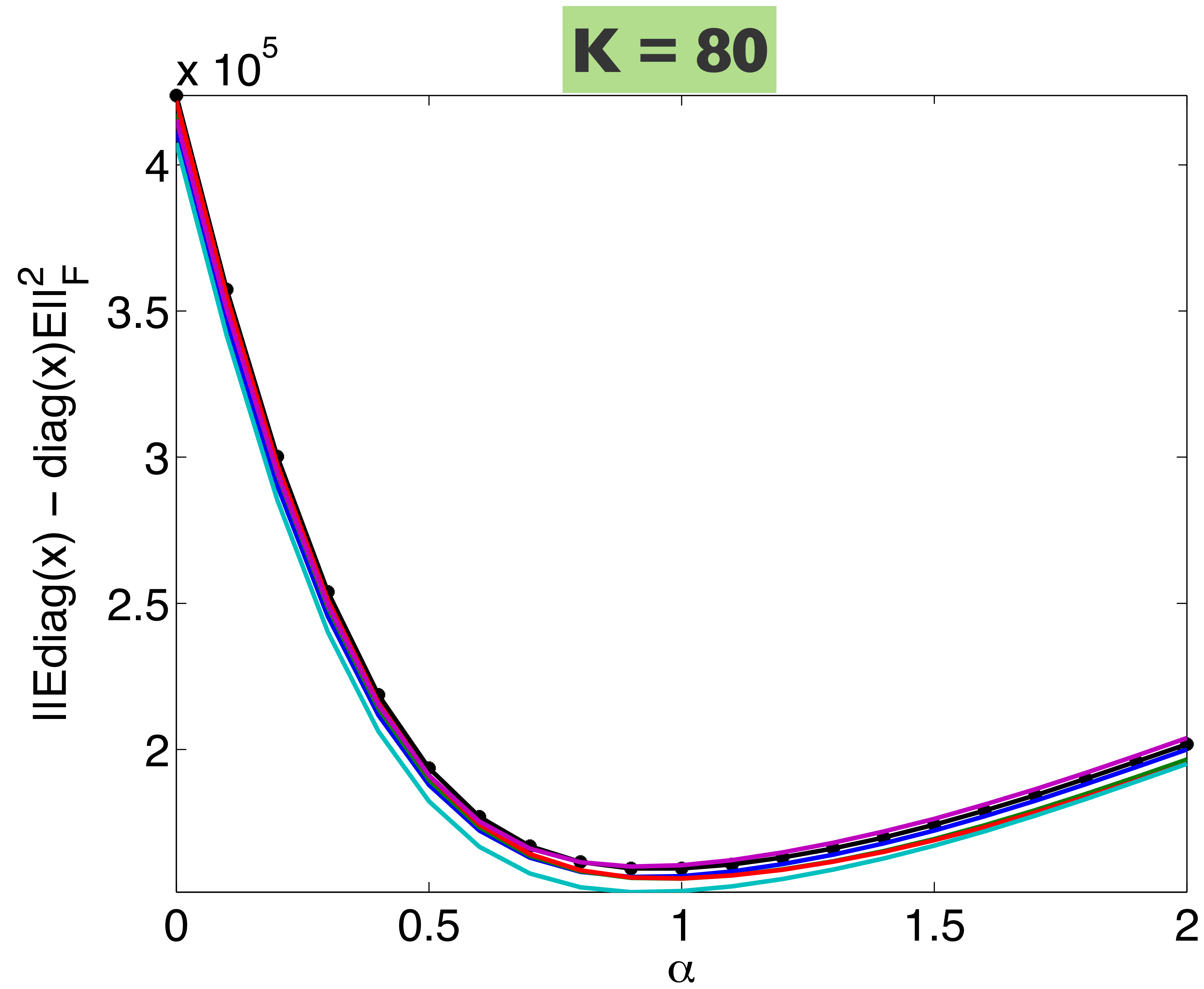


initial model

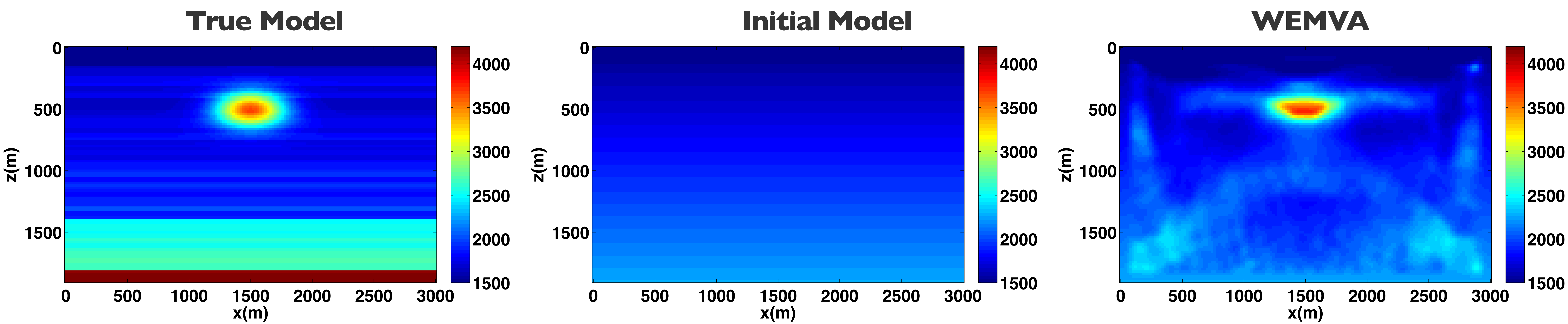
Randomized probing
reflection

- **Exact**
- **different color represents different random realization**

