STANFORD UNVERSITY

SEP meeting 2017

Preconditioned elastic full waveform inversion using approximated Hessian matrix

Ettore Biondi*, Guillaume Barnier, and Biondo Biondi

18th April 2017

Outline

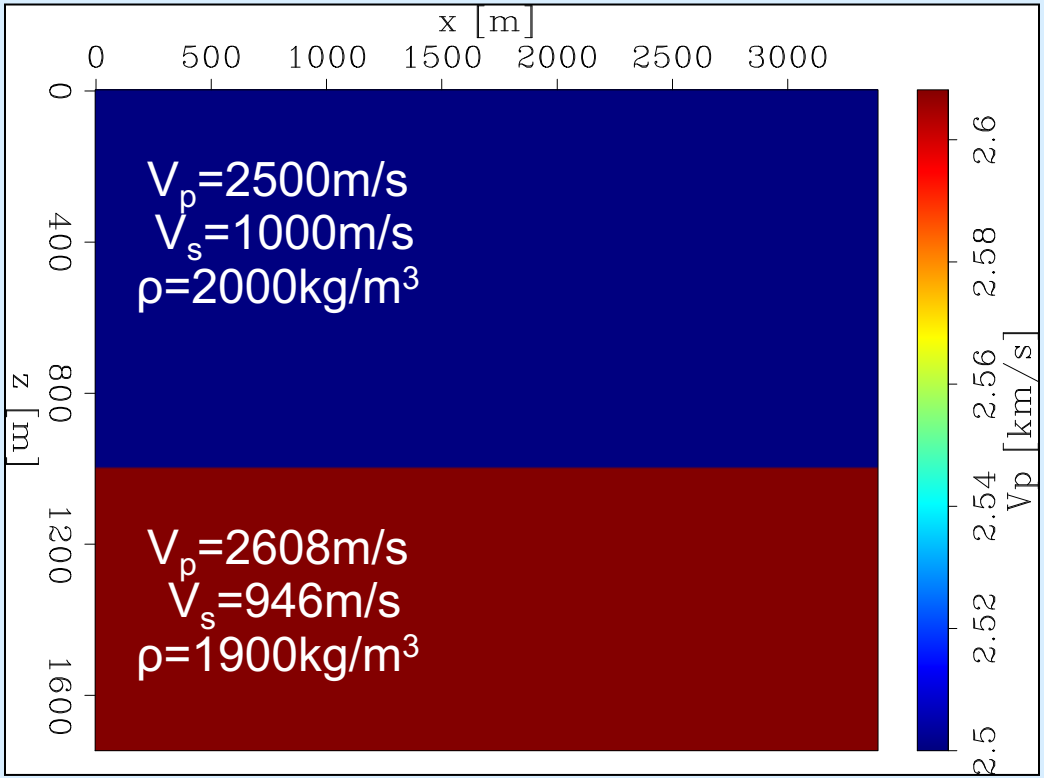
- Why we need elastic FWI
- The parameter cross-talk
- Preconditioned elastic FWI
- Conclusions

How do we invert for elastic parameters?

Usually using Amplitude Variations with Offsets

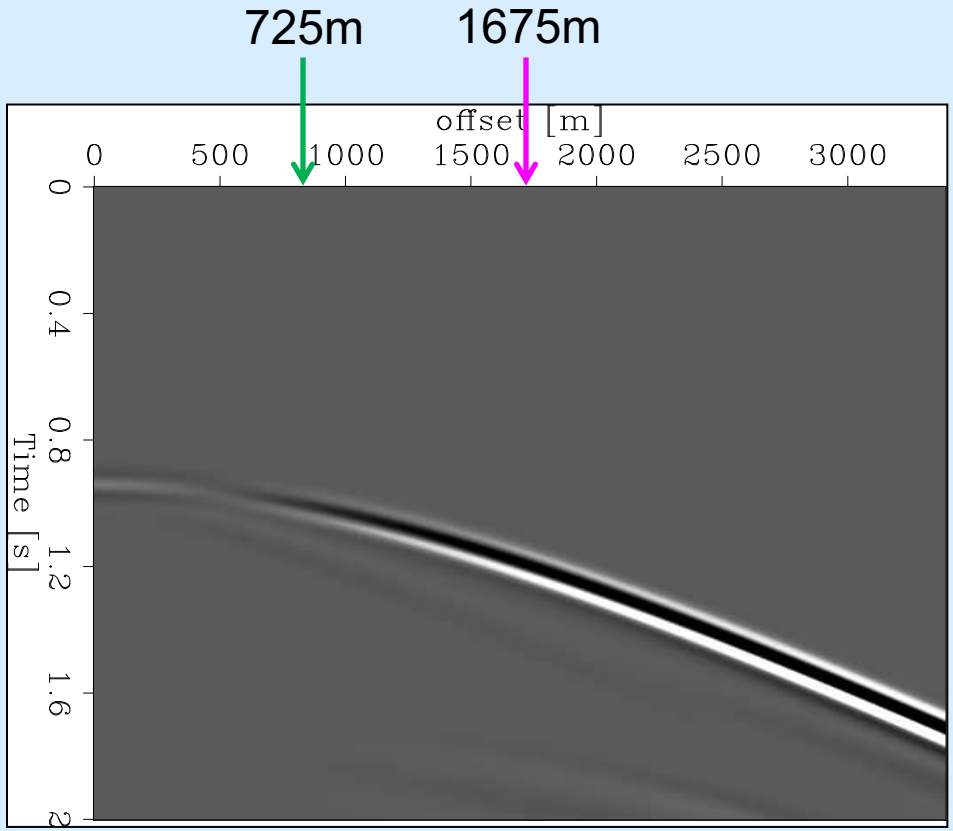
AVO response

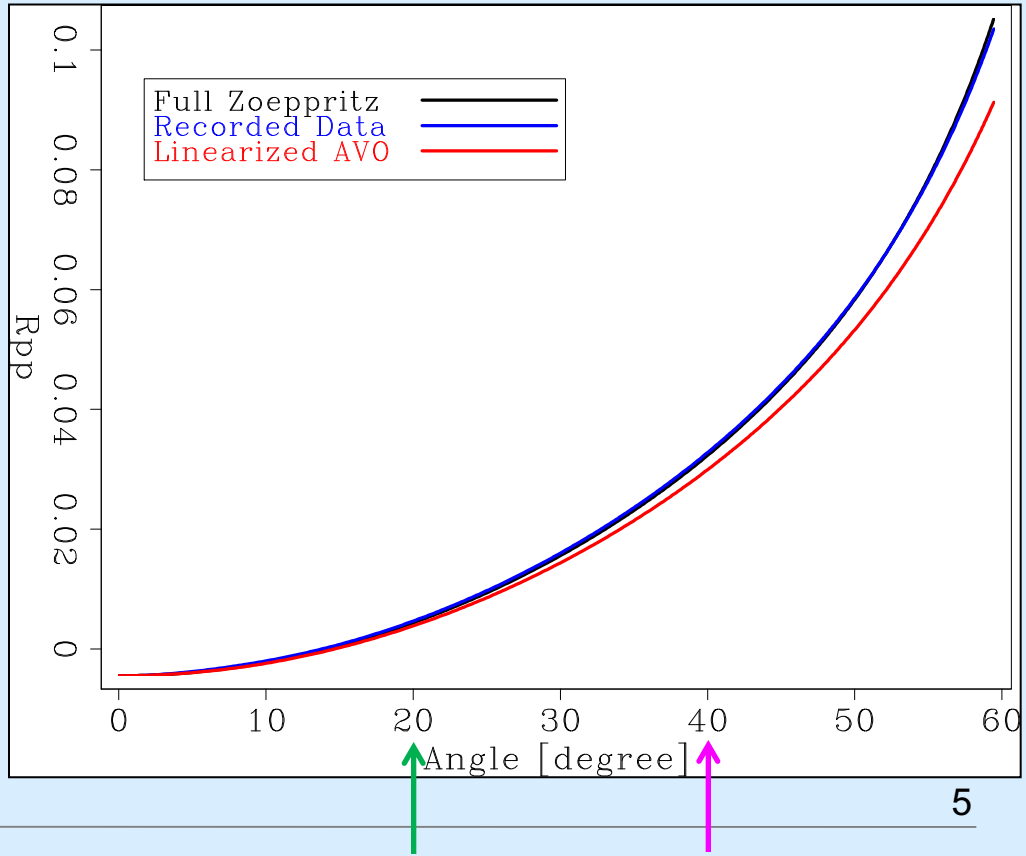
$\Delta V_p>0$; $\Delta V_s<0$ $\Delta\rho<0$



