Seismic reflector Characterization

SLIM
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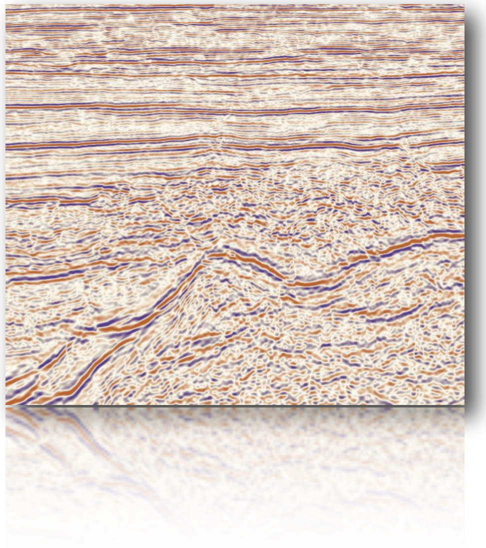


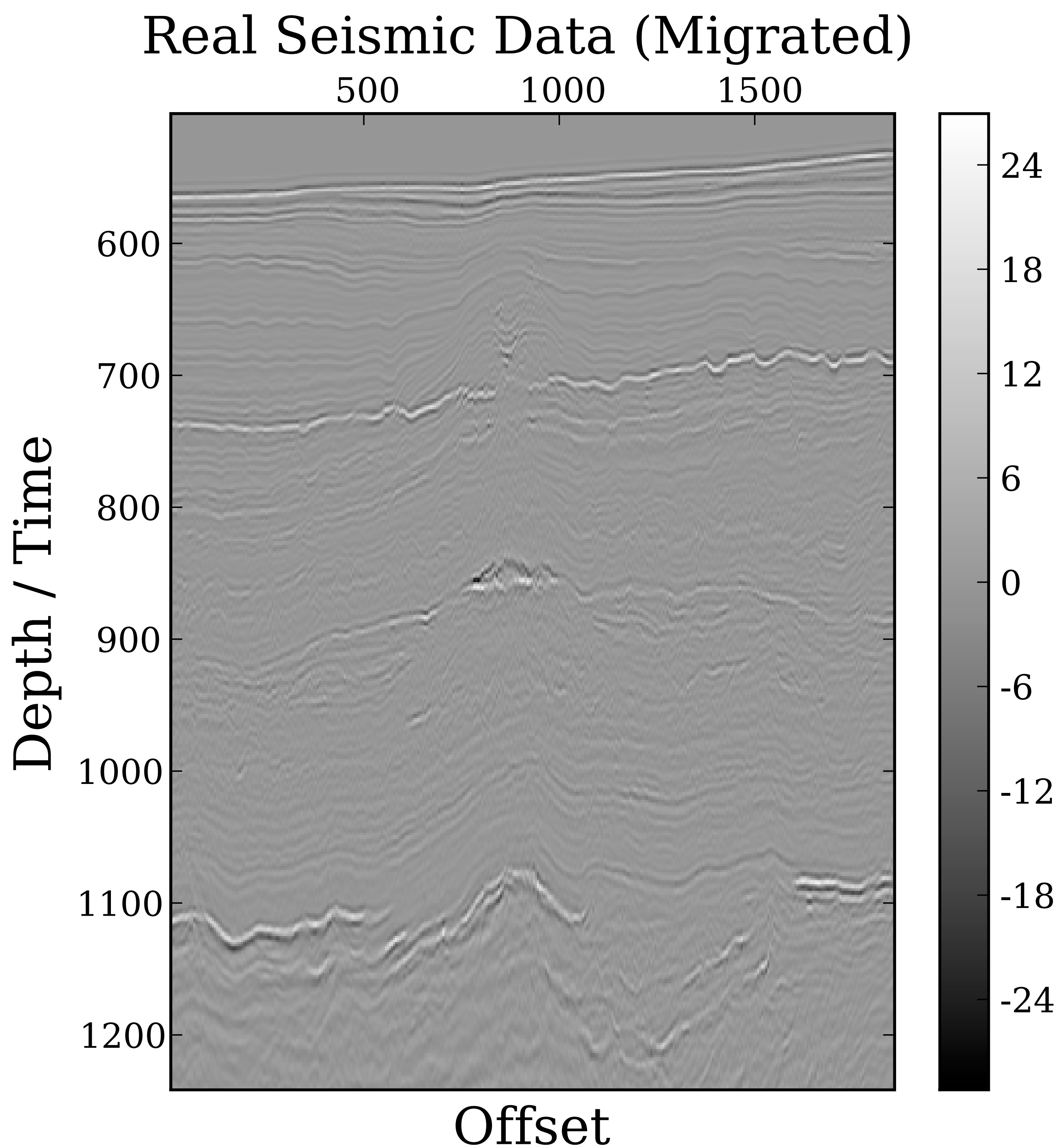
SINBAD Sponsor Meeting
London June 15, 2007

Outline

- Introduction & Background
- Overview of available methods & motivation
  - Spiky deconvolution
  - Conventional singularity estimation based on WT
- Multi-scale detection-estimation method
  - Detection with Complex CWT (Multi-scale edge detection)
  - Parametric inversion for singularity estimation
- Recent Results
- Future work