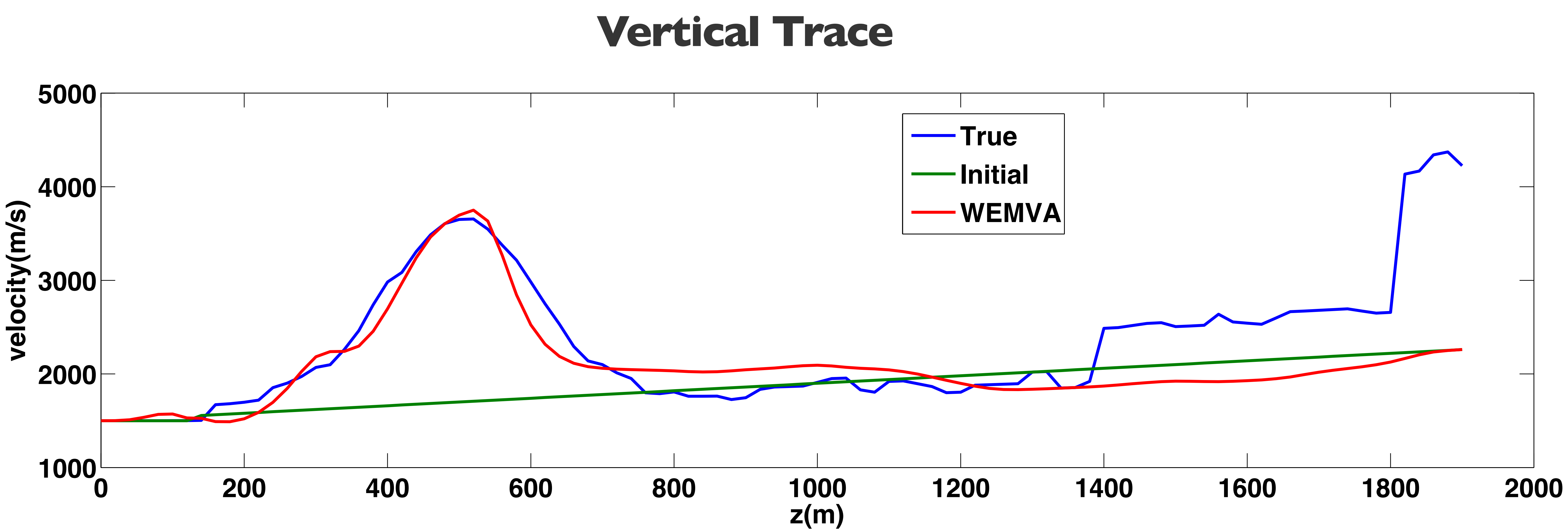




Lens Model

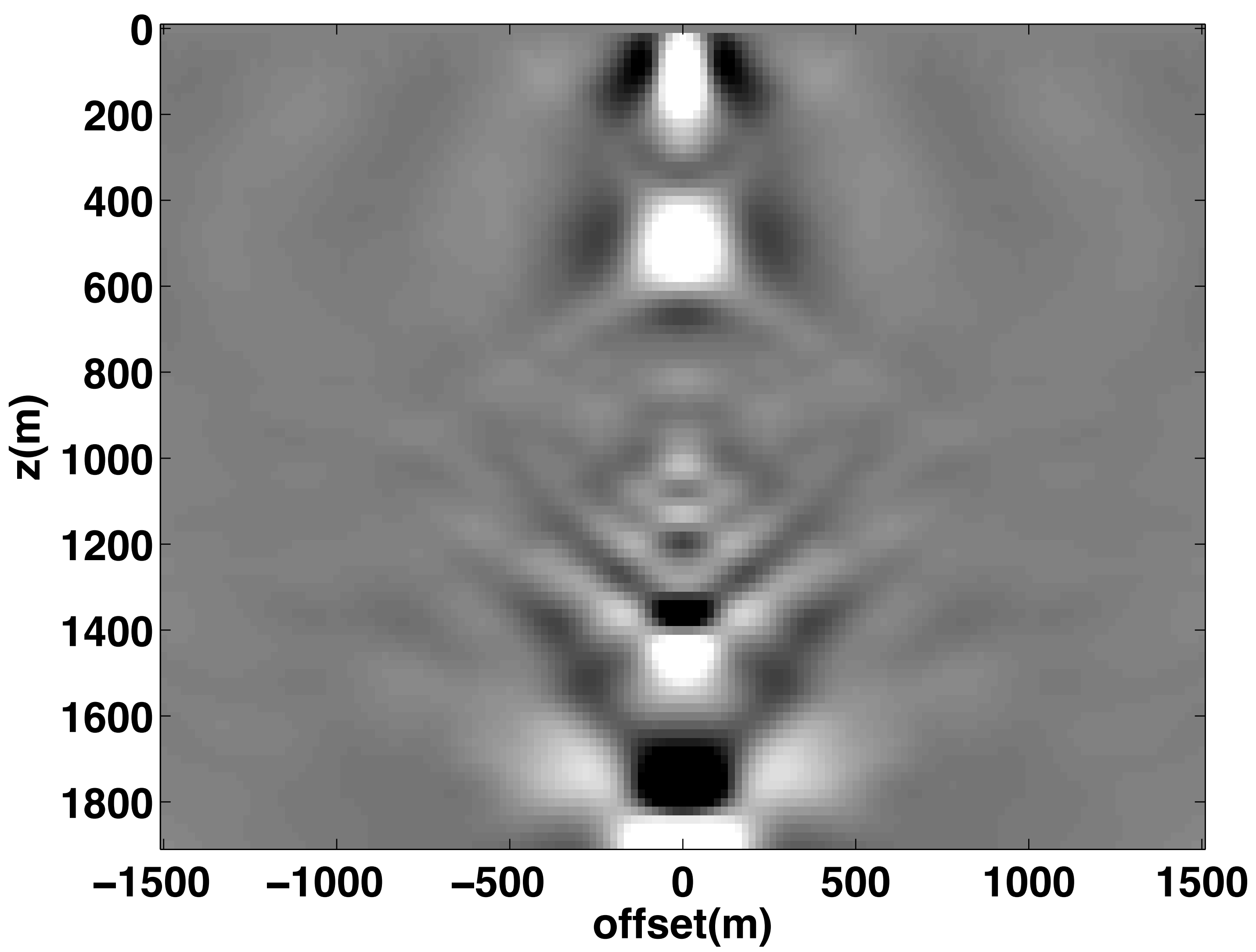


True Model
Initial Model
WEMVA
z(m)
x(m)
0
500
1000
1500
2000
2500
3000
4000
3500