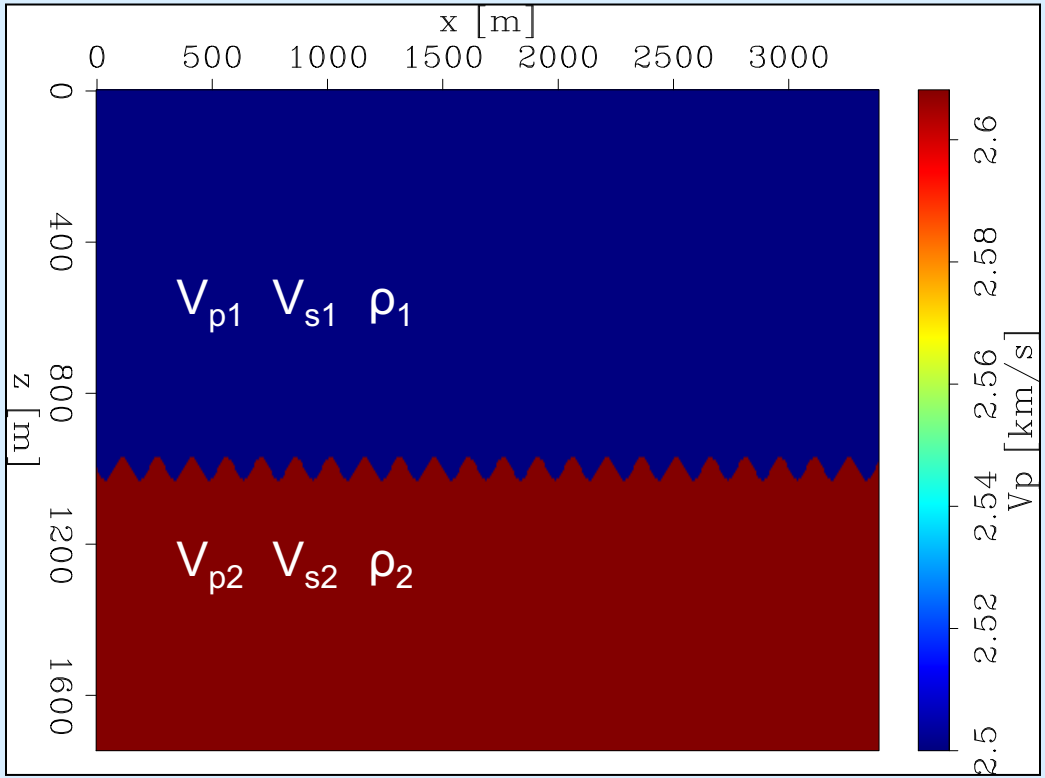
AVO response

Flat reflector case

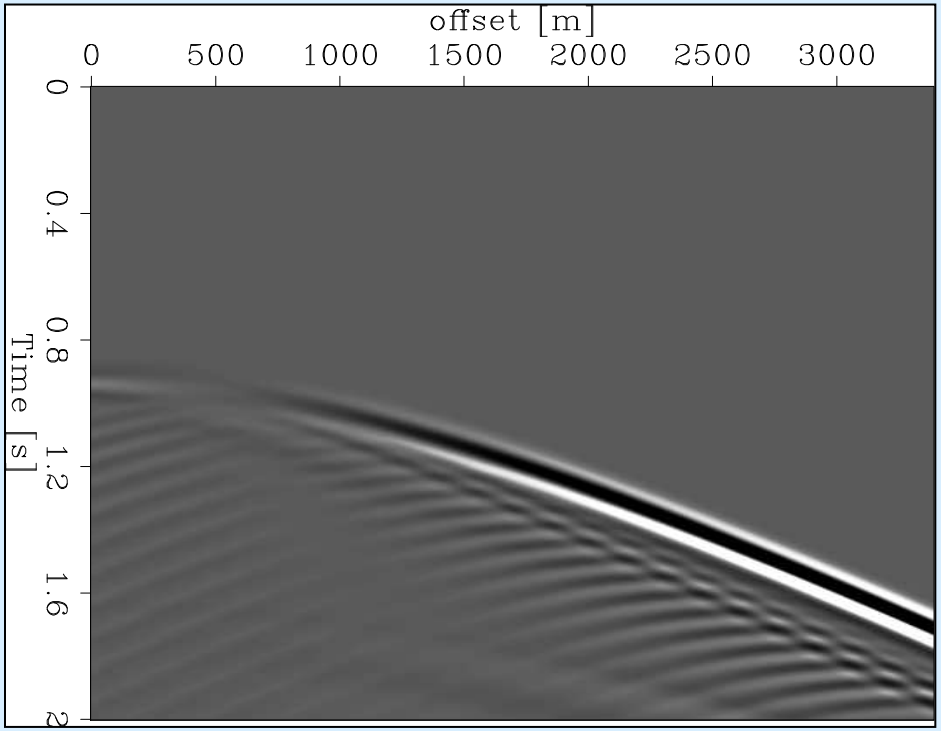


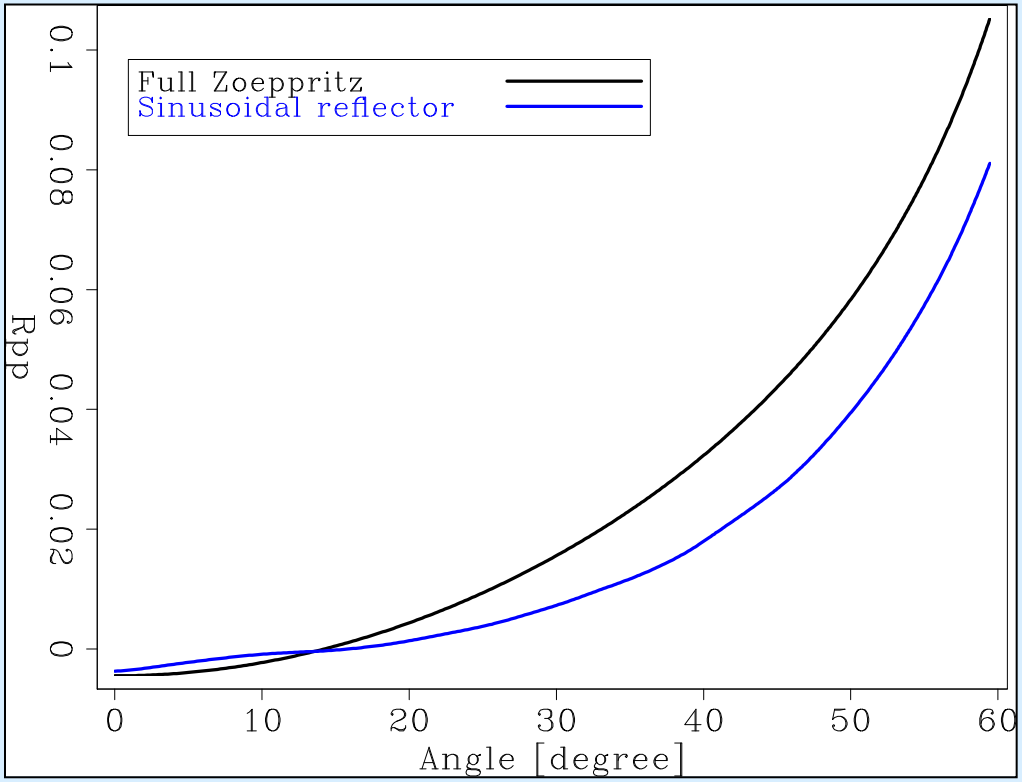


Sinusoidal reflector: planar reflector assumption



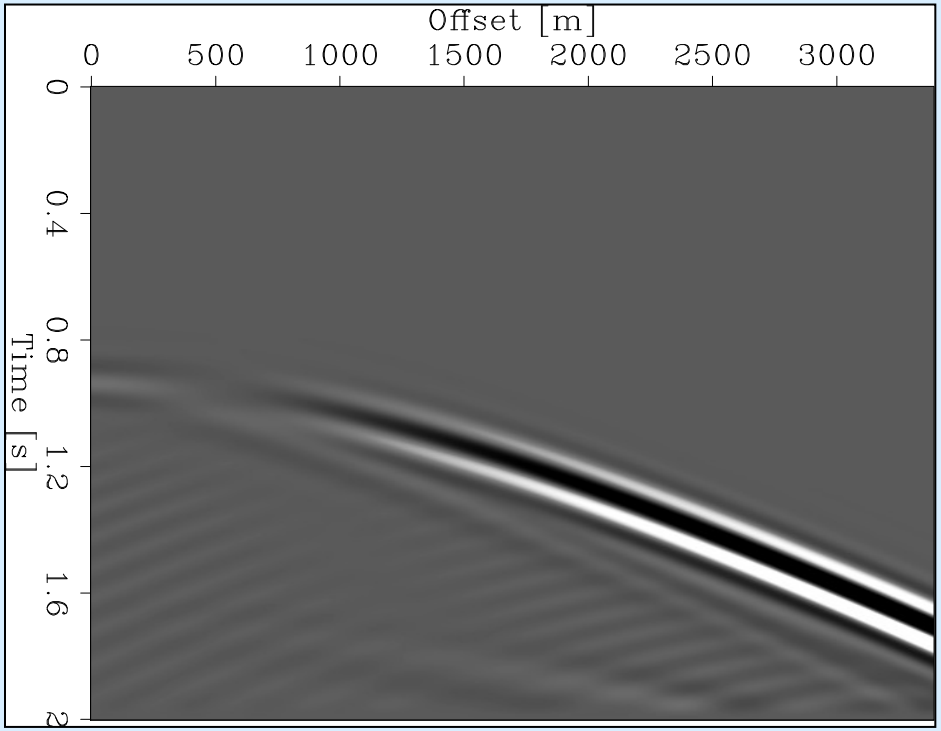
Sinusoidal reflector: planar reflector assumption

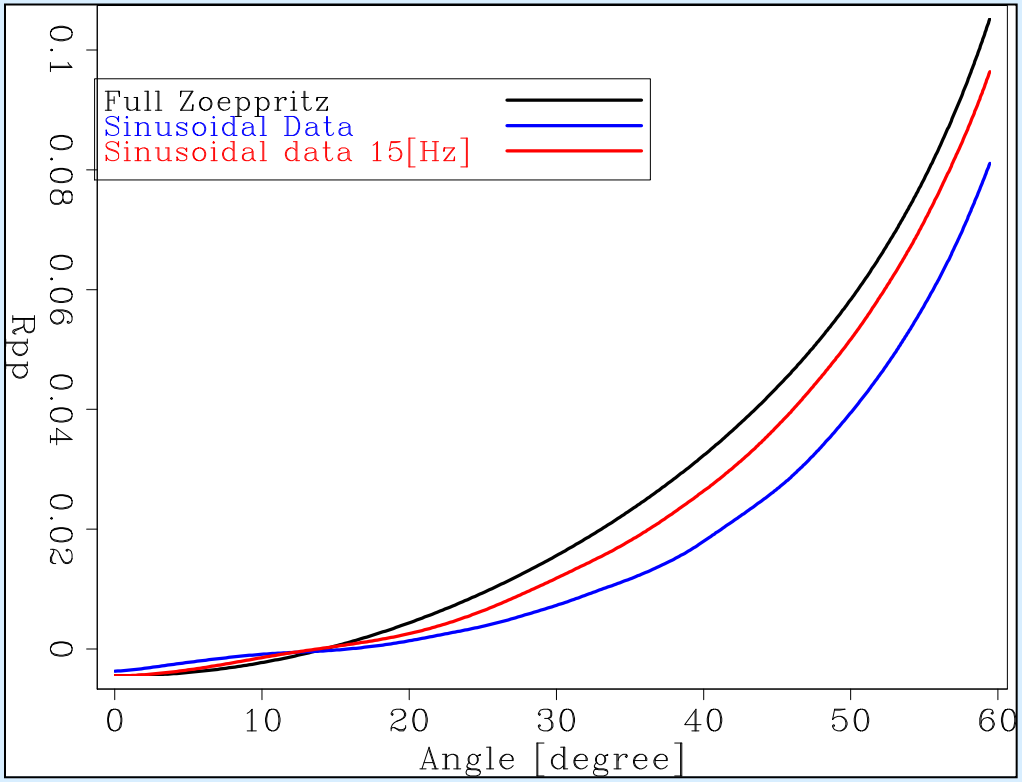




AVO response

Sinusoidal reflector: planar reflector assumption
The bandwidth matters!