Characterization at a glance

- extract seismic attributes to link the data to lithology



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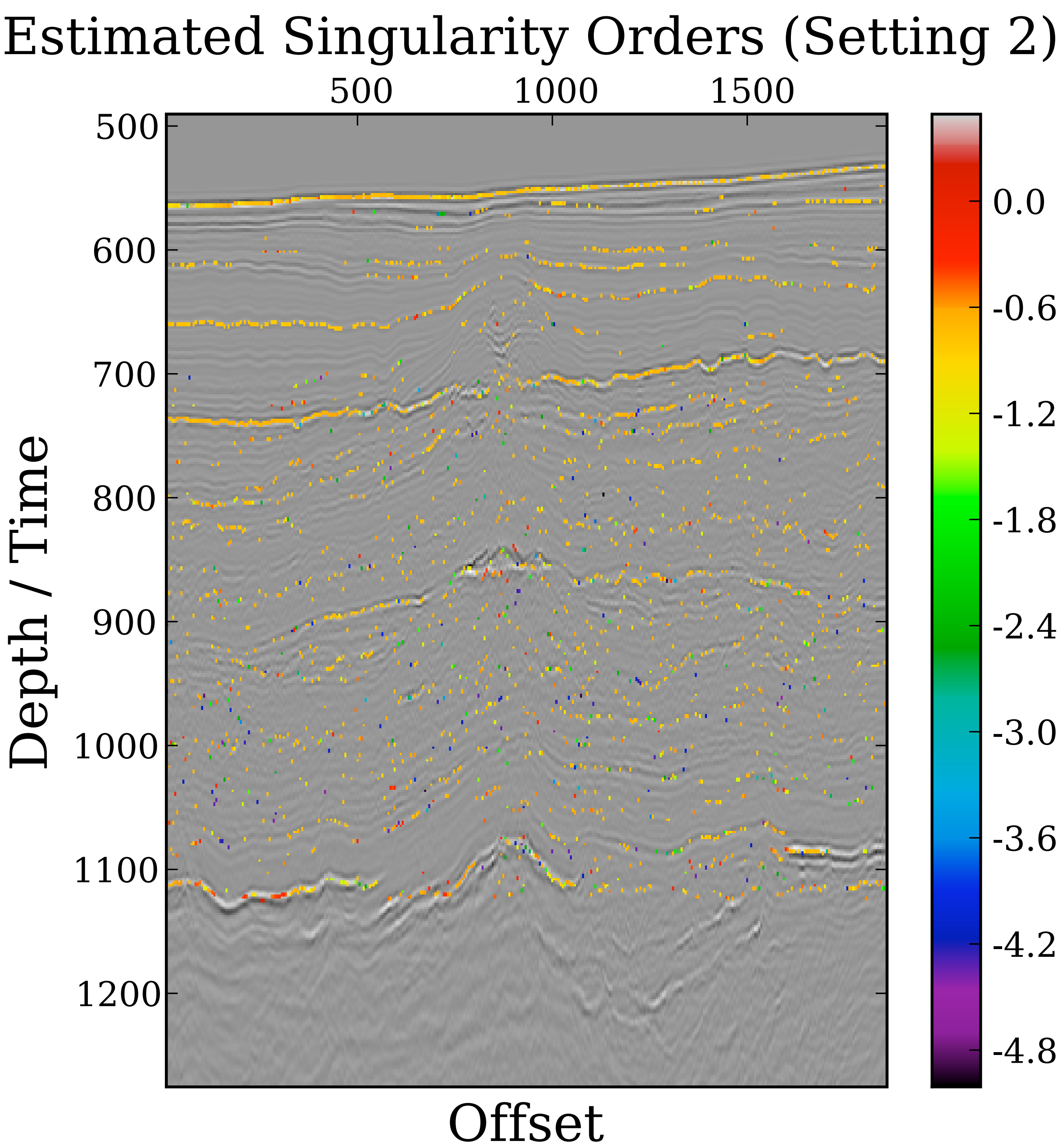
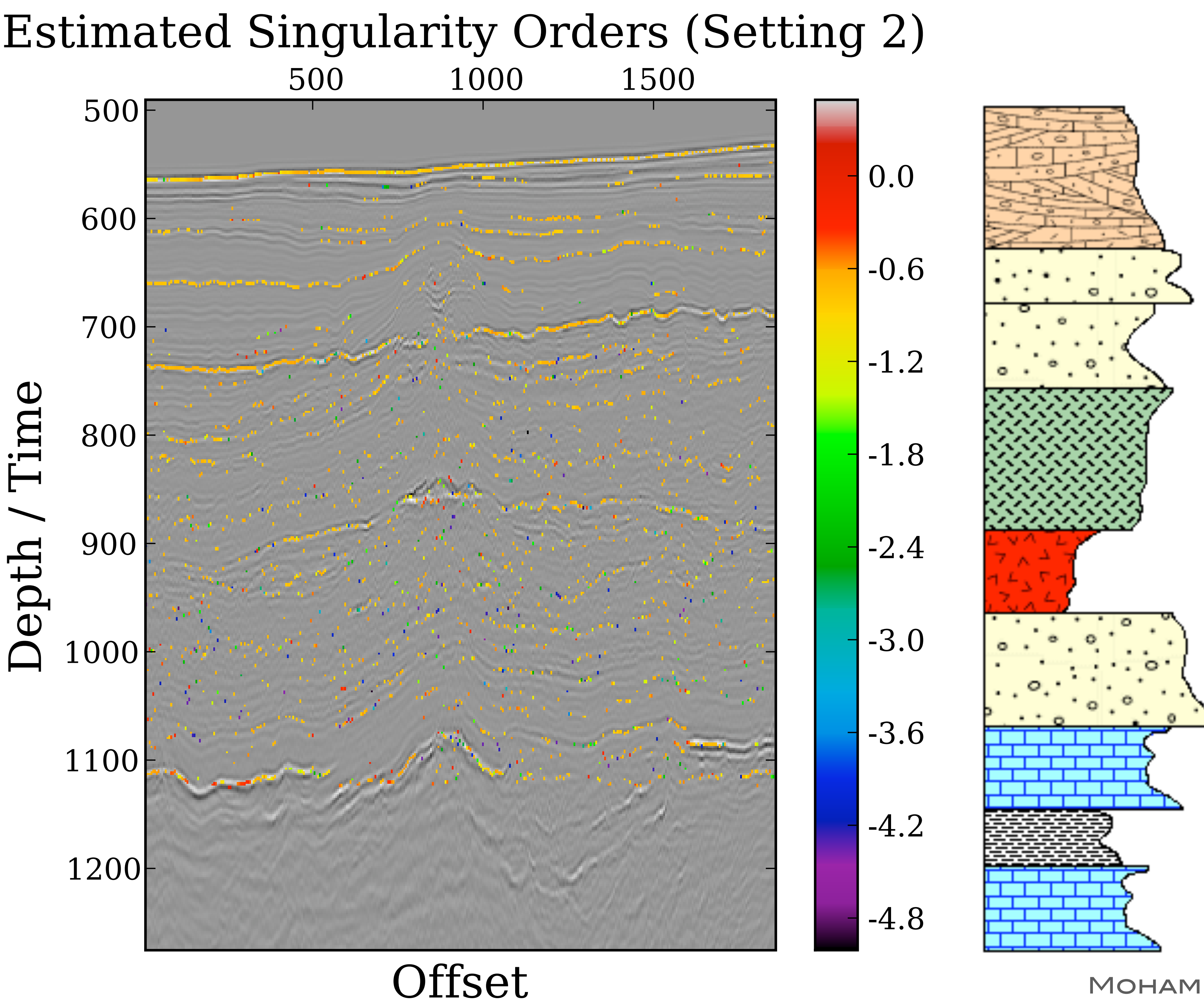
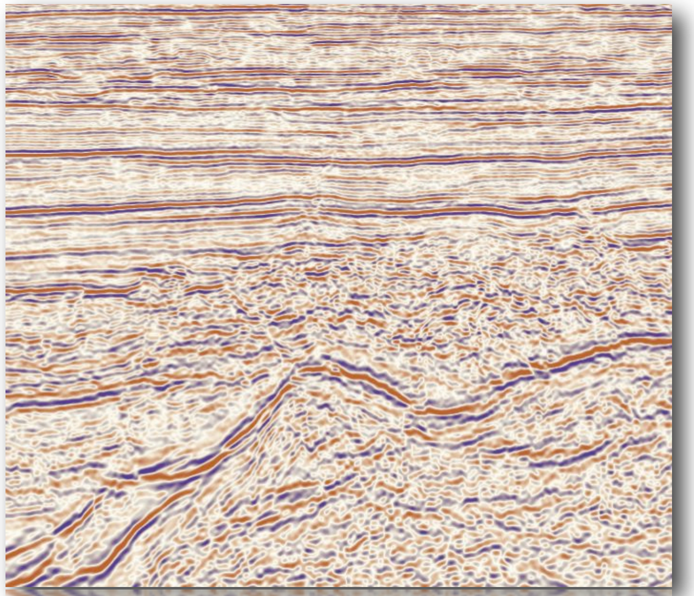


Characterization at a glance

- extract seismic attributes to link the data to lithology



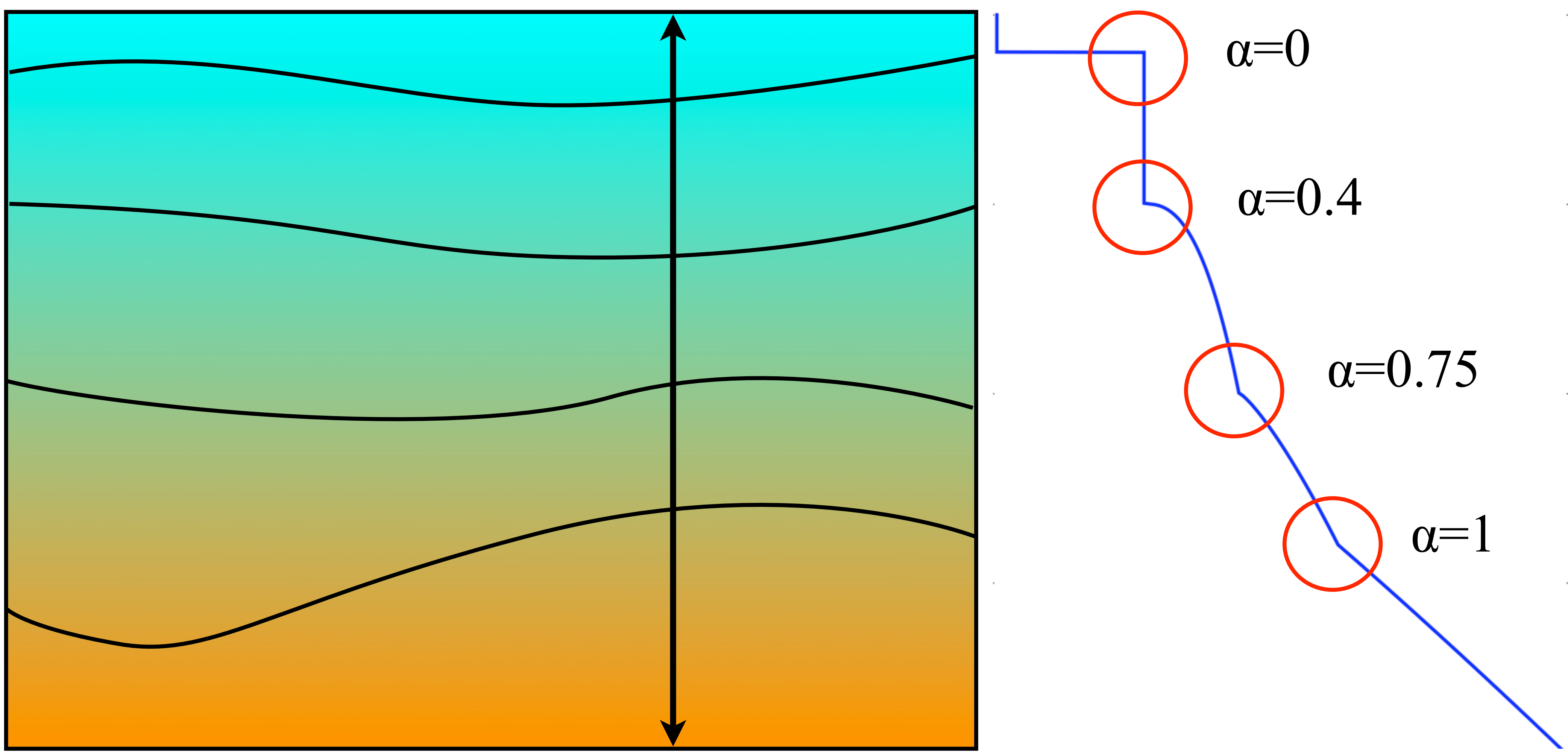
Introduction



Why Zero-Order ?