3000
2500
2000
1500

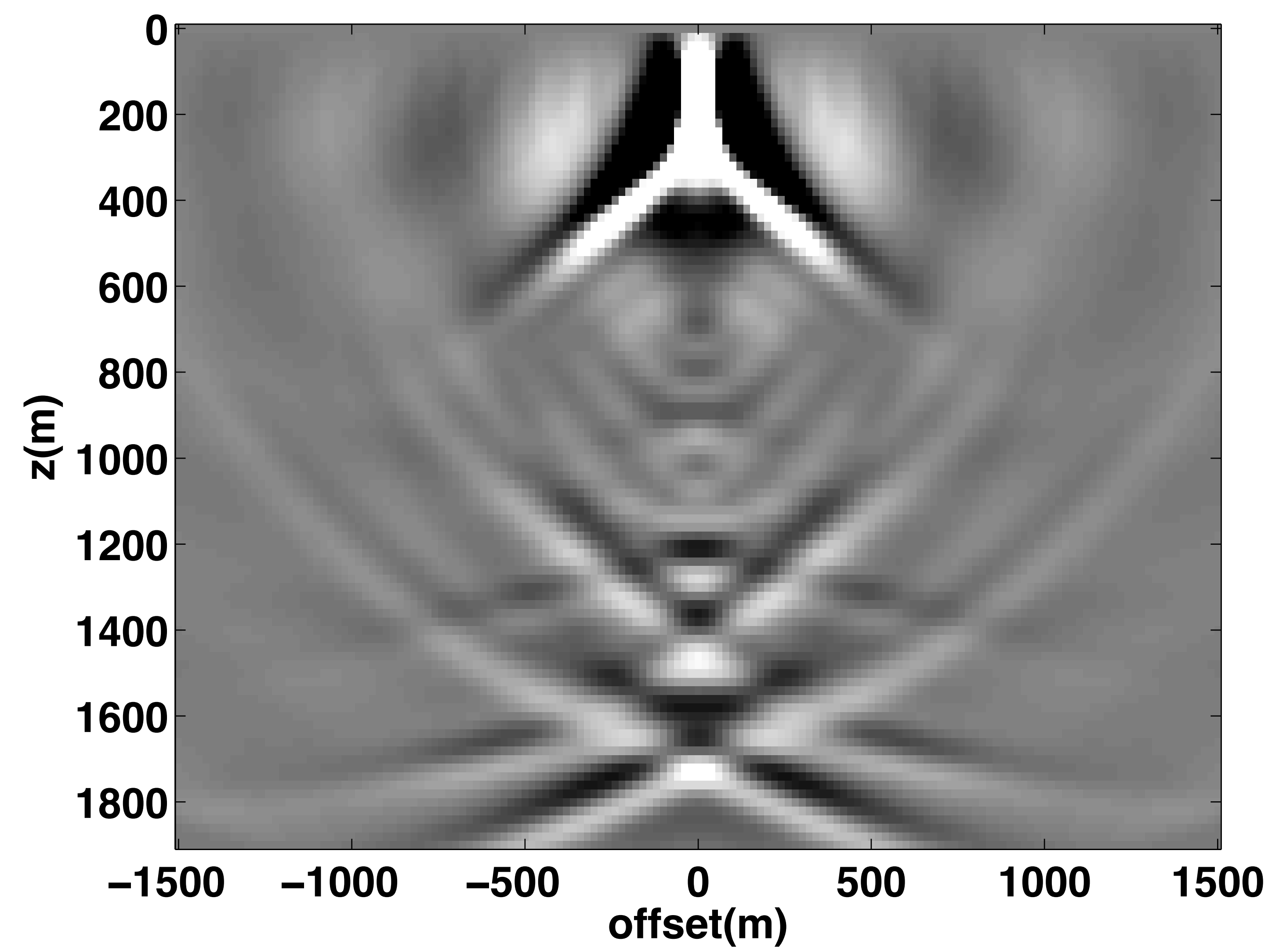


Vertical Trace
velocity(m/s)
z(m)
True
Initial
WEMVA
5000
4000
3000
2000
1000
0
200
400
600
800
1000
1200
1400
1600
1800
2000