Full waveform inversion uses all the frequencies in the data!

$$\phi(V_p, V_s, \rho) = \frac{1}{2}\left\| f(V_p, V_s, \rho) - d \right\|_2^2$$

Full waveform inversion uses all the frequencies in the data!

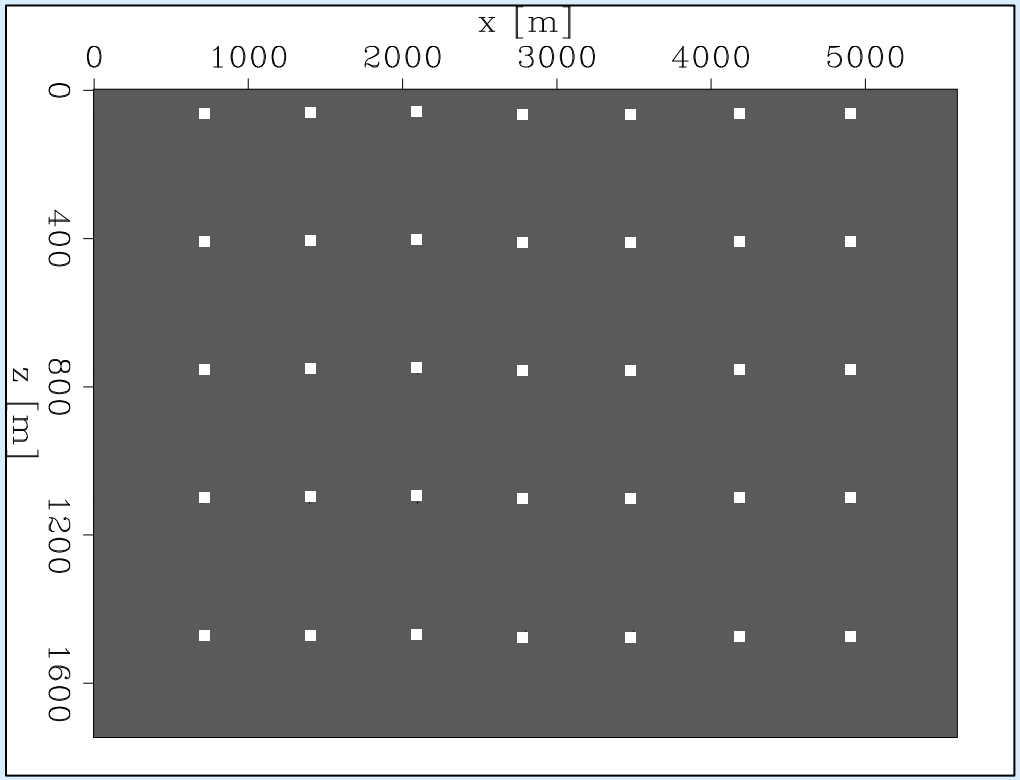
$$\phi(V_p, V_s, \rho) = \frac{1}{2}\left\| f(V_p, V_s, \rho) - d \right\|_2^2$$

However:

- Computationally intensive (wave-equation-based)

- Affected by parameter cross-talk ("leakage" of one parameter into the other)

True perturbation is in Vp only:

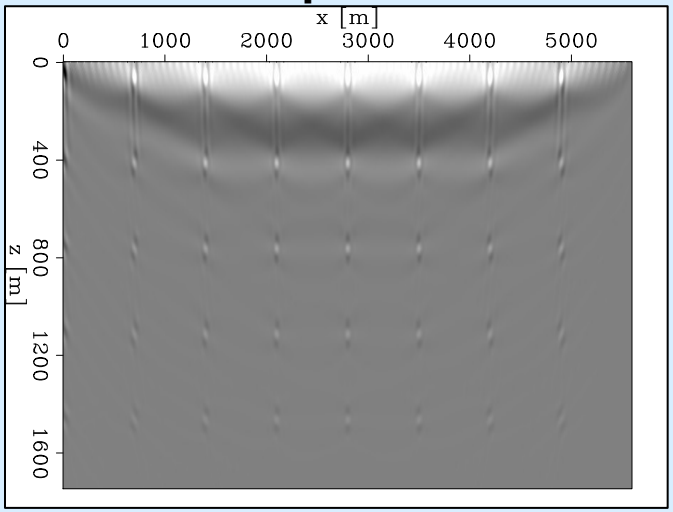


Elastic FWI: cross-talk

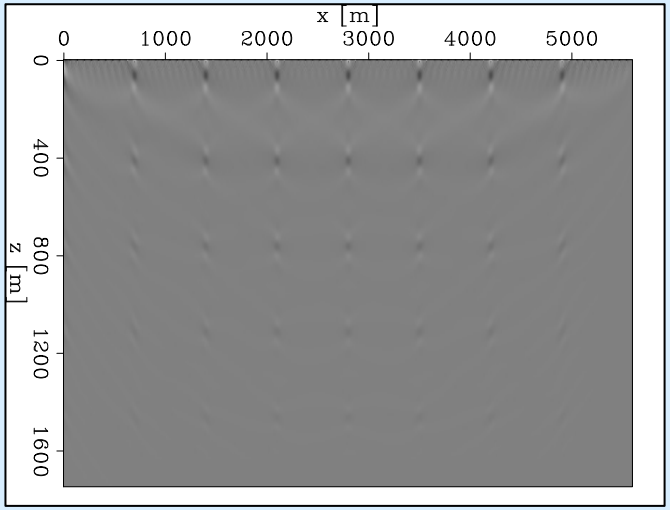
True perturbation is in Vp only:
compute the gradient

$$g(m) = B^* r$$

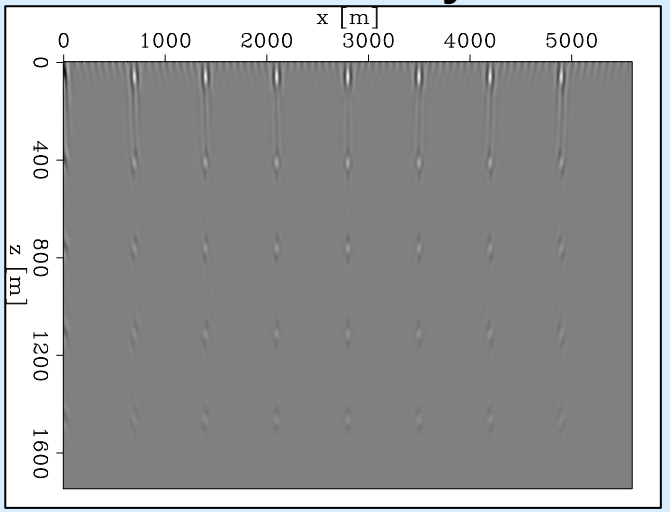
Vp



Vs



Density



Hessian-based optimization techniques (e.g., truncated Newton) diminish parameter cross-talk!

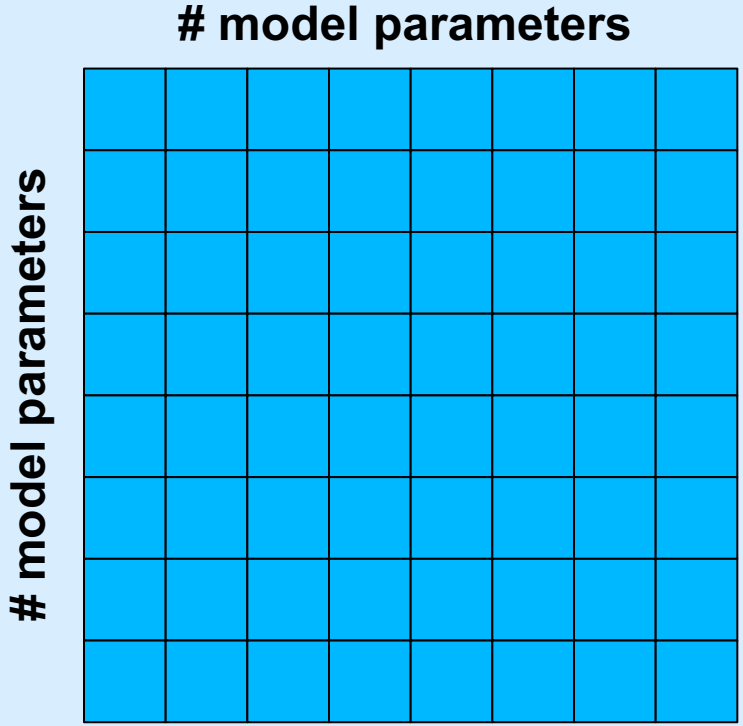
(Operto et al., 2013)

Hessian-based optimization techniques (e.g., truncated Newton) diminish parameter cross-talk!

How do we estimate a computationally efficient Hessian-based preconditioner?