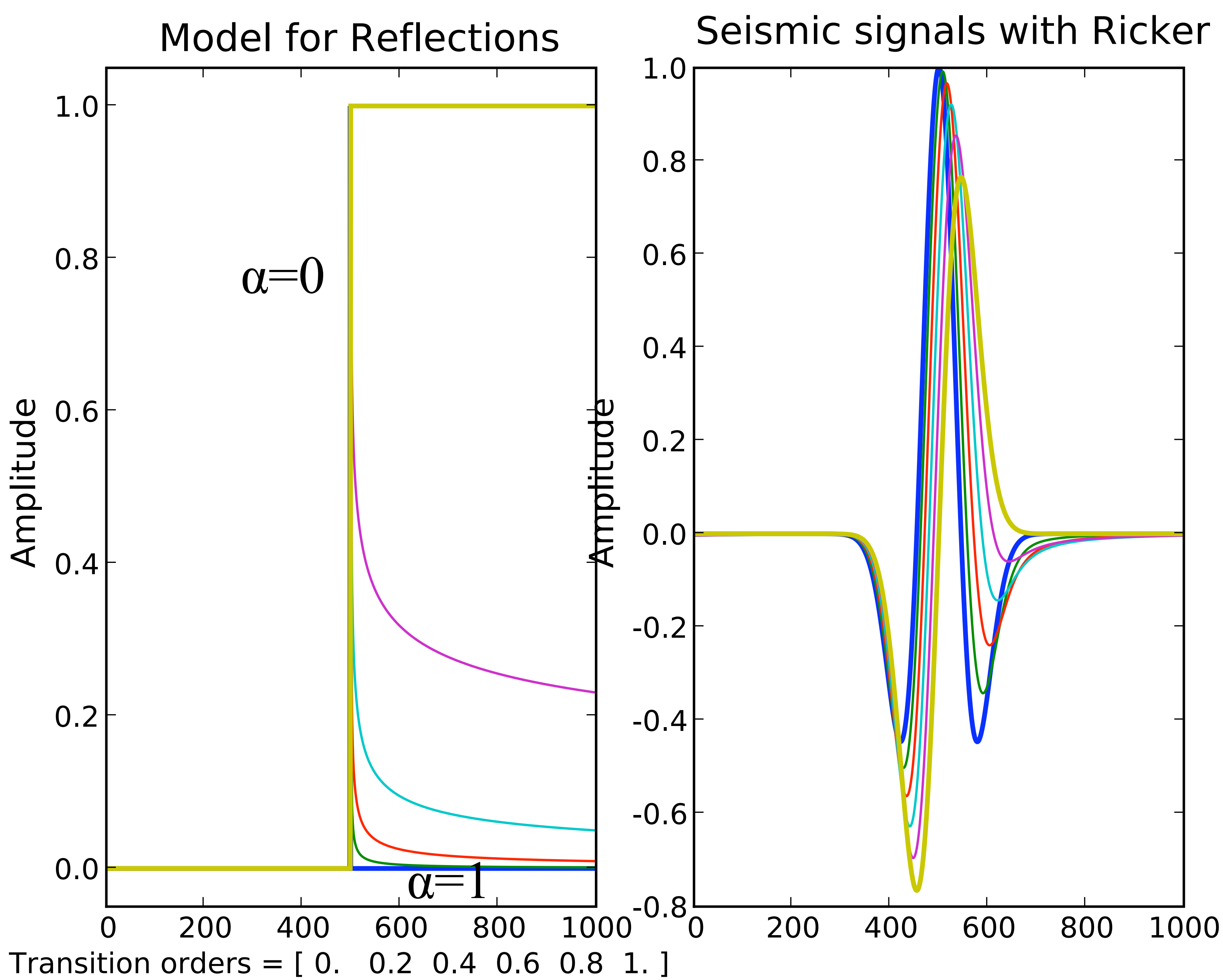
- Typical assumption: Zero-order discontinuities (step functions)
- In real world: Fraction-order singularities (singularities)
  - Transition between two lithological layers in the subsurface can have any fractional-order discontinuity, that can be obtained by fractionally differentiating/integrating a zero-order discontinuity.

Layered Model of Earth with different singularity orders (α)



Forward model

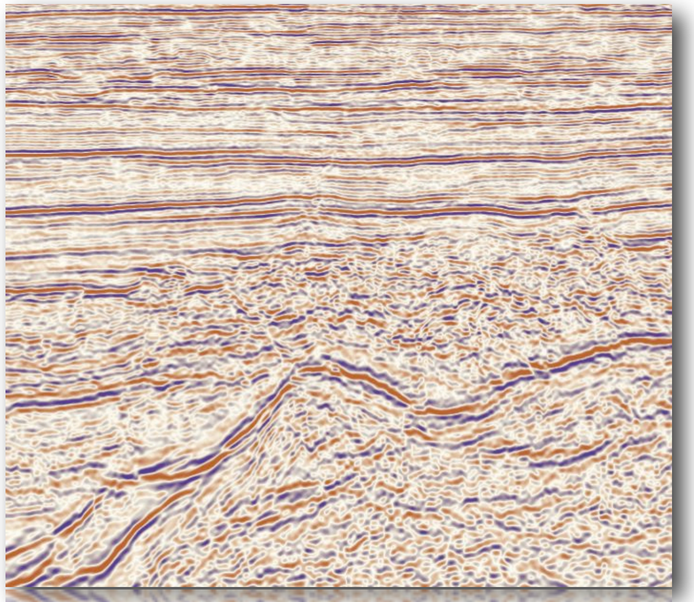
- Assume a vertical 1-D profile of the earth as a superposition of parametrized waveforms:



$$s(z) \propto (r * \psi_z)(z)$$

$$s(z) = \sum_j c_j D^{\alpha_j} \psi(z - z_j)$$

Previous Methods



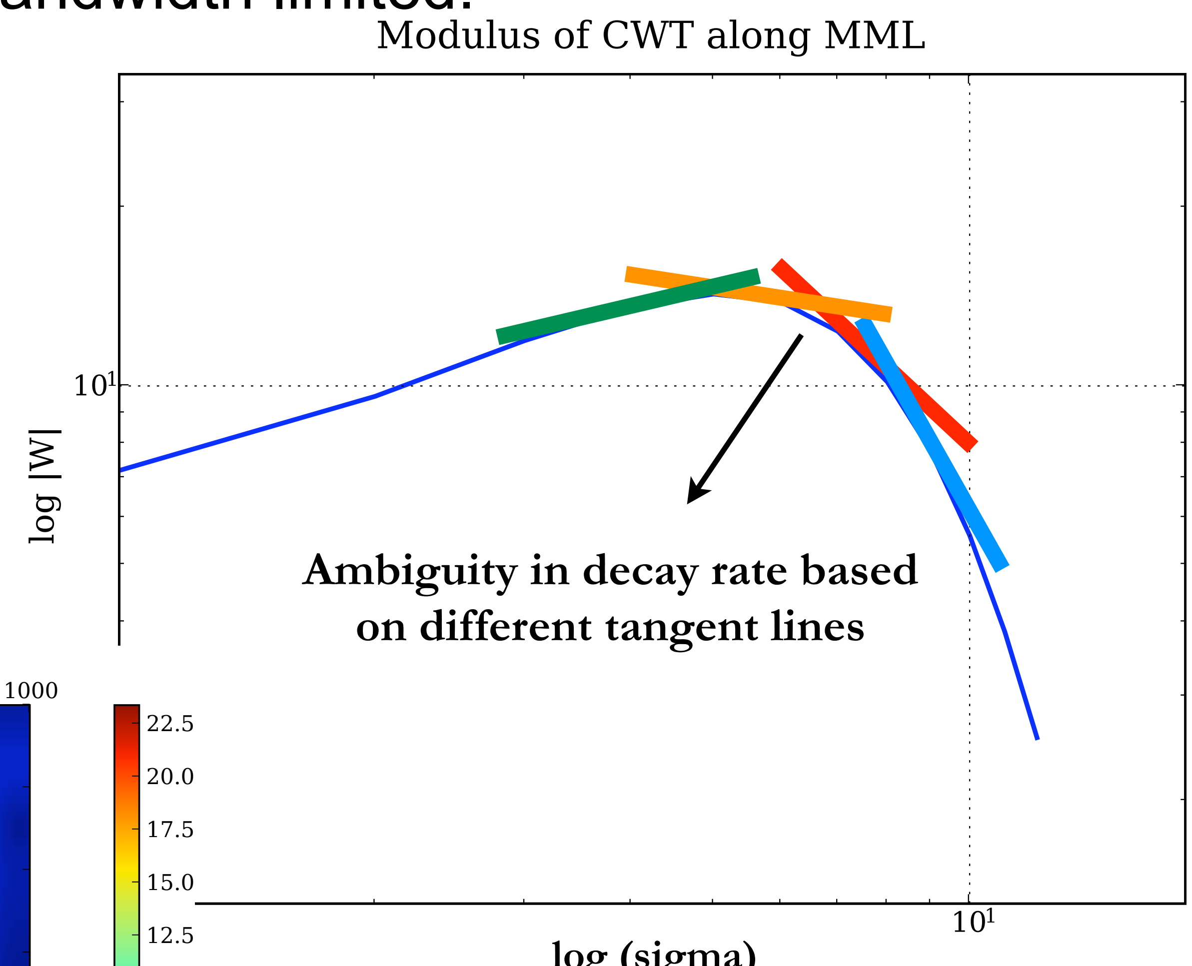
Conventional singularity estimation

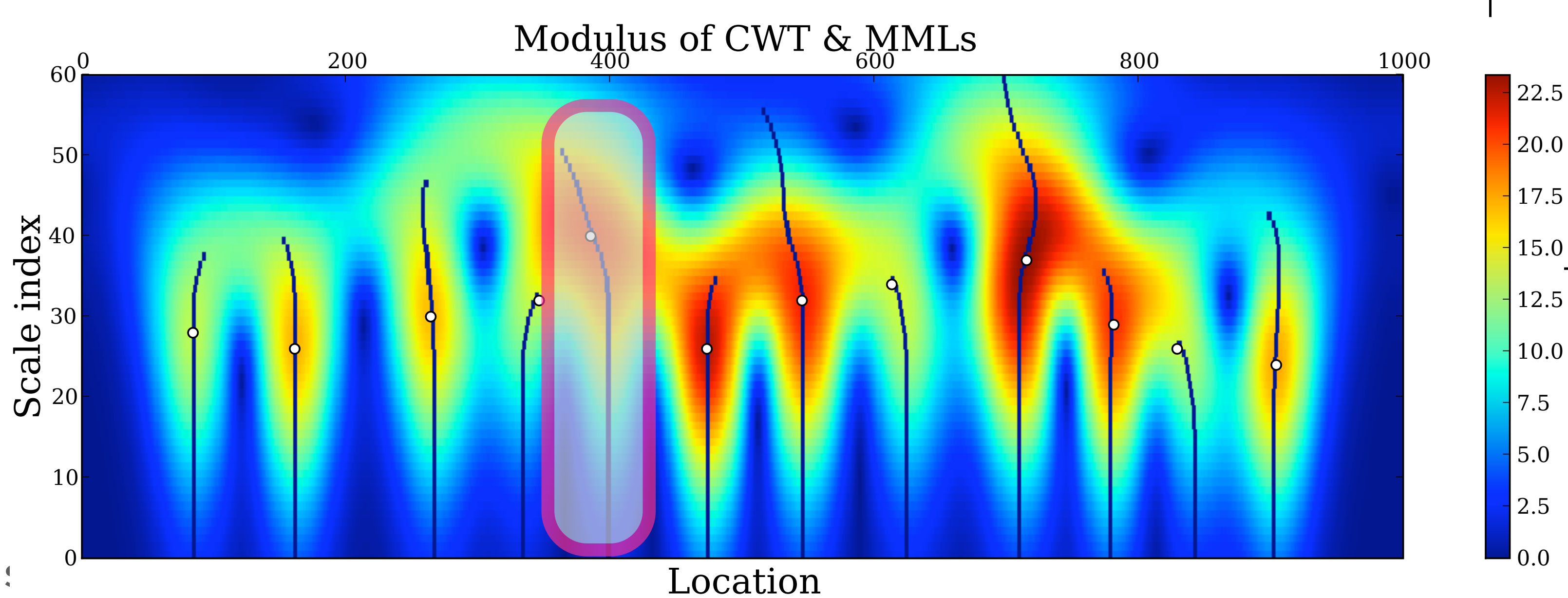
- based on estimating slope of the modulus of the wavelet coefficient [Herrmann 01,Liner et al. 04]

$$|W\{f,\psi\}(\sigma,x)| \sim \sigma^{\alpha} \quad as \quad \sigma \longrightarrow 0$$

- problematic because seismic data is bandwidth limited.
- estimation is difficult because
  - there is a scale cross-over
  - it is based on asymptotic argument
- therefore,this method leads

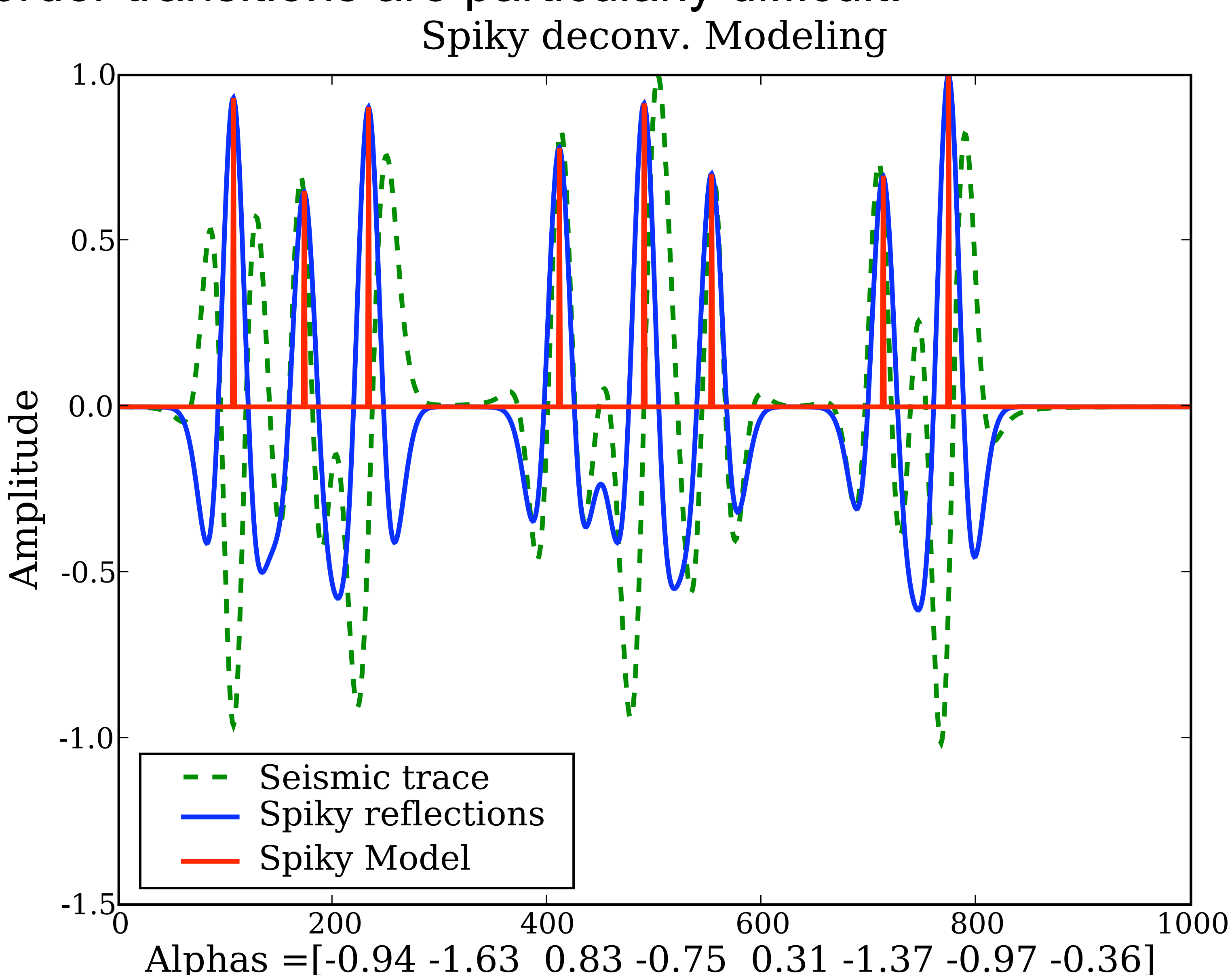
  to ambiguous results.



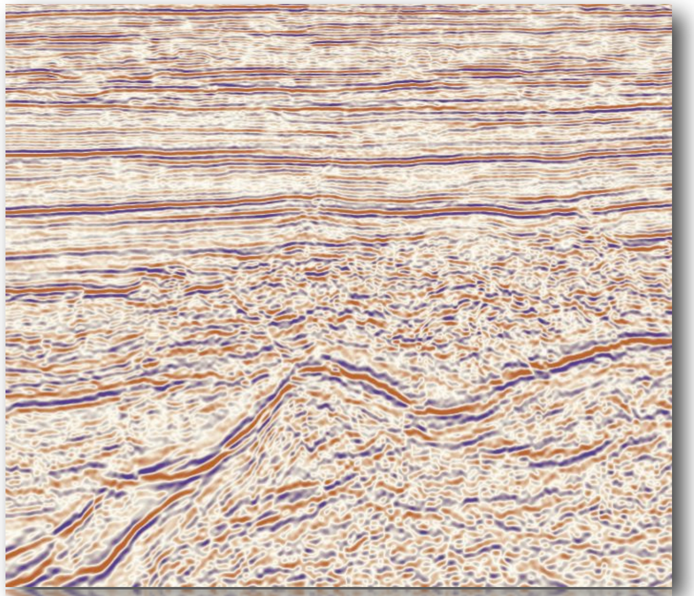


Spiky deconv.

- based on spikes and zero-order discontinuities in the impedance
- generalization to fractional-order transitions is not trivial.
- varying-order transitions are particularly difficult.