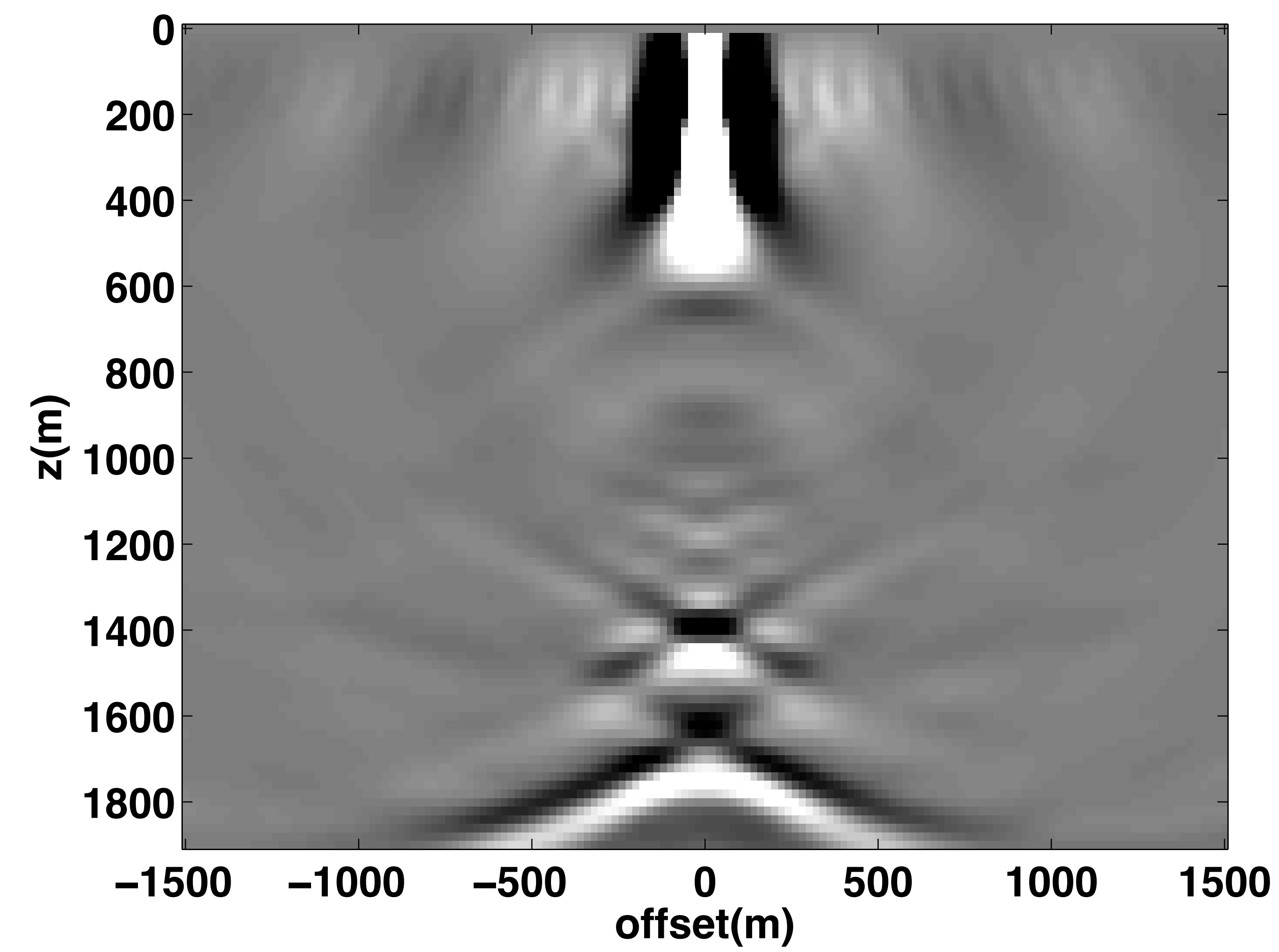
Lens Model
common image gathers



true model



initial model



WEMVA

Ivan Vasconcelos and James Rickett, "**Broadband extended images by joint inversion of multples blended wavefields** ", 2013, Geophysics