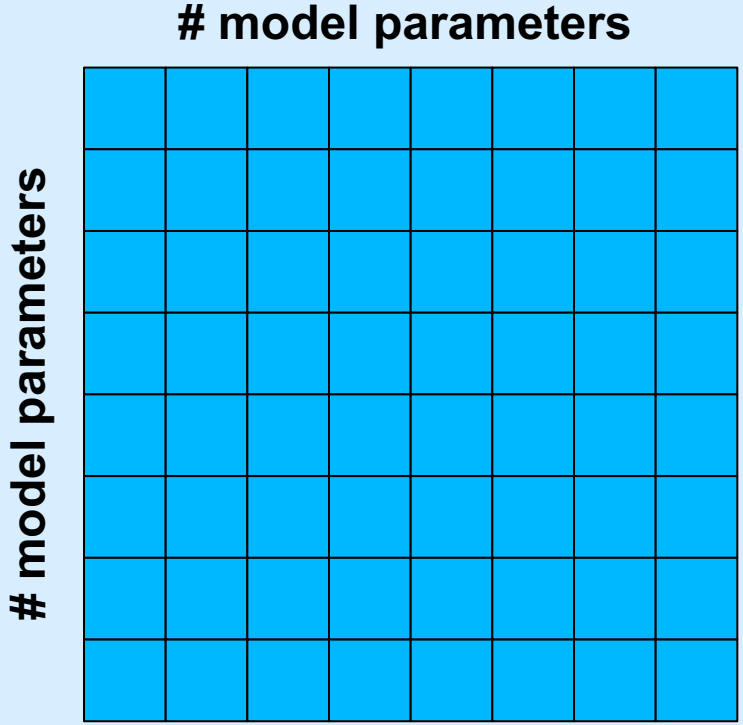
Elastic FWI: Hessian estimation

$$\frac{\partial^2 \phi(m)}{\partial m^2} = H(m)$$



Elastic FWI: Hessian estimation

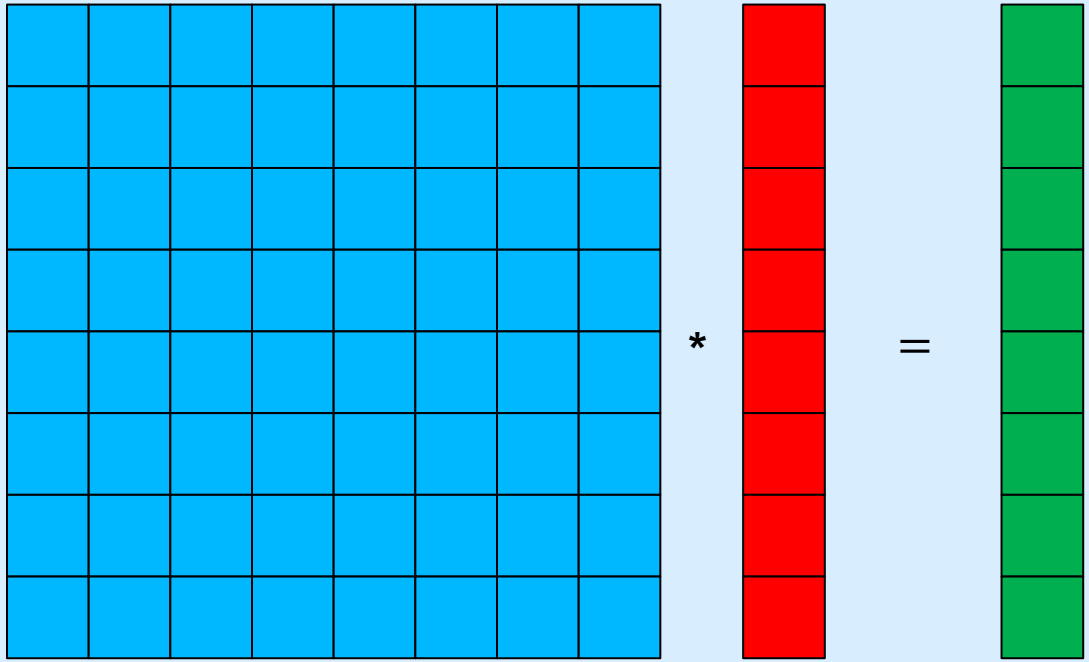
$$\frac{\partial^2 \phi(m)}{\partial m^2} = H(m)$$