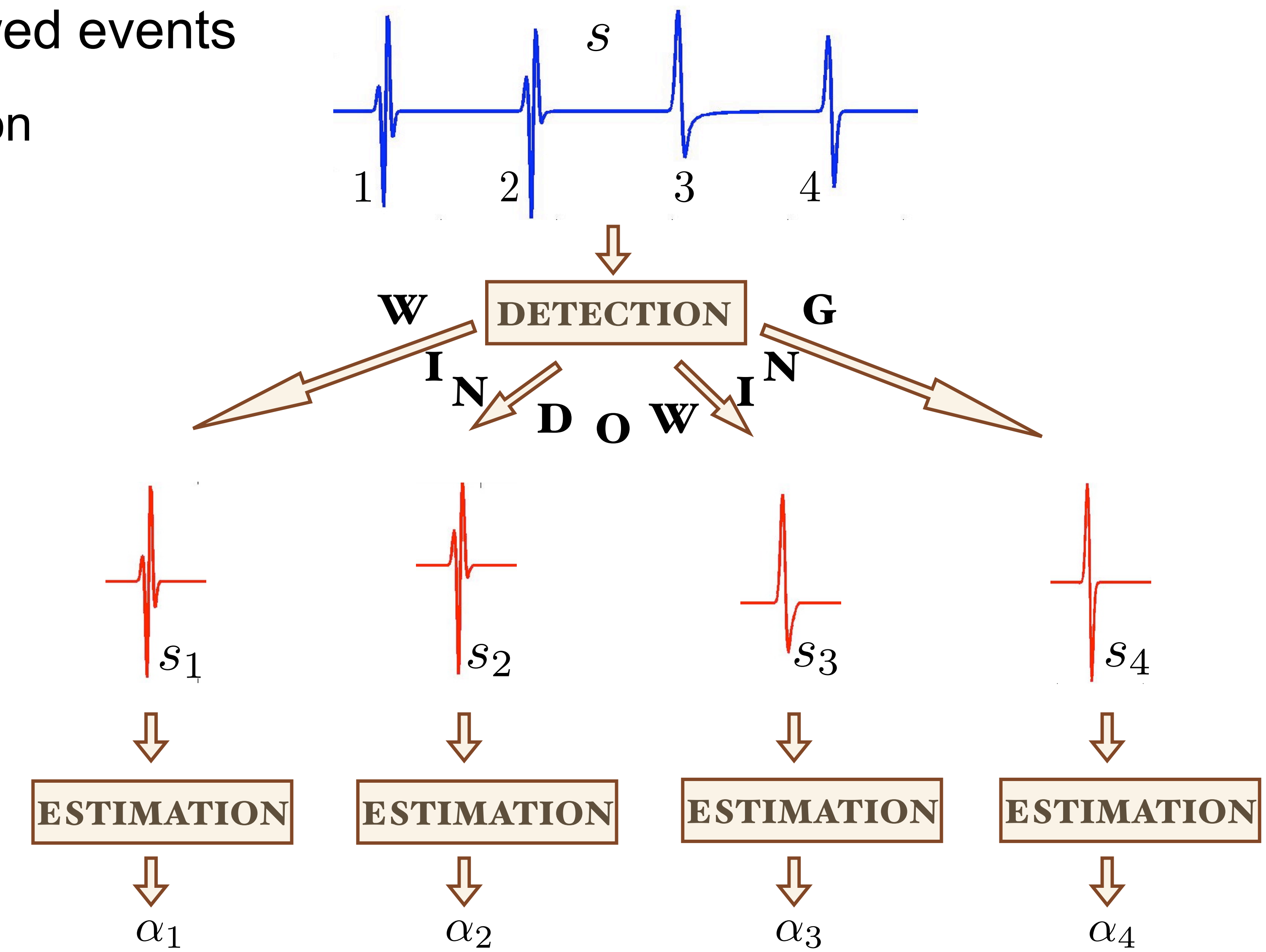


New characterization method



Multiscale detection-estimation method

- Detect the events
  - multiscale edge analysis with no assumption regarding the type of transitions
- Isolate the events
  - Windowing based on location & scale of events
- Estimate attributes of windowed events
  - Parametric nonlinear inversion

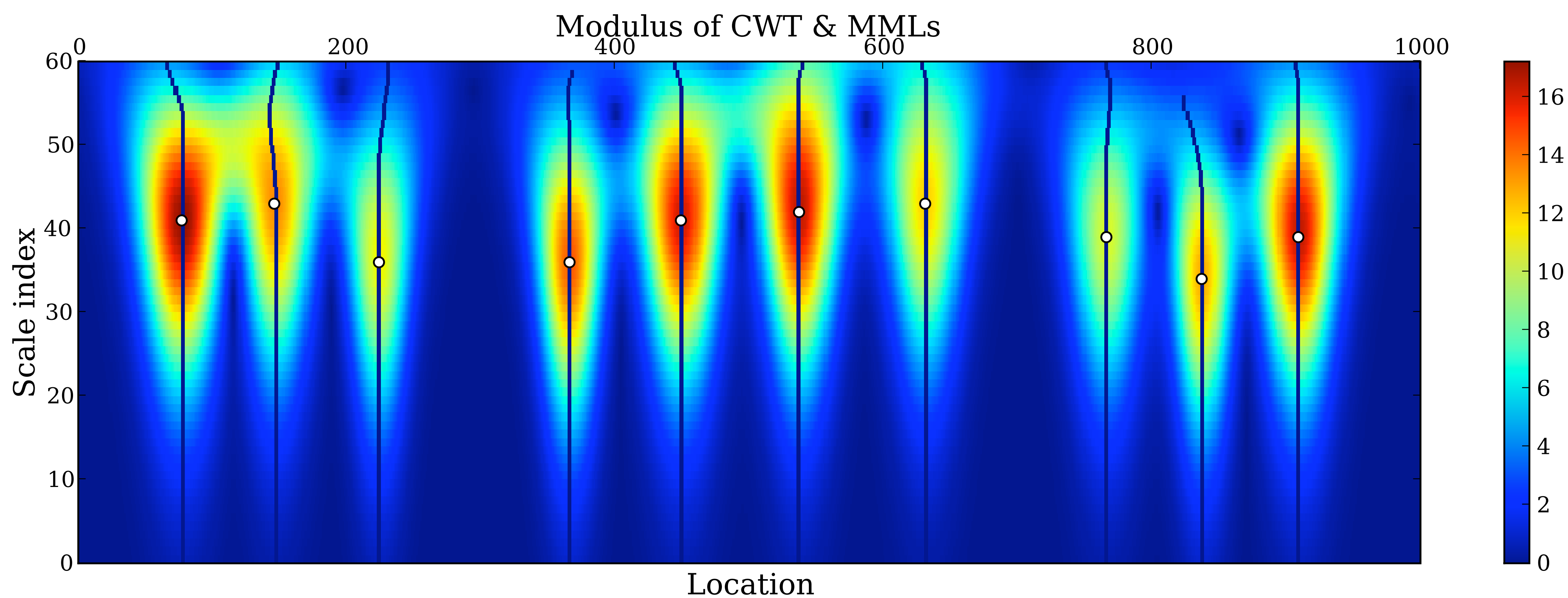


Detection

- Continuous wavelet transform on seismic traces along time(depth) axis as

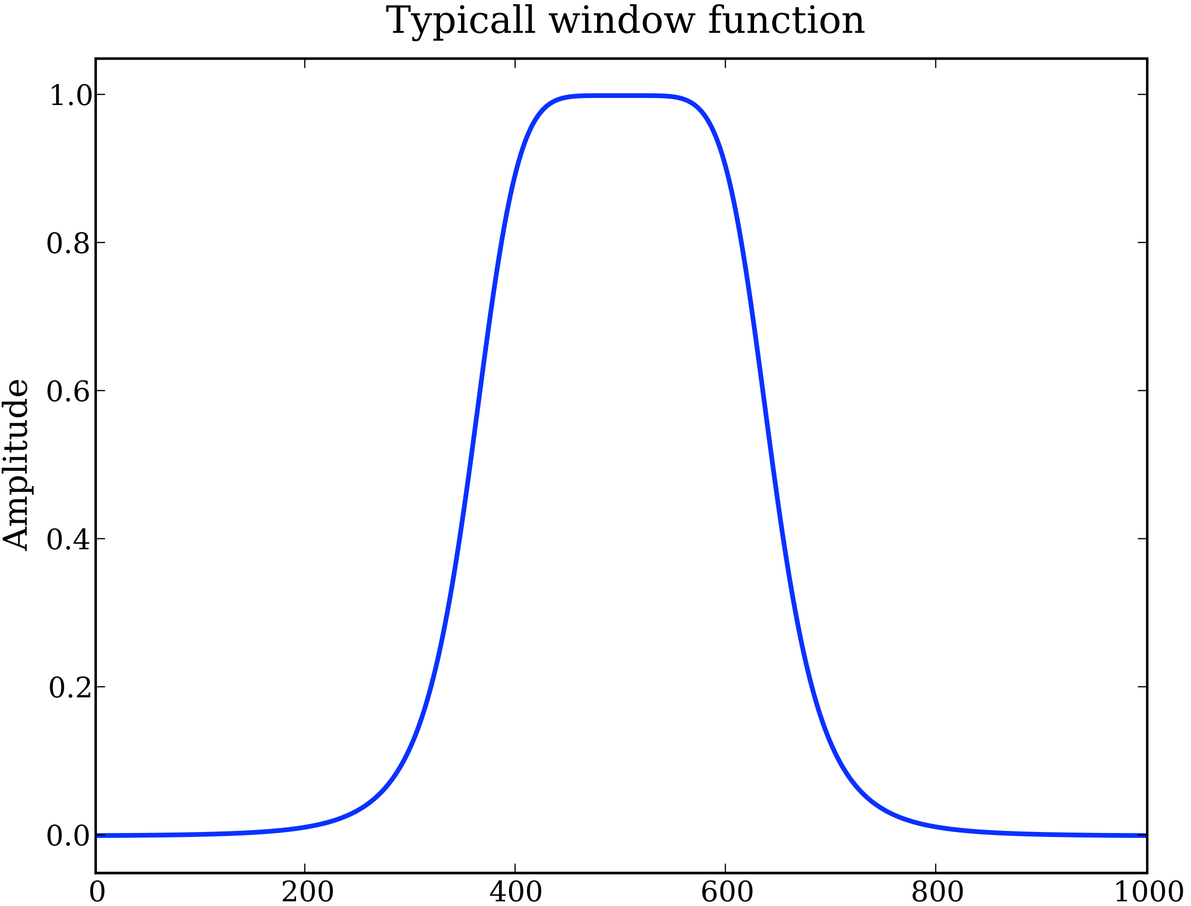
$$\mathbb{W}s(\sigma, t) = \left(s * \bar{\psi}_\sigma\right)(t)$$