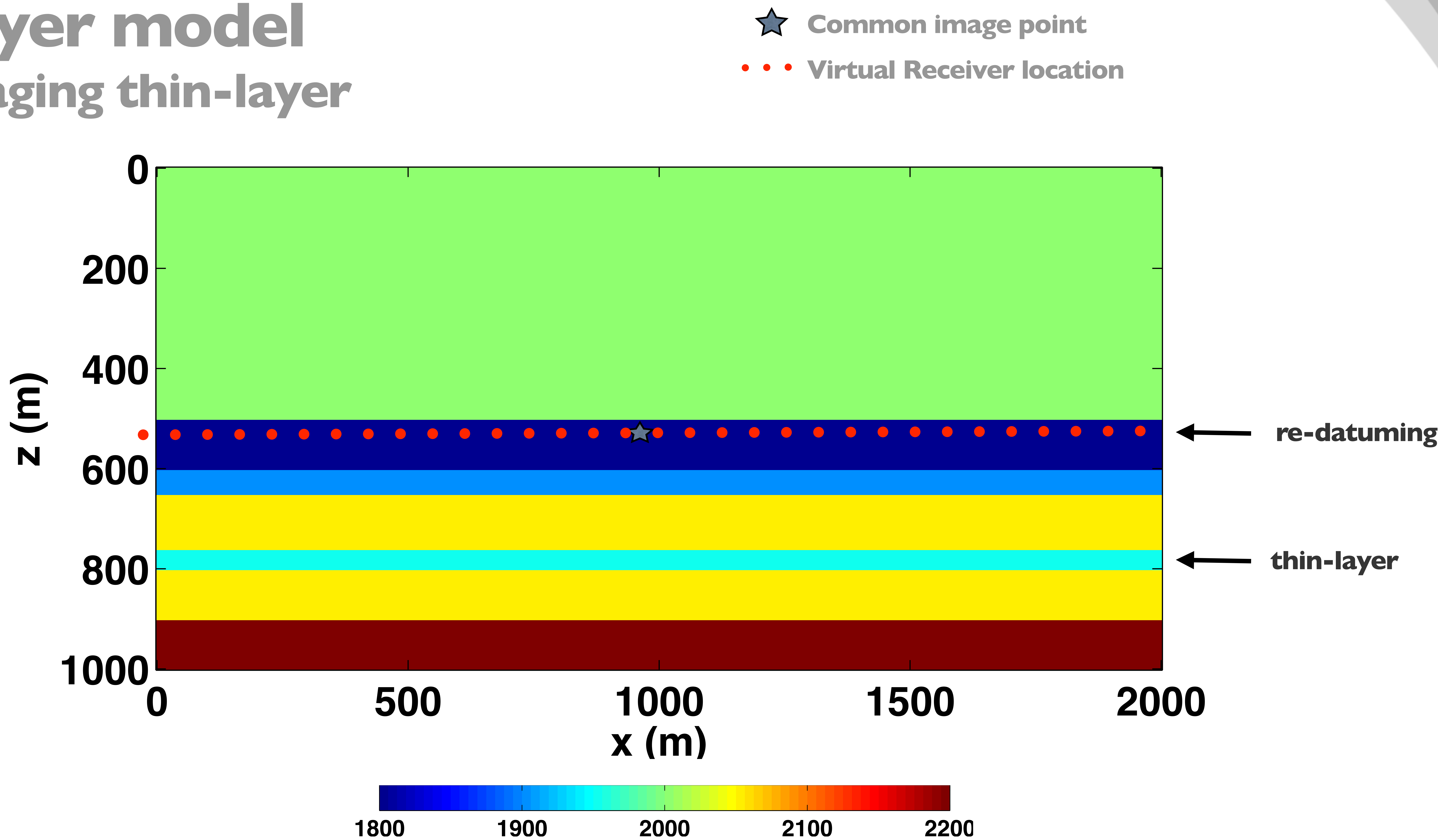
Targeted Imaging

Image only reservoir area

Re-datum data above the reservoir

Mitigate overburden artifacts

Layer model
imaging thin-layer



Experimental details

101 source (20 m spacing) , 201 receivers (10 m spacing)