EVEN FOR SIMPLE 2D PROBLEM IT HAS:
$\approx 10^{9-12}$ elements

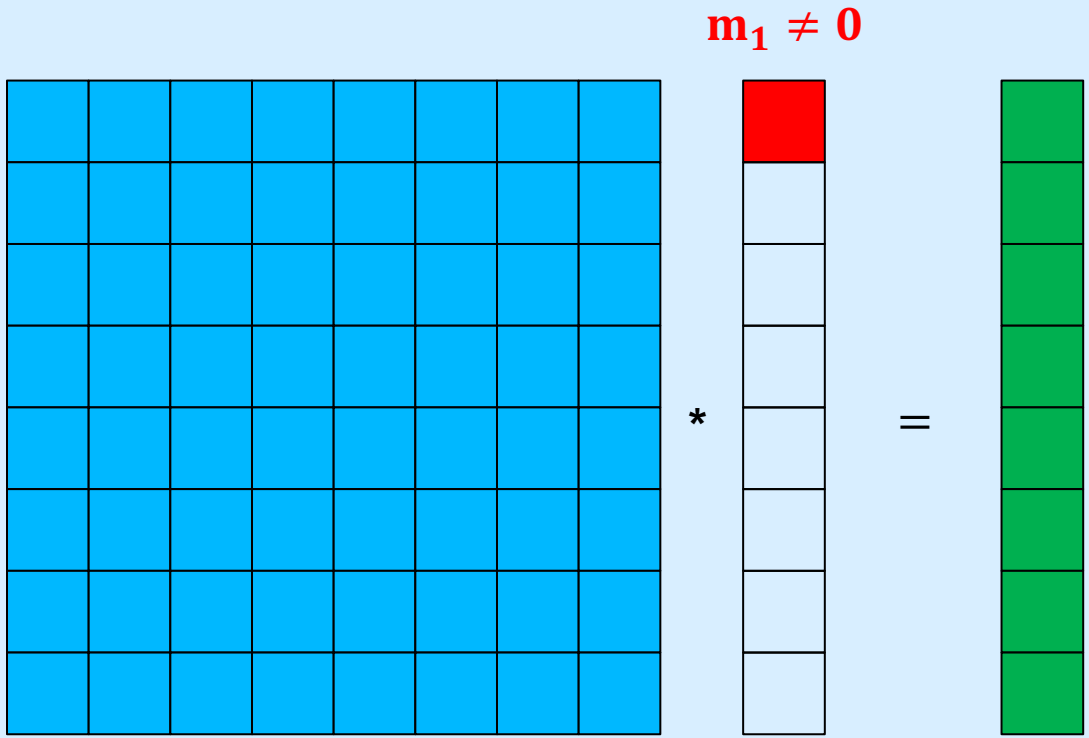
Elastic FWI: Hessian estimation

$$H(m)\mathbf{m} = \tilde{m}$$



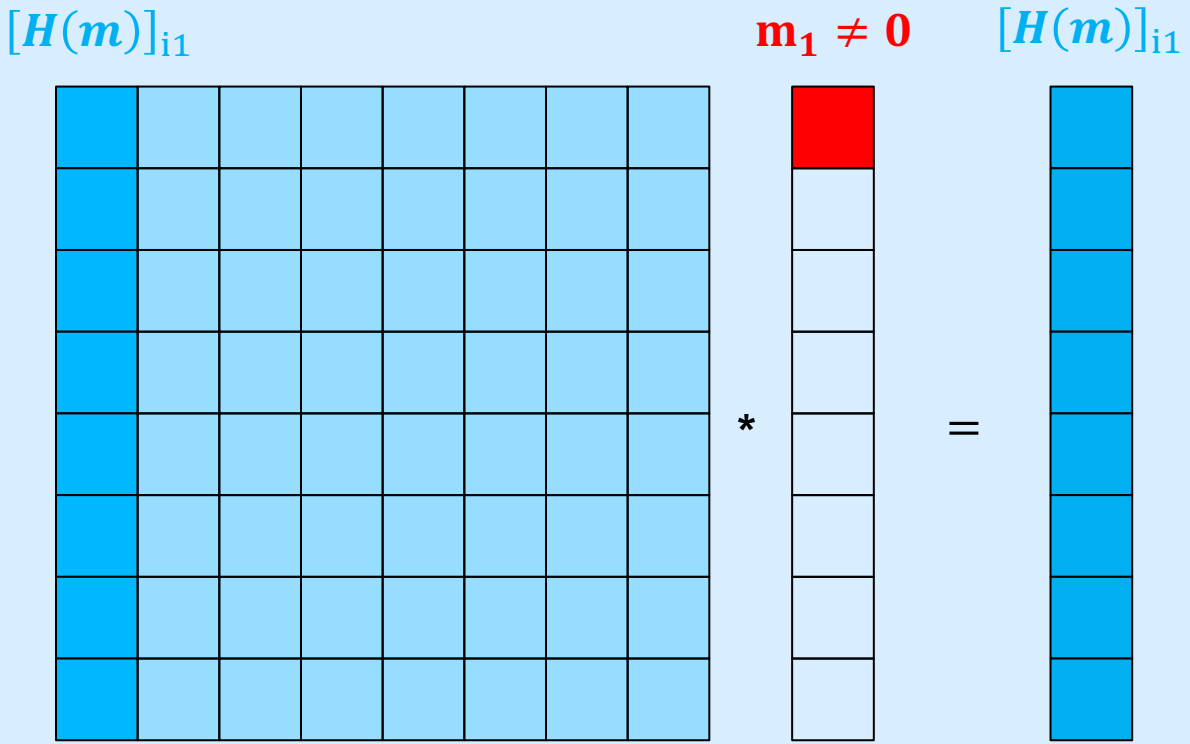
Elastic FWI: Hessian estimation

$$H(m)\mathbf{m} = \tilde{m}$$



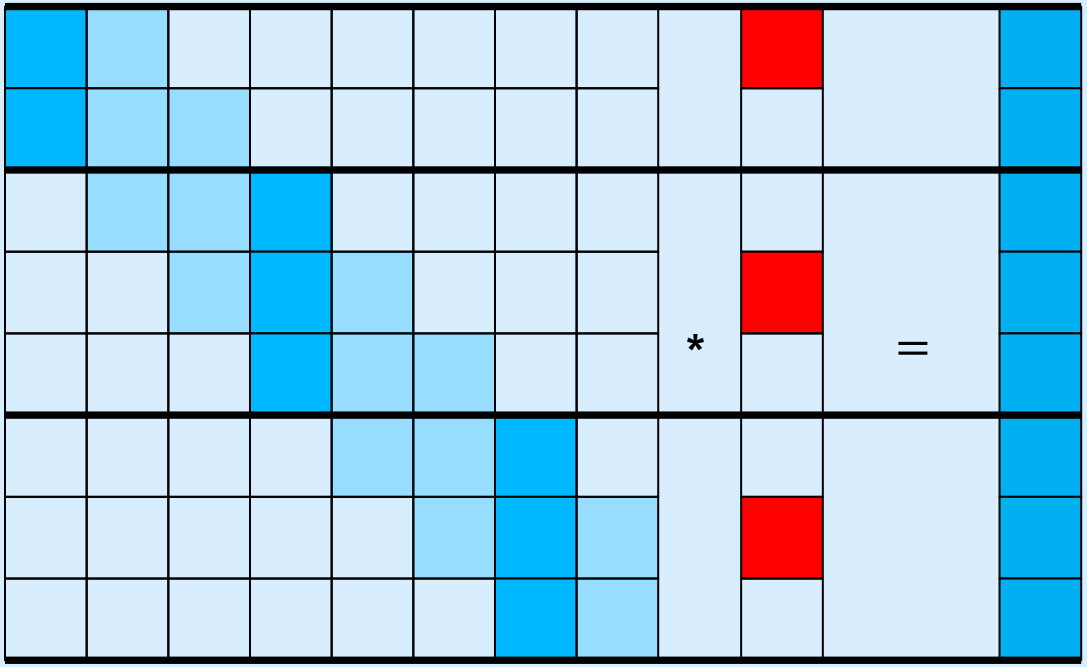
Elastic FWI: Hessian estimation

$$H(m)\mathbf{m} = [H(m)]_{i1}$$

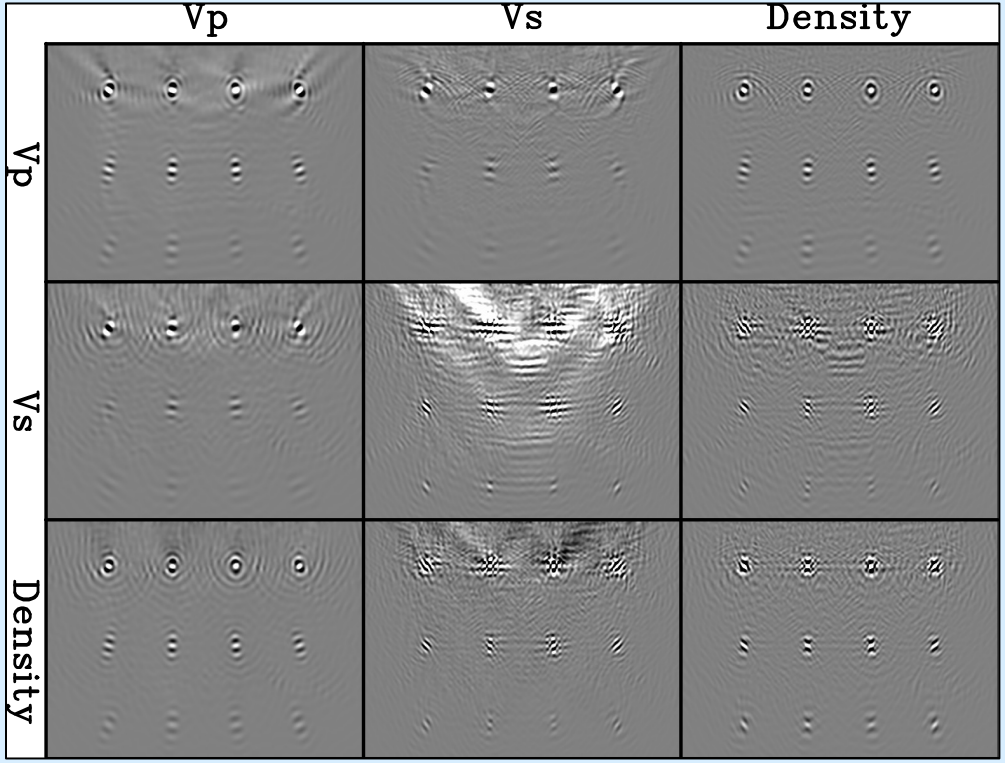


Elastic FWI: Hessian estimation

$$H(m)\mathbf{m} = \tilde{m}$$



Application of the Hessian for element estimation

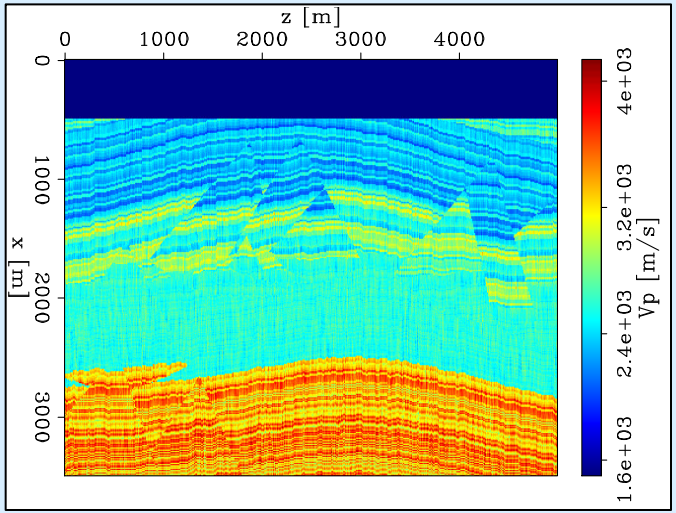


(Tang, 2015)

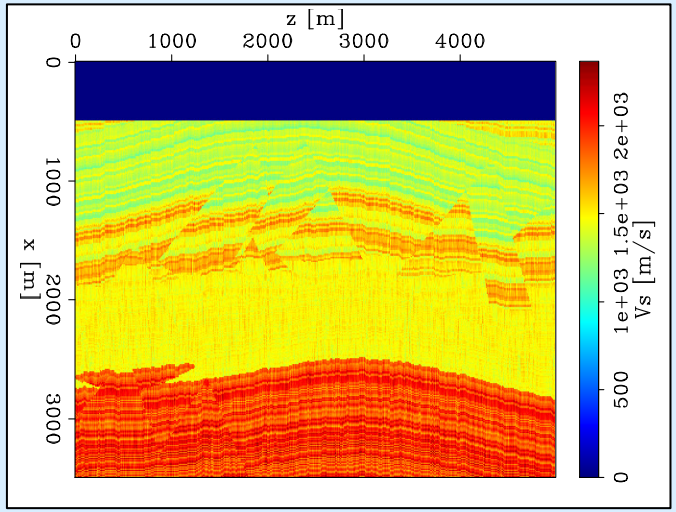
Elastic FWI: synthetic test

Elastic Full Waveform Inversion with multi-component data

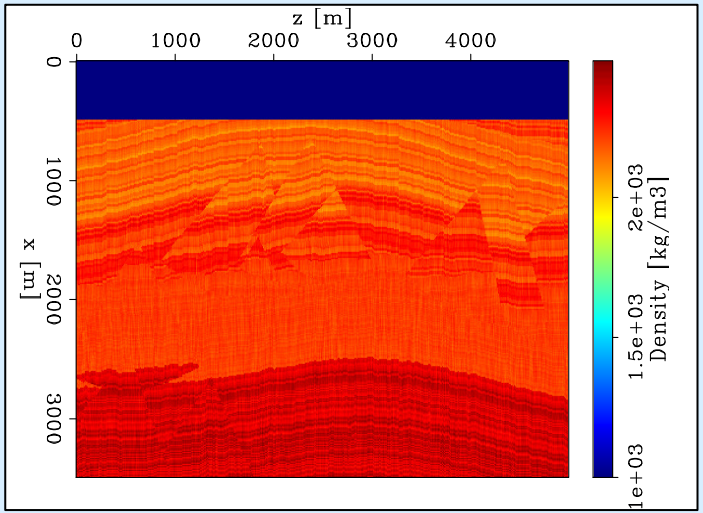
- **50 shots with 500 multi-component receivers**



Vp



Vs

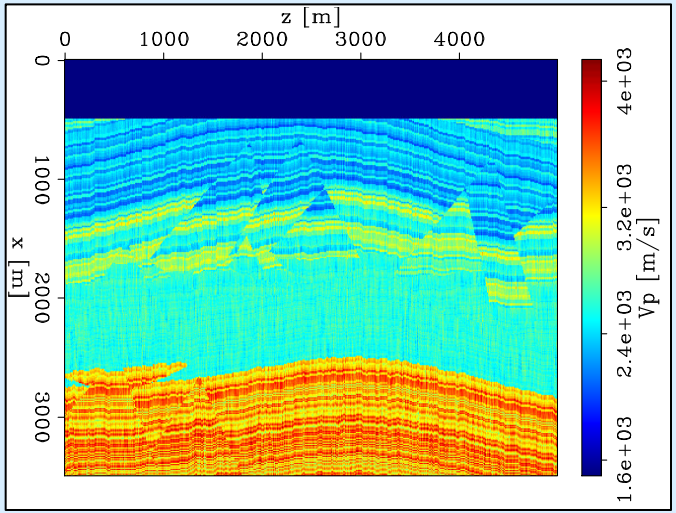


Density

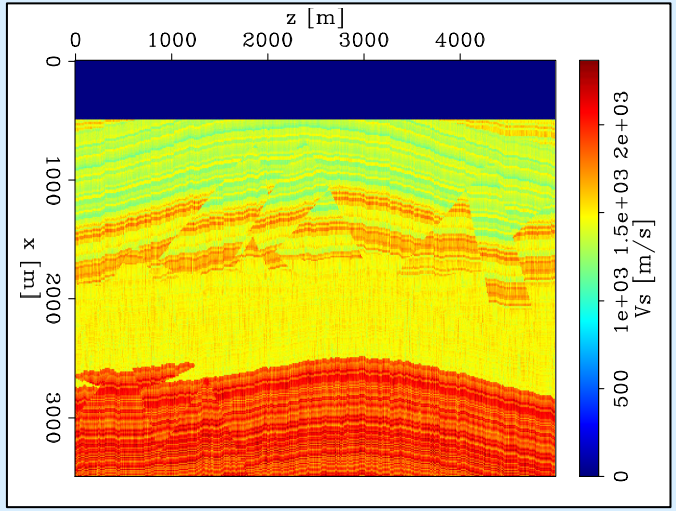
(Clapp, 2014)

Elastic Full Waveform Inversion with multi-component data

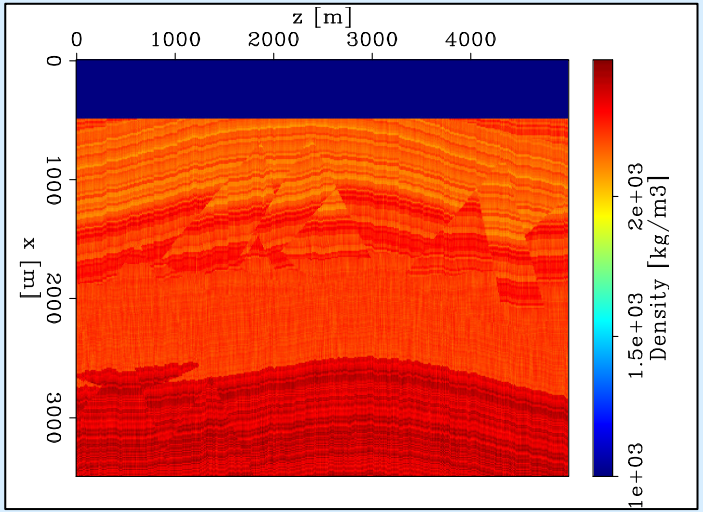
- 50 shots with 500 multi-component receivers
- Multi-scale approach (4 bands: up to 5/10/15/20 Hz)