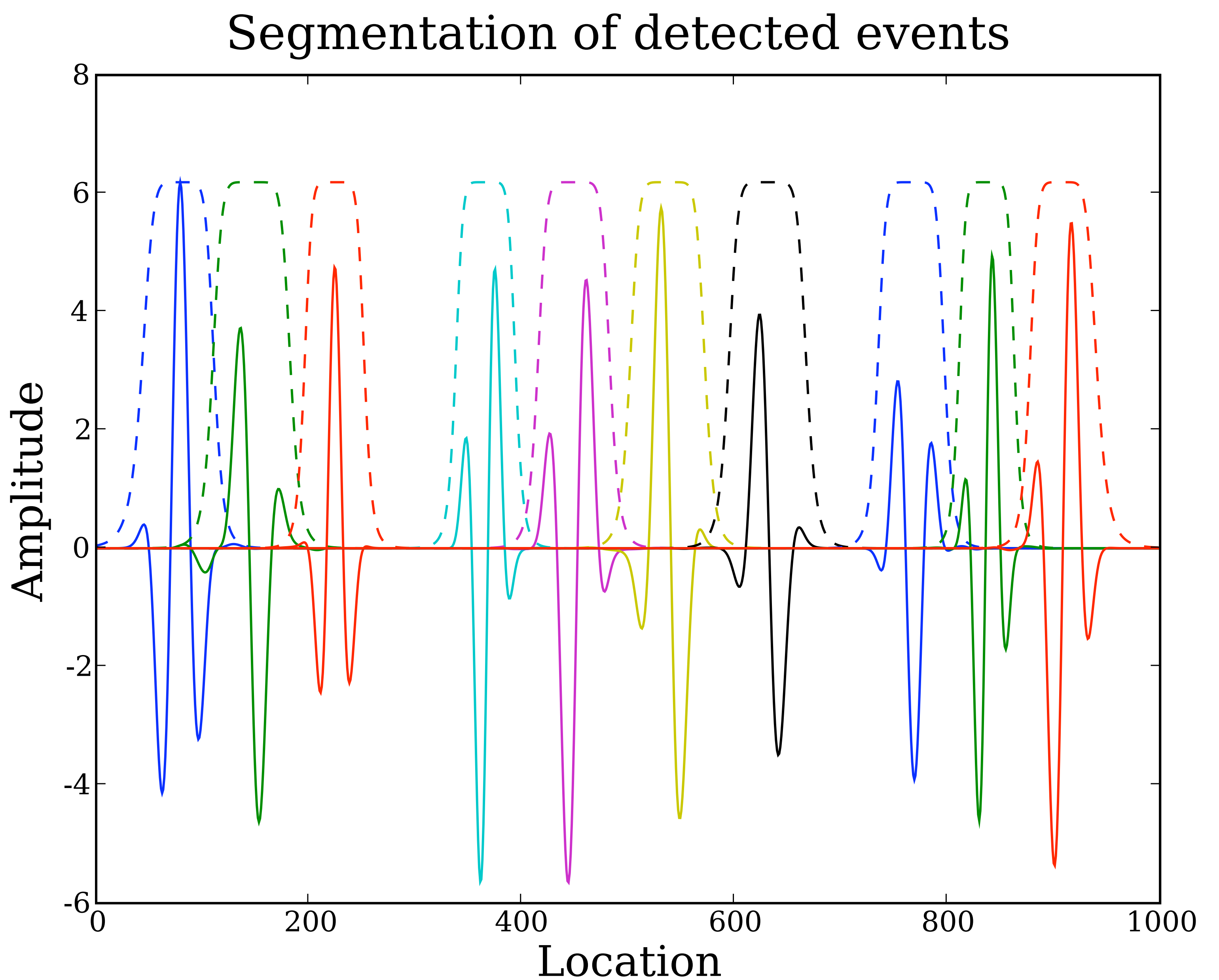
$$\text{where} \quad \bar{\psi}_\sigma(t) = \frac{1}{\sqrt{\sigma}}\psi^*(\frac{-t}{\sigma})$$



Segmentation

- Separate detected events by applying a window function on location & scale of event





$$s^{(n)}(t) = \mathbf{W}[\tau^{(n)}, \sigma^{(n)}]s(t)$$

$$\text{with} \quad n = 1 \cdots N$$

Gaussian manifolds for parametric modeling

- The family of waveforms is parametrized by :
  - Old attributes
    - position τ
    - Instantaneous phase Φ
  - New attributes
    - scale σ
    - singularity order α
- These waveforms in time domain are defined as

$$f_\theta(t) = H^\phi D^\alpha \left(\frac{1}{\sqrt{2\pi\sigma^2}} e^{(t-\tau)^2/2\sigma^2} \right)$$

$$\Theta = [\tau, \sigma, \alpha, \phi]$$

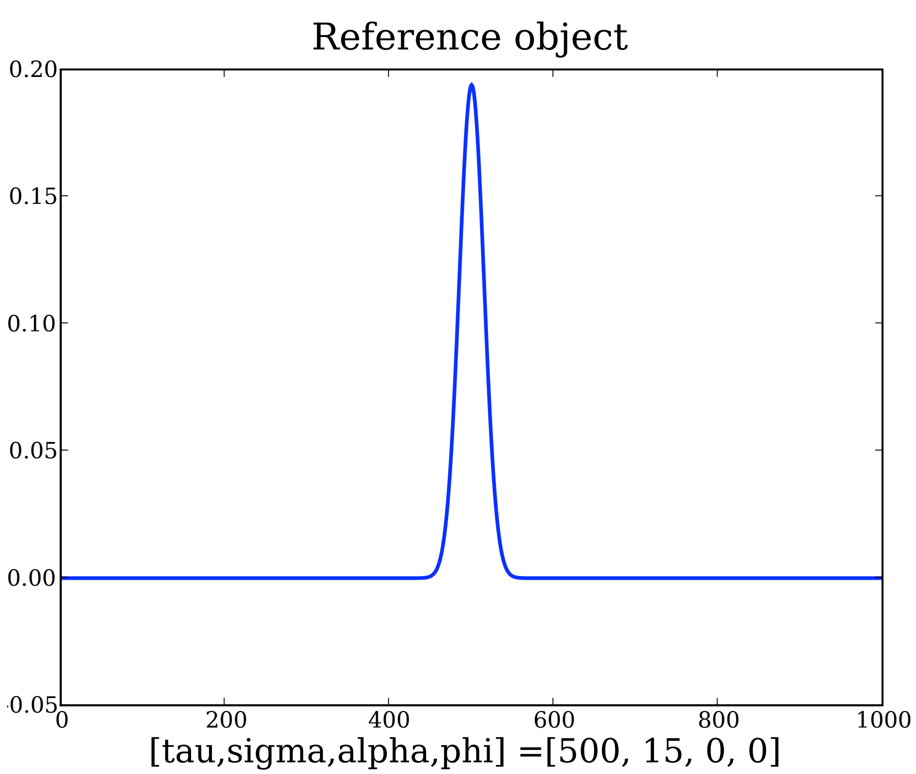
  - or in frequency domain as

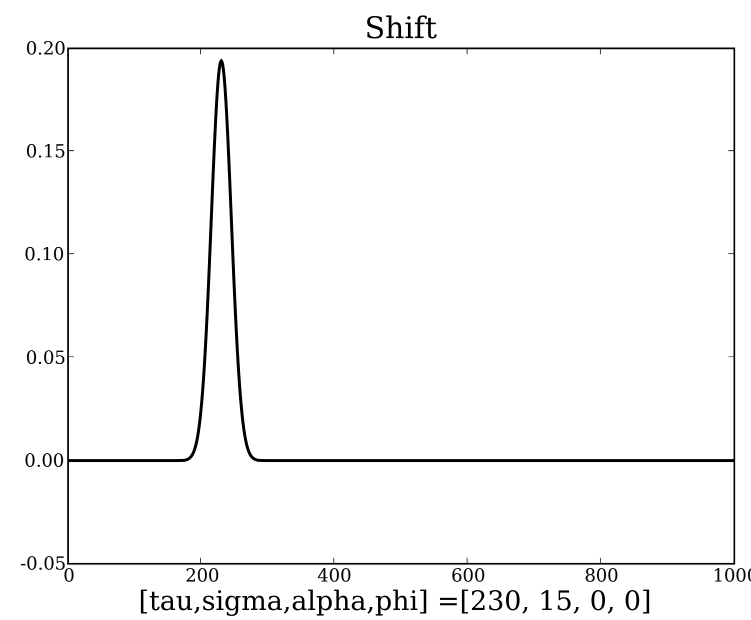
$$\bar{f}_\theta = \mathbb{F}(f_\theta) = (-j\omega)^{\alpha/2-\phi} . (j\omega)^{\alpha/2+\phi} . e^{-\frac{(\sigma^2\omega^2)}{2}} . e^{-j\omega\tau}$$