3-60 Hz

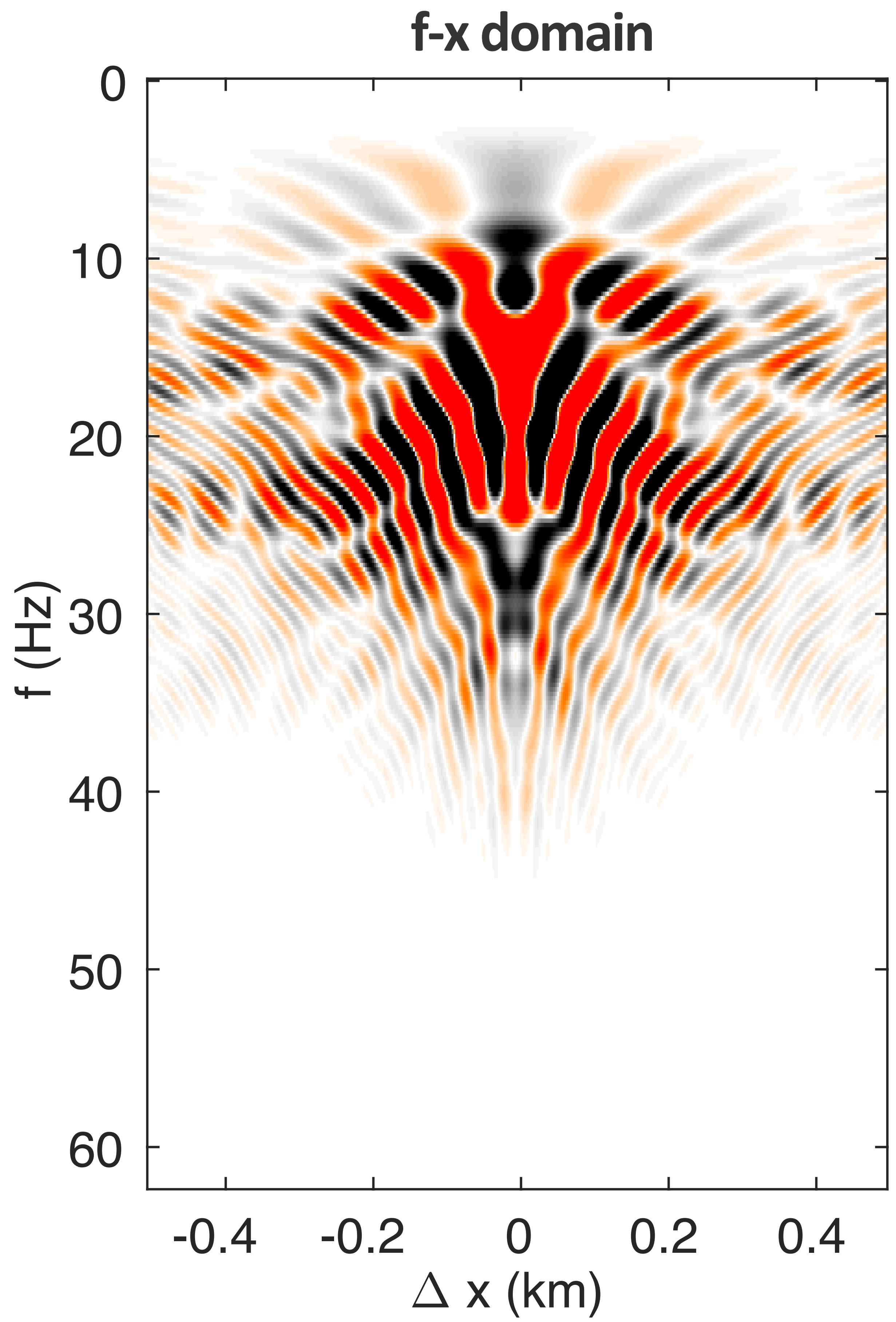
split-spread acquisition

recording length 4s, sampling interval 4ms

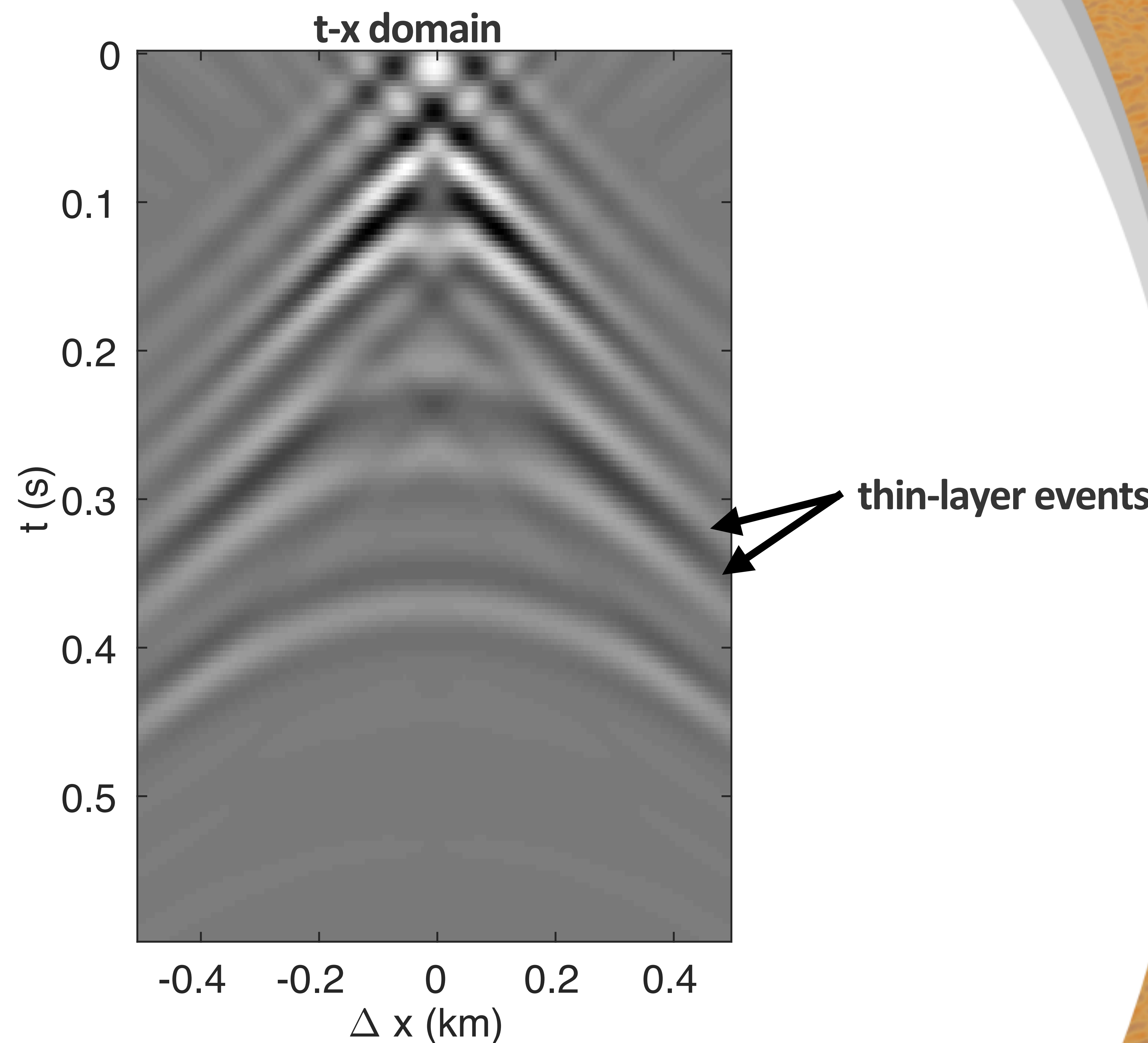
peak frequency 20 Hz

1 node, 10 workers

Layer model