Vp



Vs



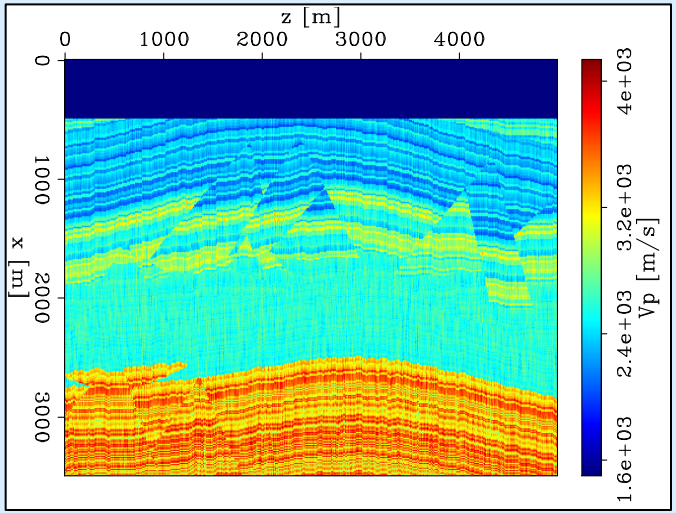
Density

(Clapp, 2014)

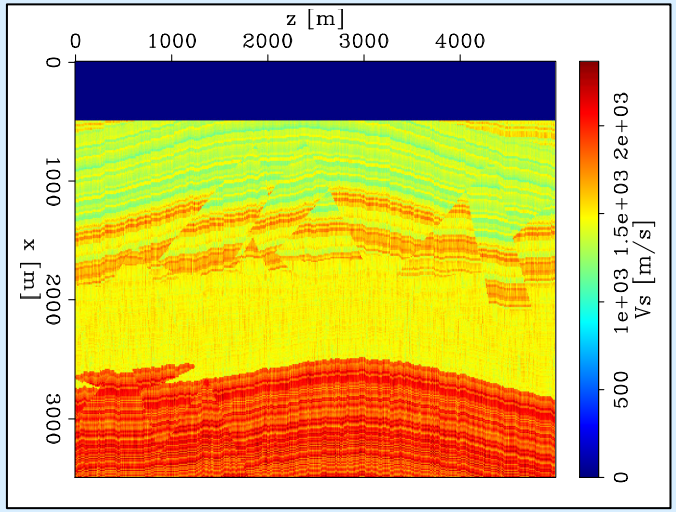
Elastic FWI: synthetic test

Elastic Full Waveform Inversion with multi-component data

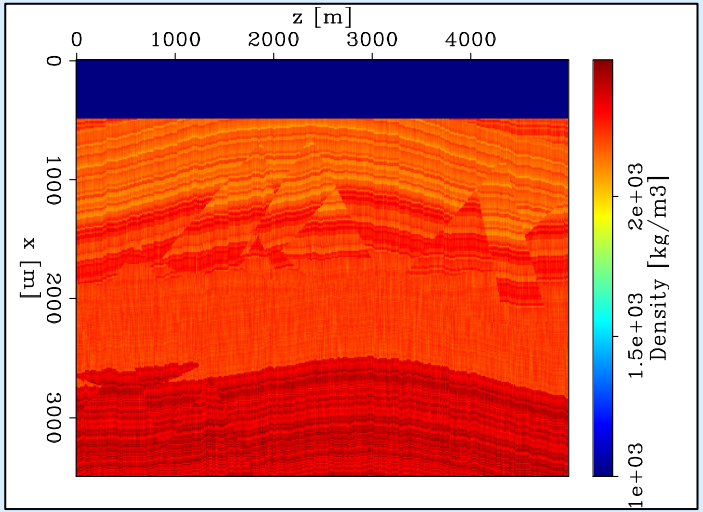
- 50 shots with 500 multi-component receivers
- Multi-scale approach (4 bands: up to 5/10/15/20 Hz)
- 40 iterations for each band



Vp



Vs

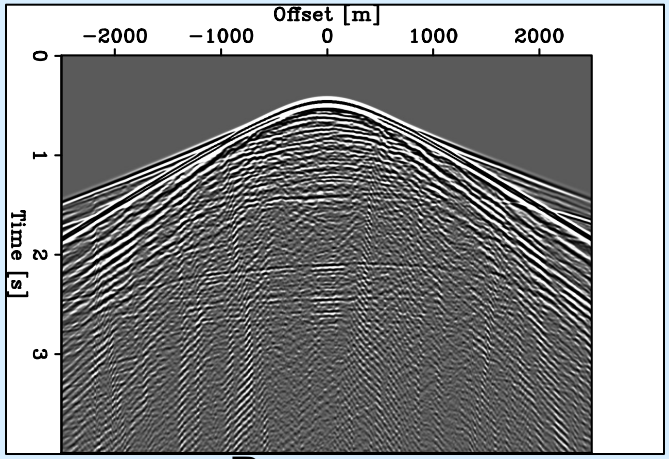


Density

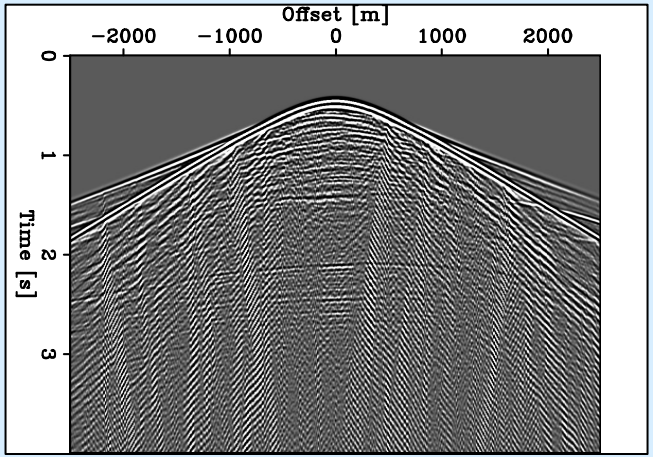
(Clapp, 2014)

Elastic FWI: synthetic test

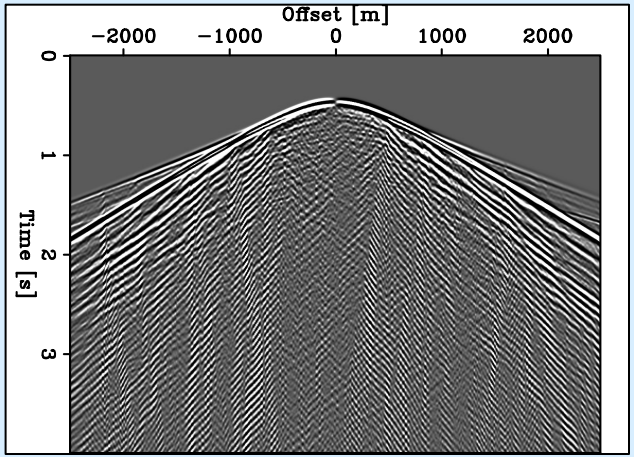
Recorded multi-component data for central shot