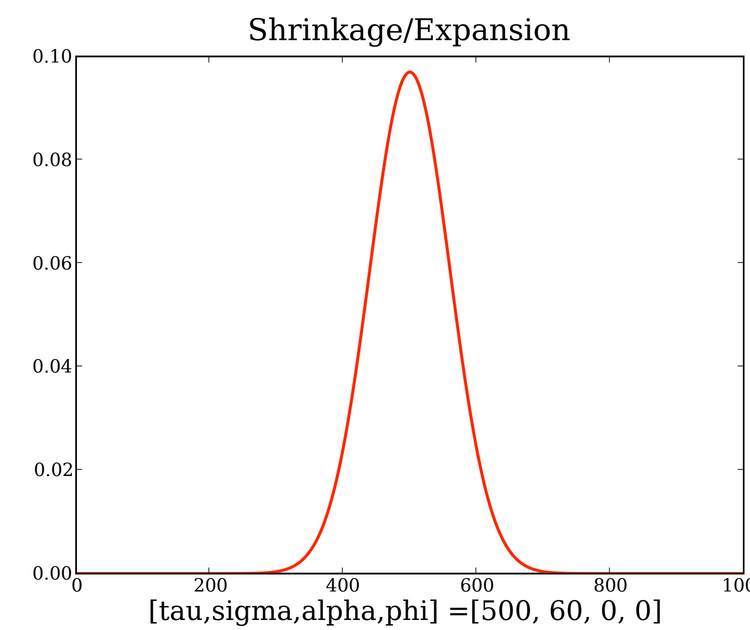
Gaussian manifolds *(cont'd)*

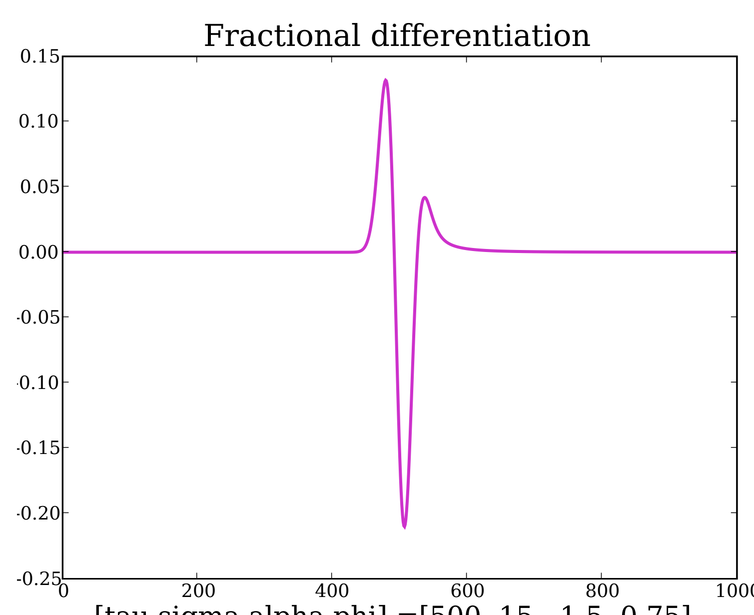
- The family is defined as

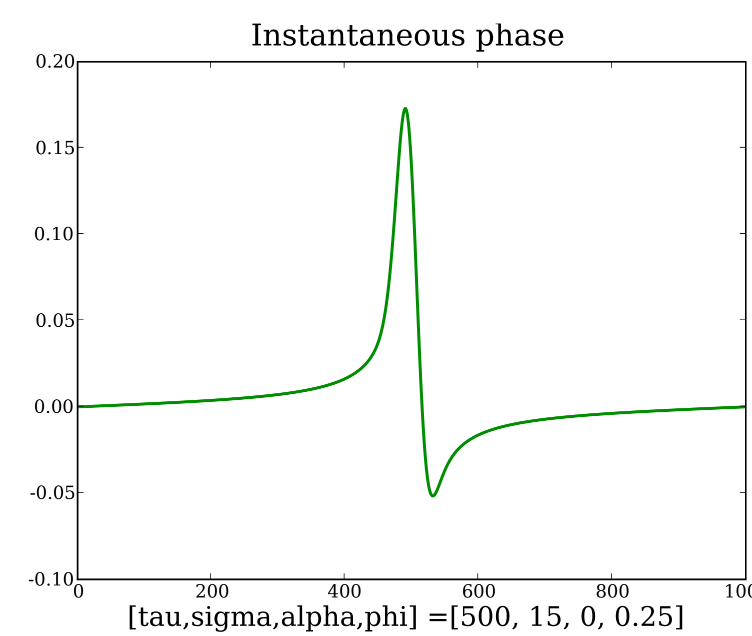
$$M[\theta] = \{f_\theta : \theta \in \boldsymbol{\Theta}\}$$











Estimation

- Aims to extract the attributes from the windowed waveforms. Method is based on finding the best matching waveform.

$$\tilde{\theta}^{(n)} = \arg\min_{\theta} e^{(n)}(\theta)$$

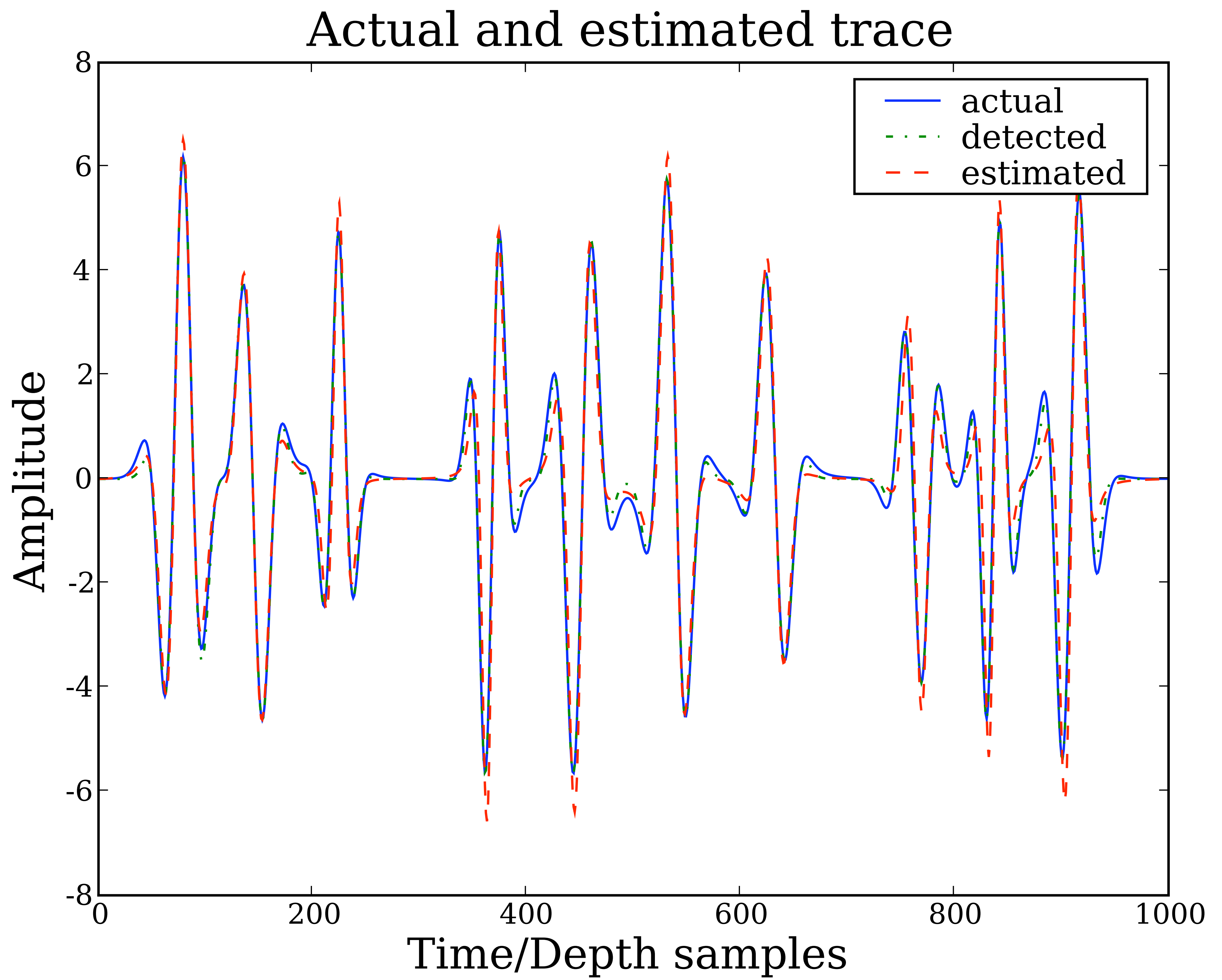
$$e^{(n)}(\theta) = \left\| s^{(n)} - M[\theta] \right\|_2^2$$

- This minimization problem is solved by either LBFGS or Levenberg-Marquardt.

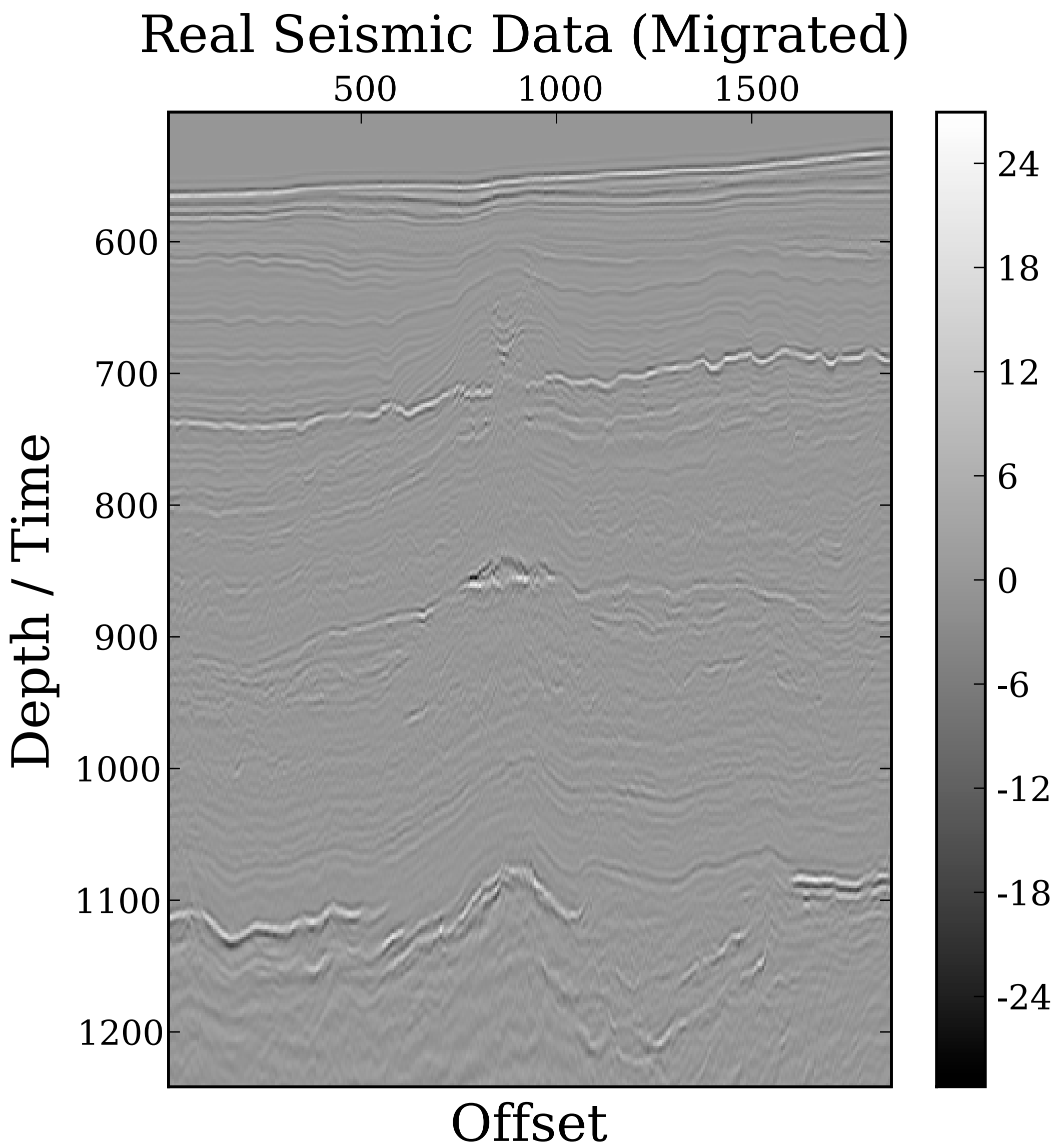
$$\mathbf{J}^{(n)} = \{J_i^{(n)} \ : i = 1 \cdots 4\}$$