common-image gather along z = 500



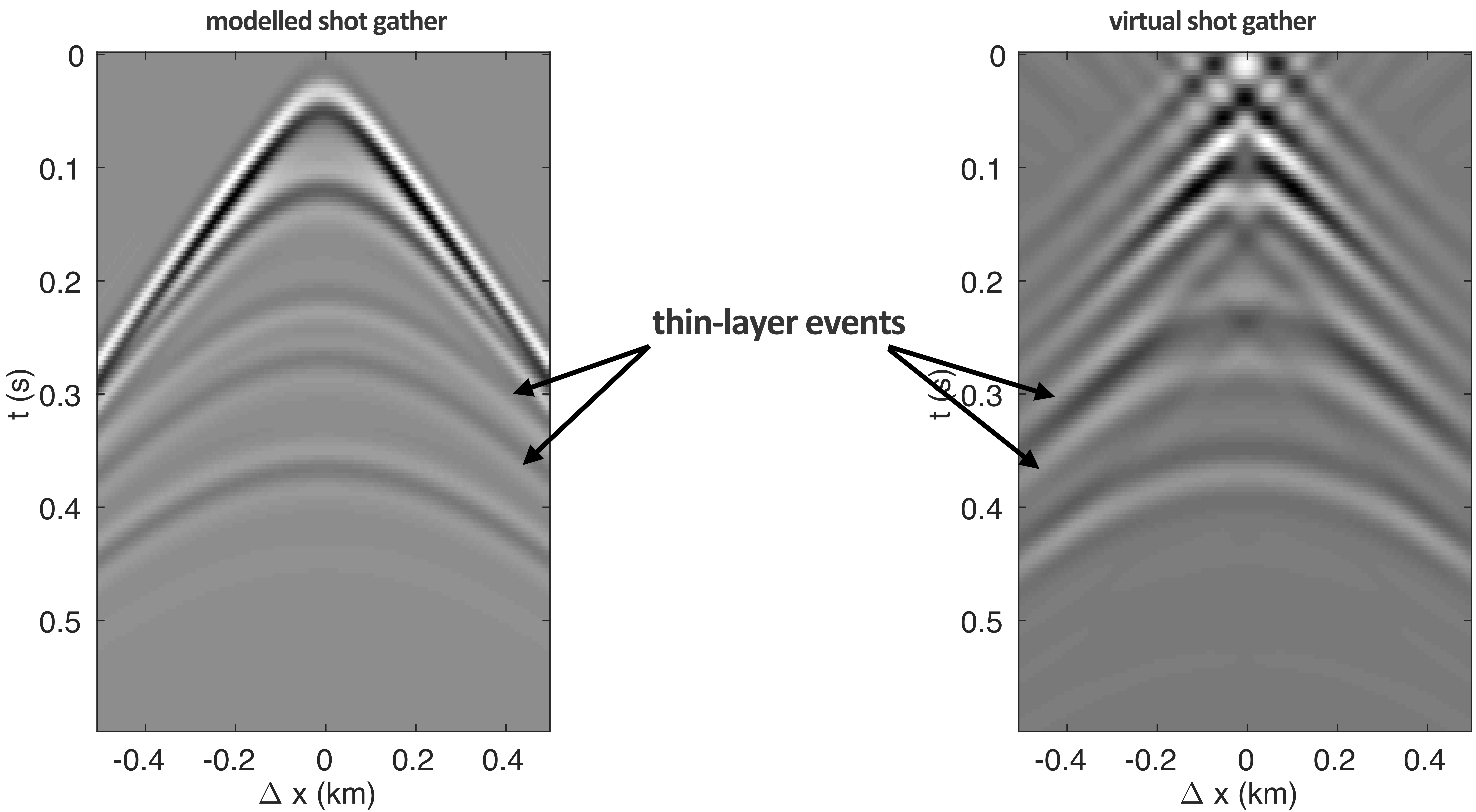
Inverse FFT



computational time ~ 4 min (proposed)   v/s   10 hrs (classical)

Layer model

comparison (modelled versus virtual source)