Pressure



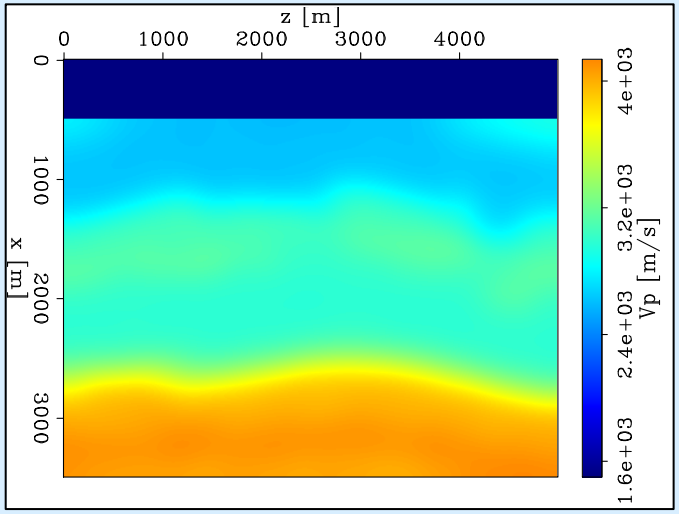
v_z



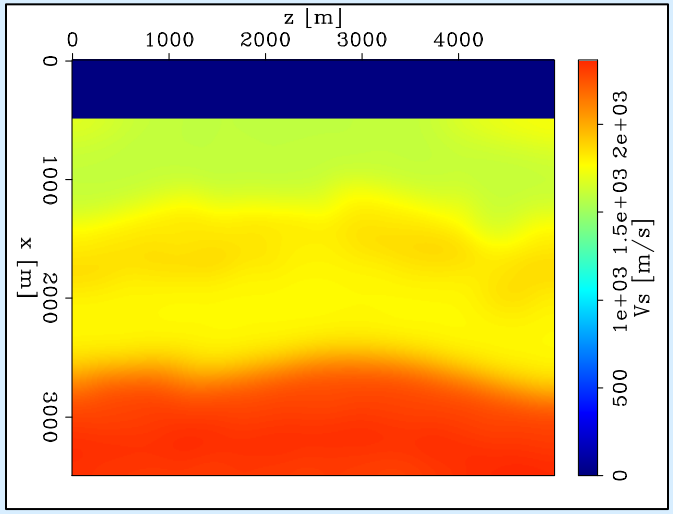
v_x

Elastic FWI: synthetic test

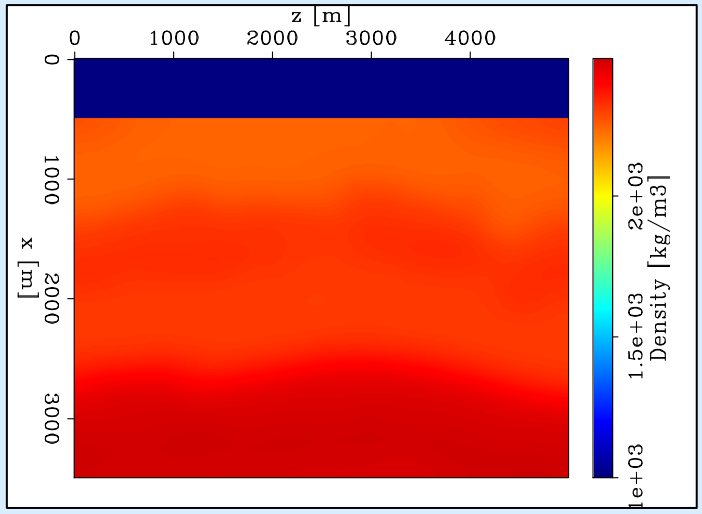
Starting subsurface model



Vp



Vs

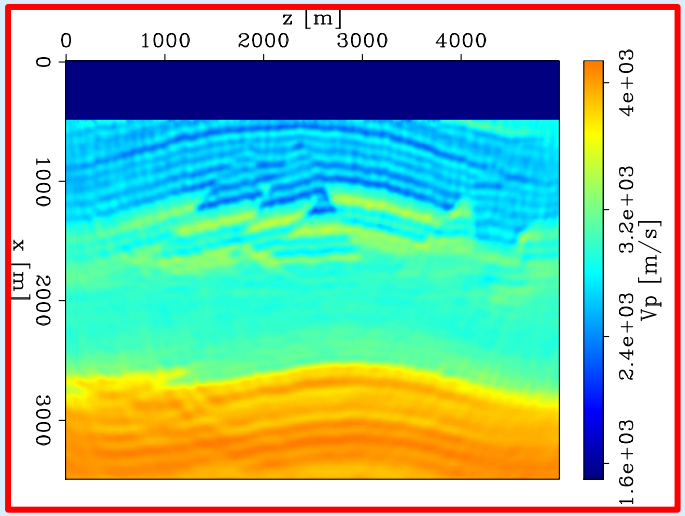


Density

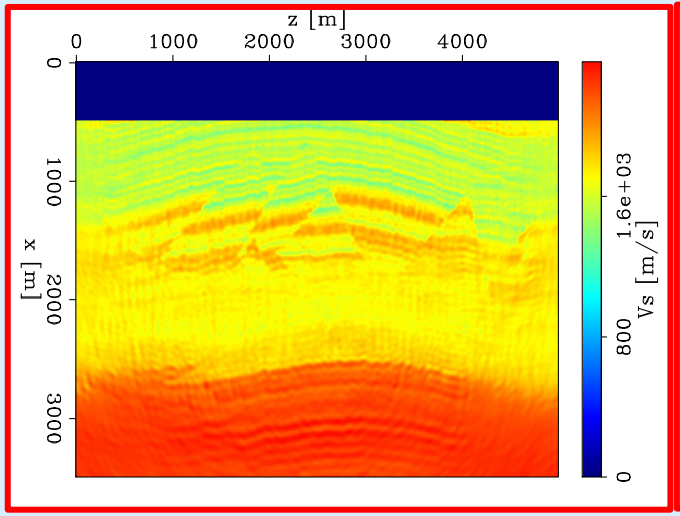
Elastic FWI: synthetic test

40 iterations for 4 bands (5/10/15/20)

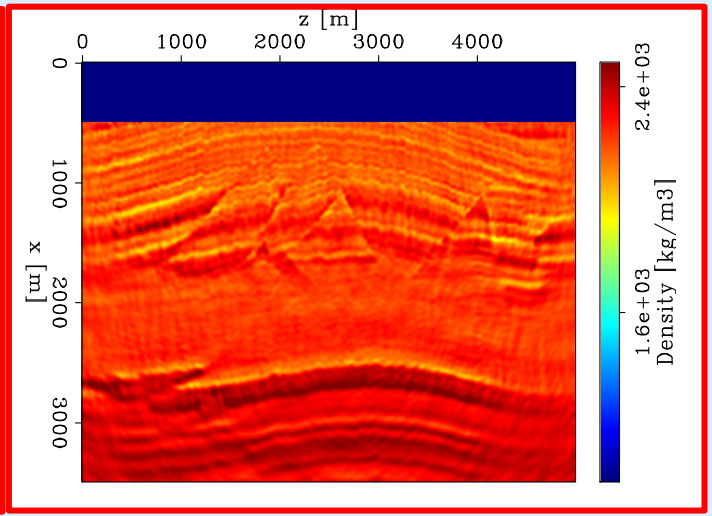
Inverted model without preconditioning



Vp



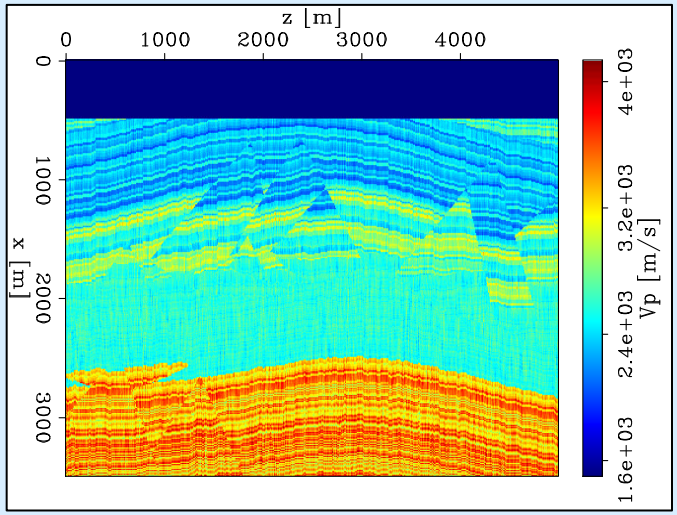
Vs



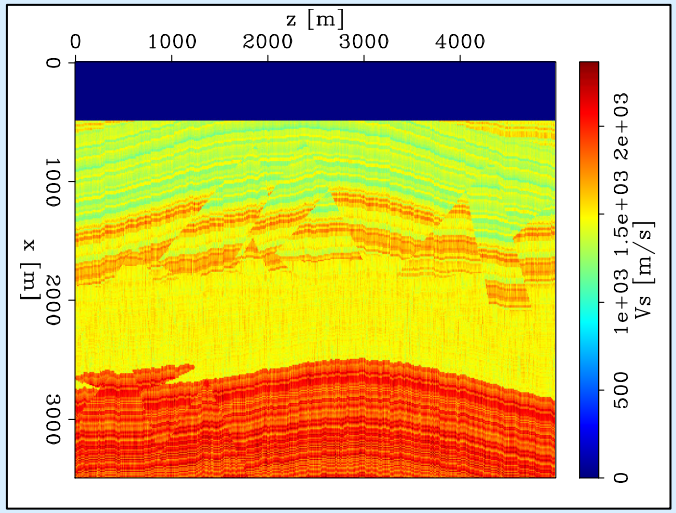
Density

Elastic FWI: synthetic test

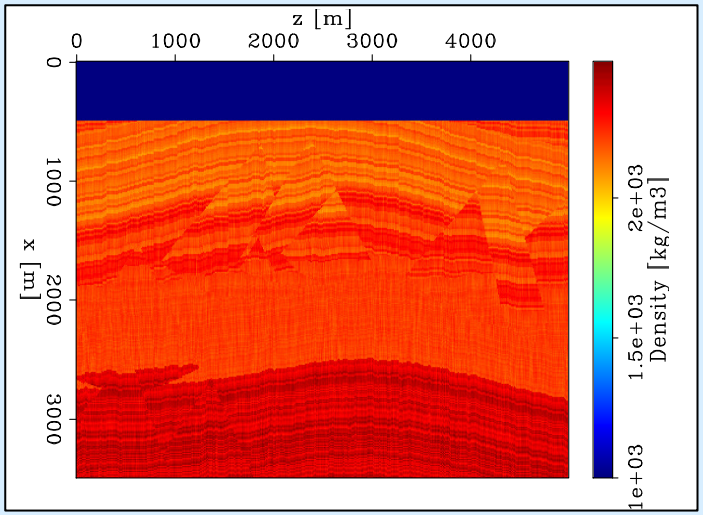
True subsurface model



Vp



Vs

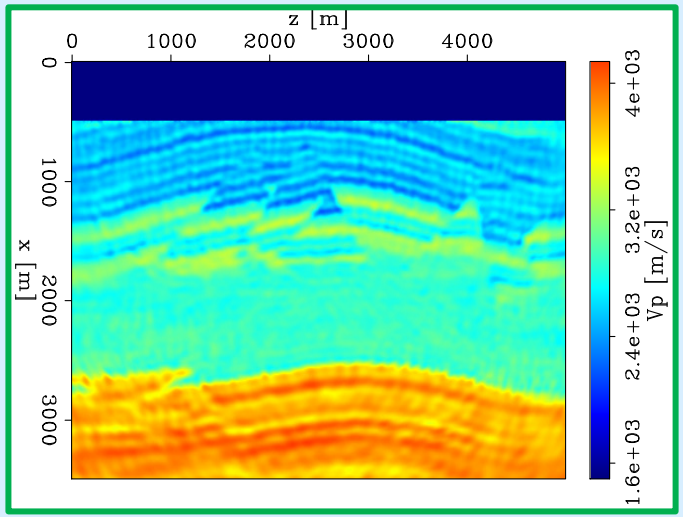


Density

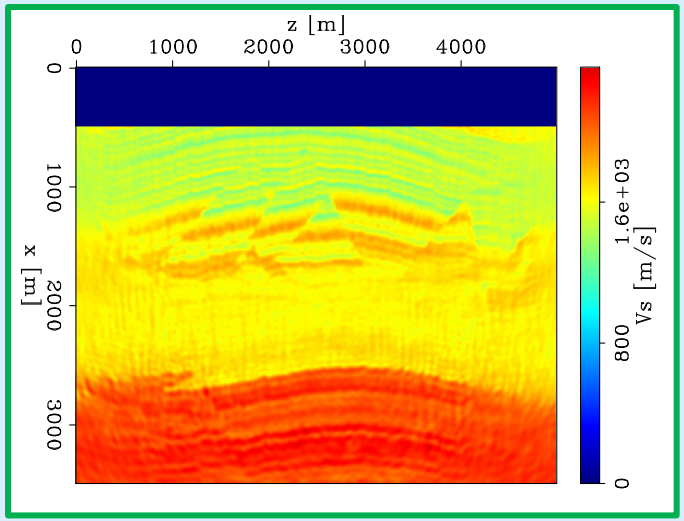
Elastic FWI: synthetic test

40 iterations for 4 bands (5/10/15/20)

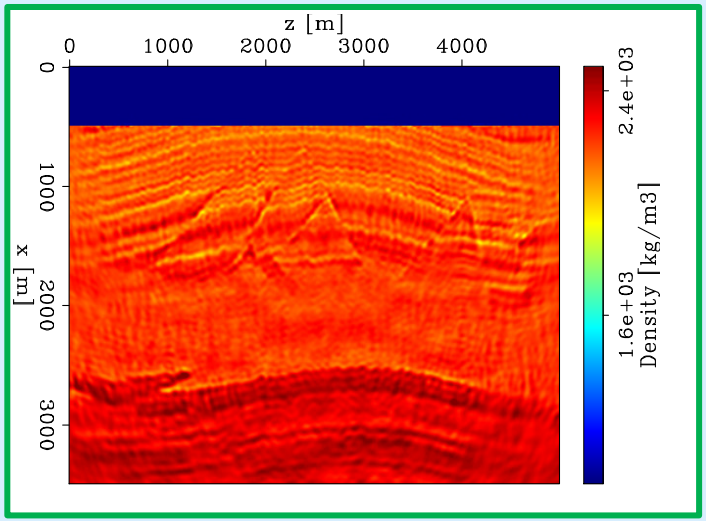
Inverted model with preconditioning



Vp



Vs

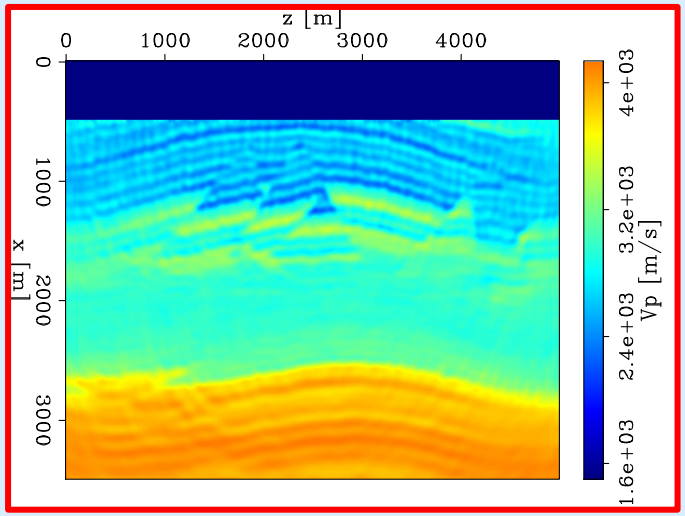


Density

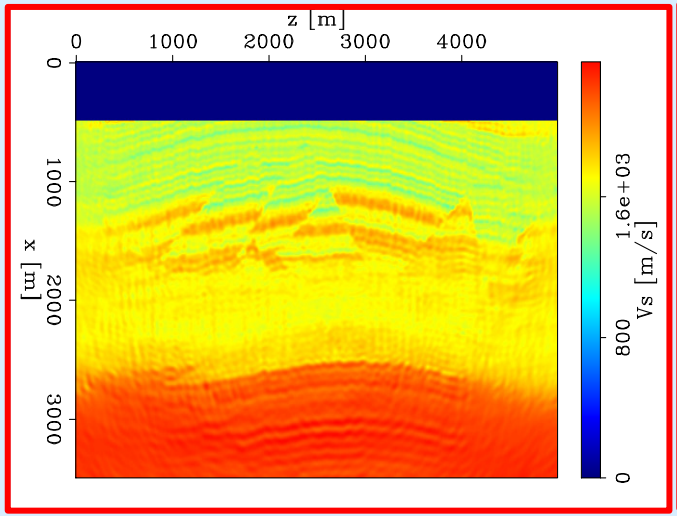
Elastic FWI: synthetic test

40 iterations for 4 bands (5/10/15/20)

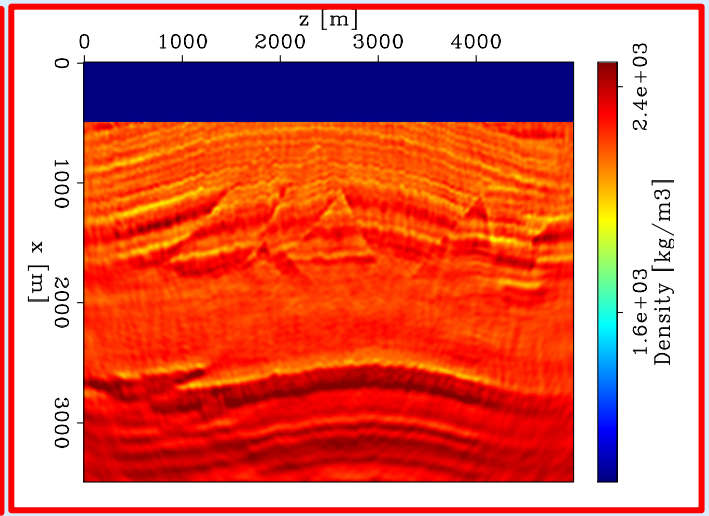
Inverted model without preconditioning



Vp

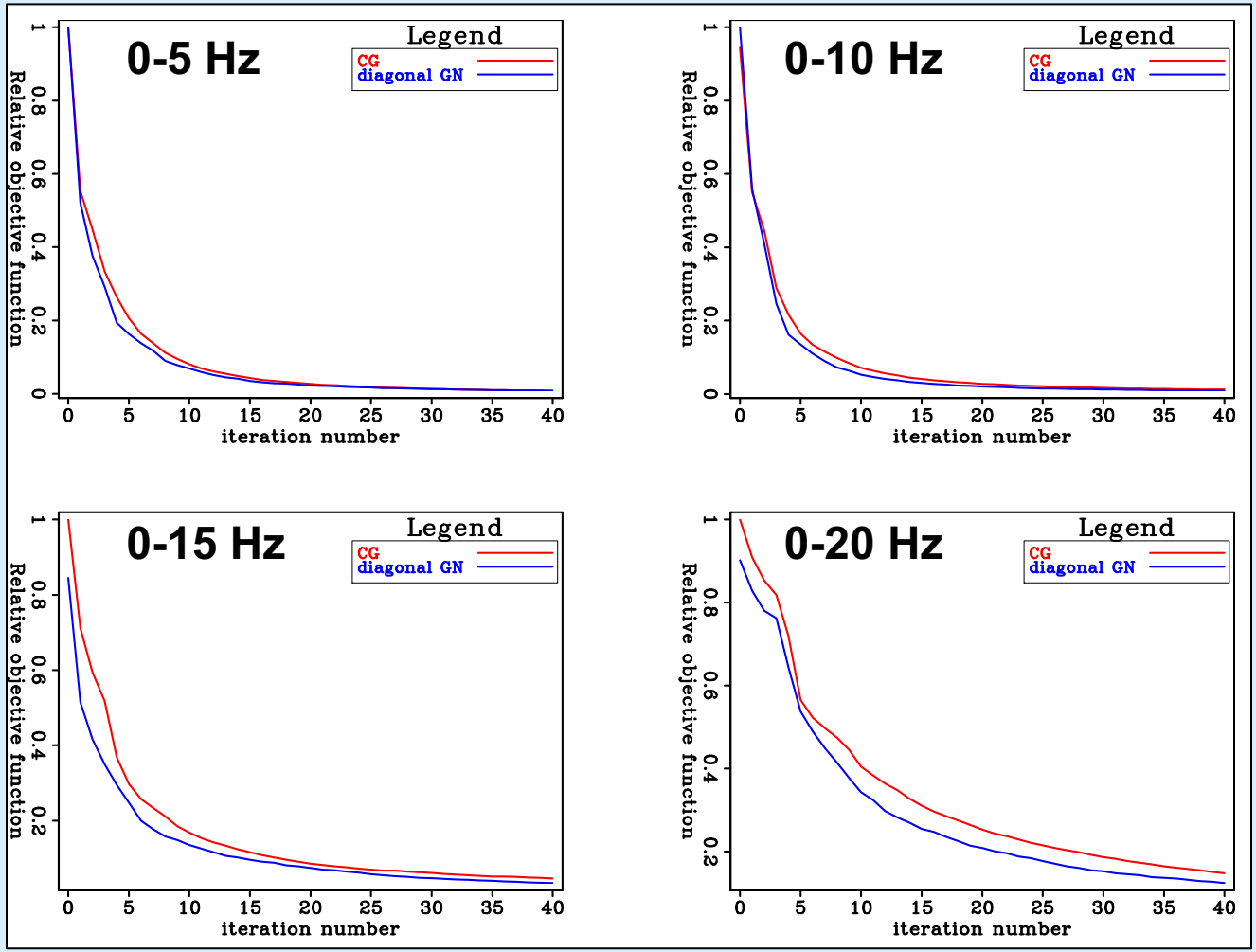


Vs



Density

Elastic FWI: synthetic test



Conclusions

1. Conventional AVO modeling/inversion fails for complex interface

2. Elastic full waveform inversion solves for all the frequencies in the data but is affected by parameter cross-talk

3. A simple diagonal approximation already reduces cross-talk in the FWI results for a complex subsurface model

STANFORD UNVERSITY

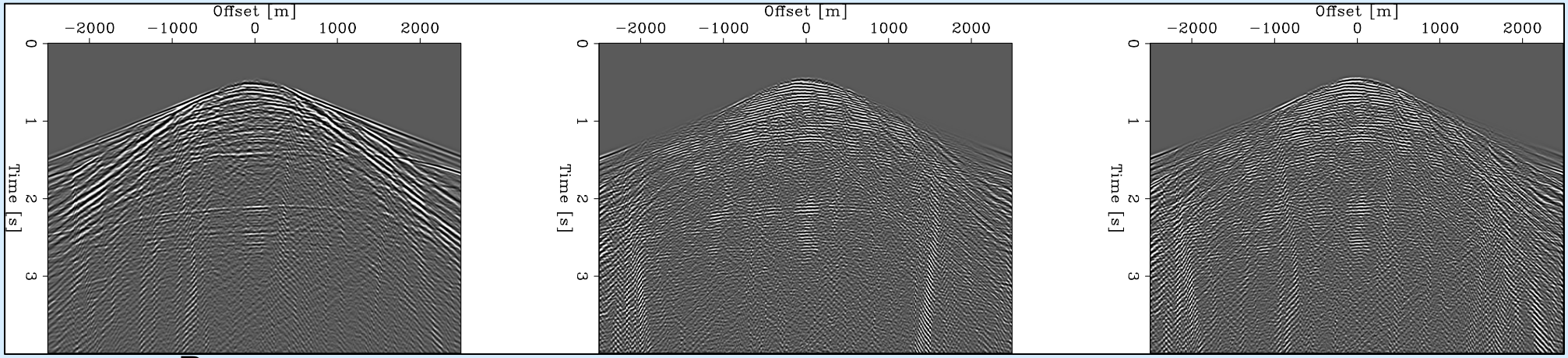
SEP meeting 2017

Thank you for your attention
Questions?

18th April 2017

Elastic FWI: synthetic test

Residuals comparison after inversion



Pressure (Starting model)

Pressure (No preconditioning)

Pressure (Preconditioned)