Extension to 3D

Impediments

No direct solver for Helmholtz

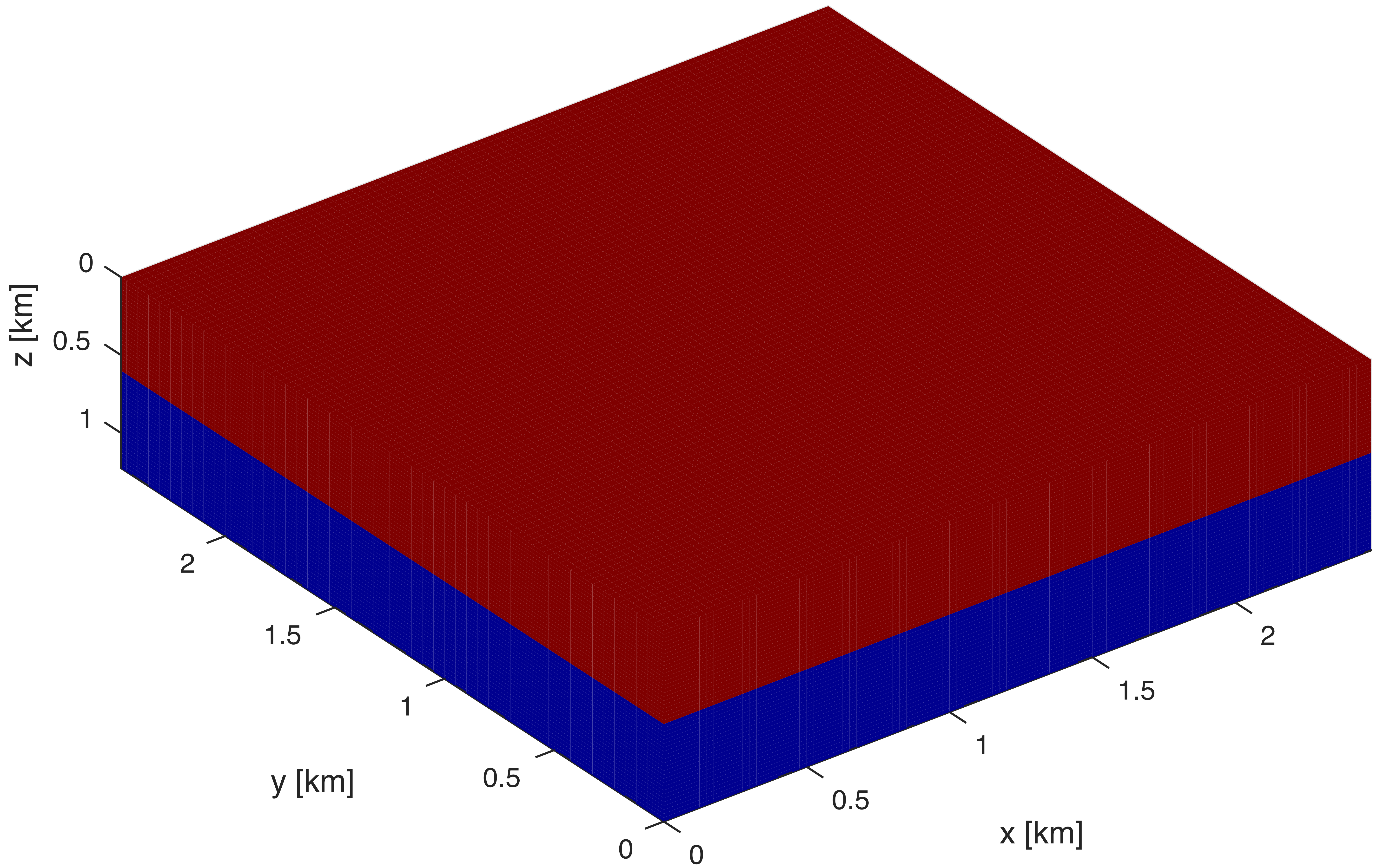
- *iterative solver*

Limited budget

- in terms of # of wave-equation to solve

Practically impossible to form full subsurface image volume in 3D!

1-Layer model



Experimental details

2500 sources (50 m spacing) , 625 receivers (100 m spacing)

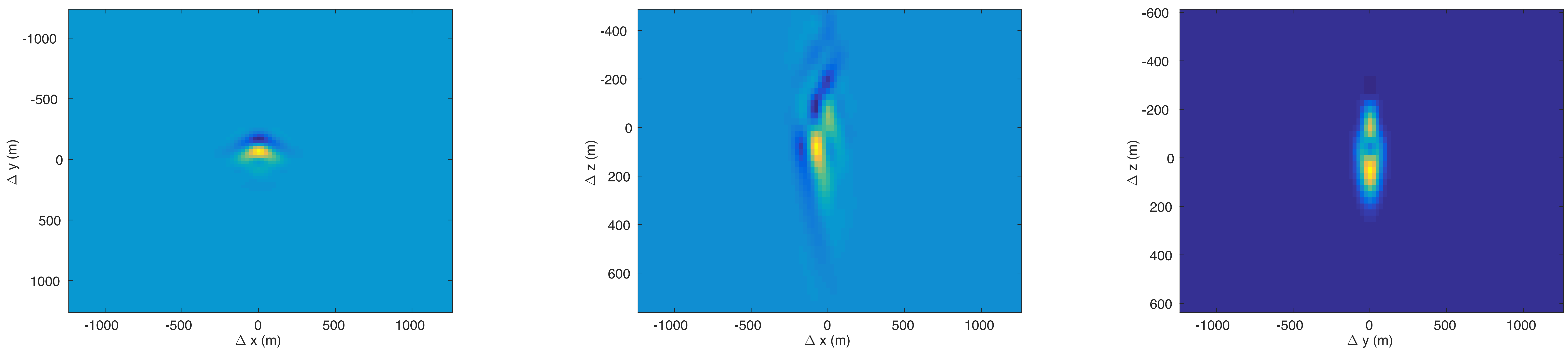
5-15 Hz , 0.5 Hz sampling

ocean-bottom acquisition node

peak frequency 10 Hz

3 node, 7 workers

1-Layer model
common image gather



computational time ~ 45 min (proposed)   v/s 47 days (classical)

Conclusions

Probings make computation of full subsurface-offset image gathers in 3D affordable

Enabler for

- automatic velocity model building (WEMVA)
- forming of densely sampled subsurface image volumes
  - Least-squares extended imaging (reduce artifacts)
- AVO/AVP analyses
- targeted imaging

Future Work

Incorporate *free-surface multiple* in 3D

Extension to WEMVA in 3D

Extension to time-stepping

Target imaging in more complex environment

Acknowledgements

Thank you for your attention !

https://www.slim.eos.ubc.ca/

SINBAD

NSERC CRSNG

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