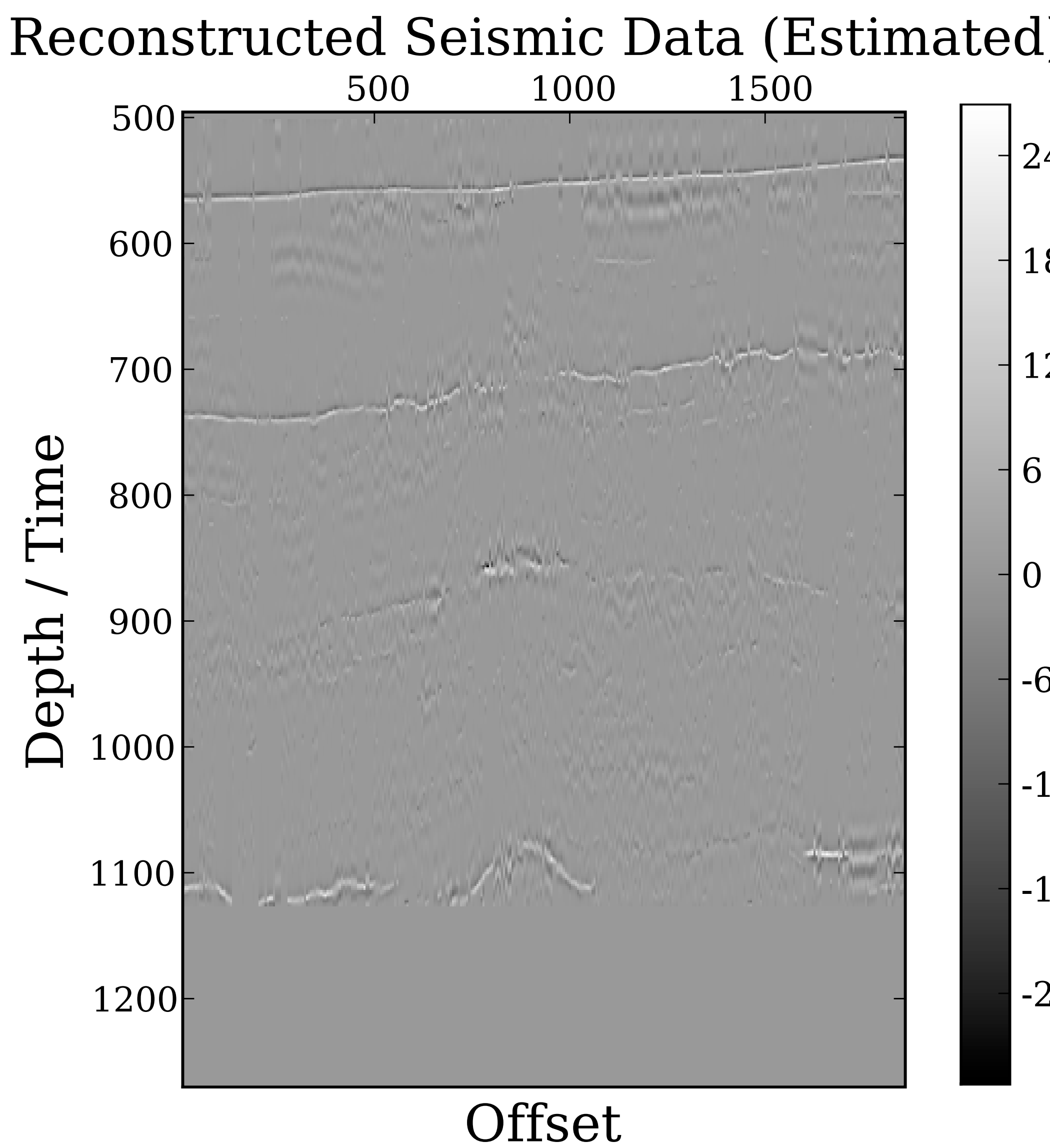
$$J_i^{(n)} = \frac{\partial e^{(n)}}{\partial \theta_i} = 2 \left\langle s^{(n)} - M[\theta], \gamma_{\theta_i} \right\rangle$$

Synthetic result

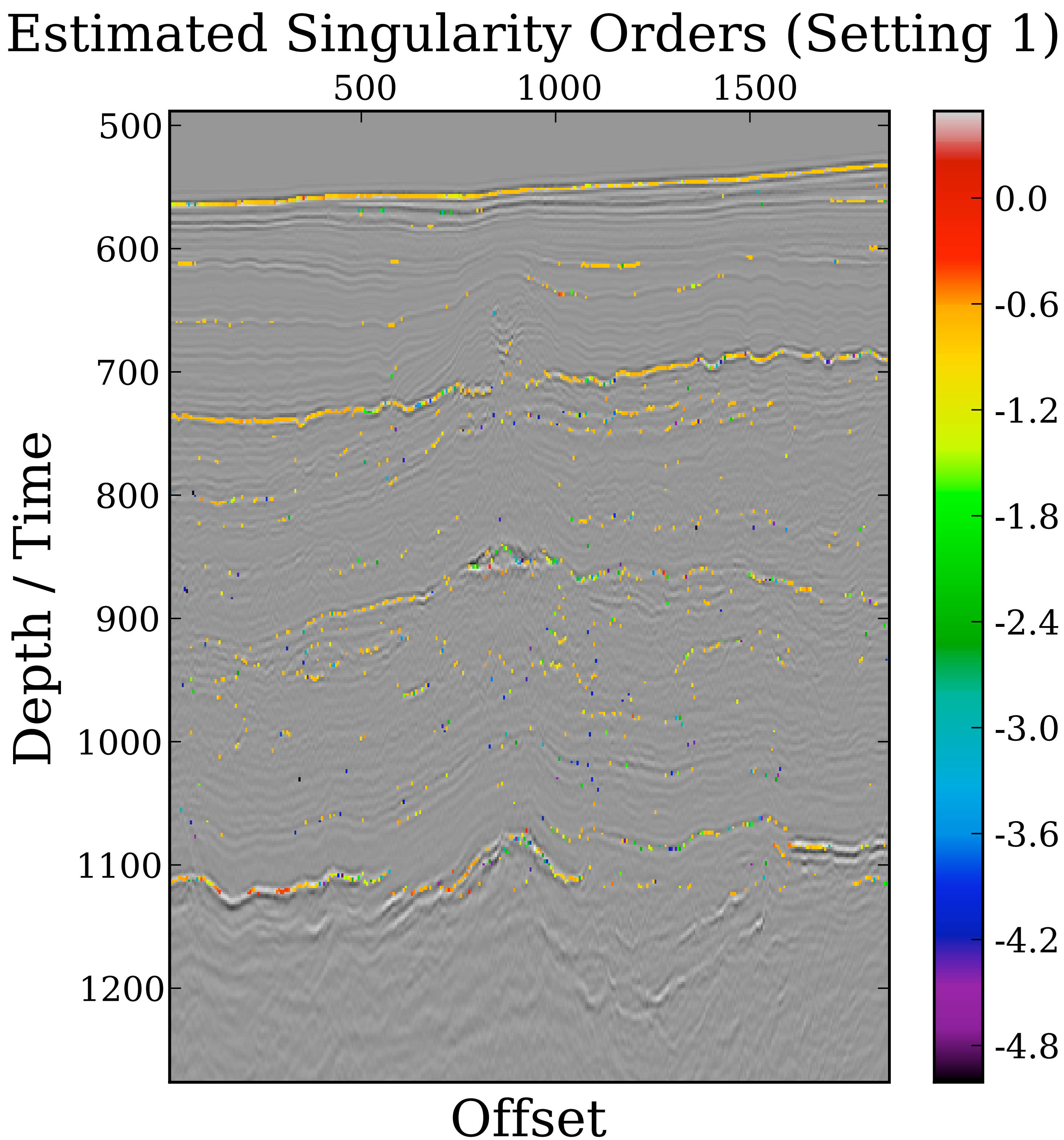


Application to real data

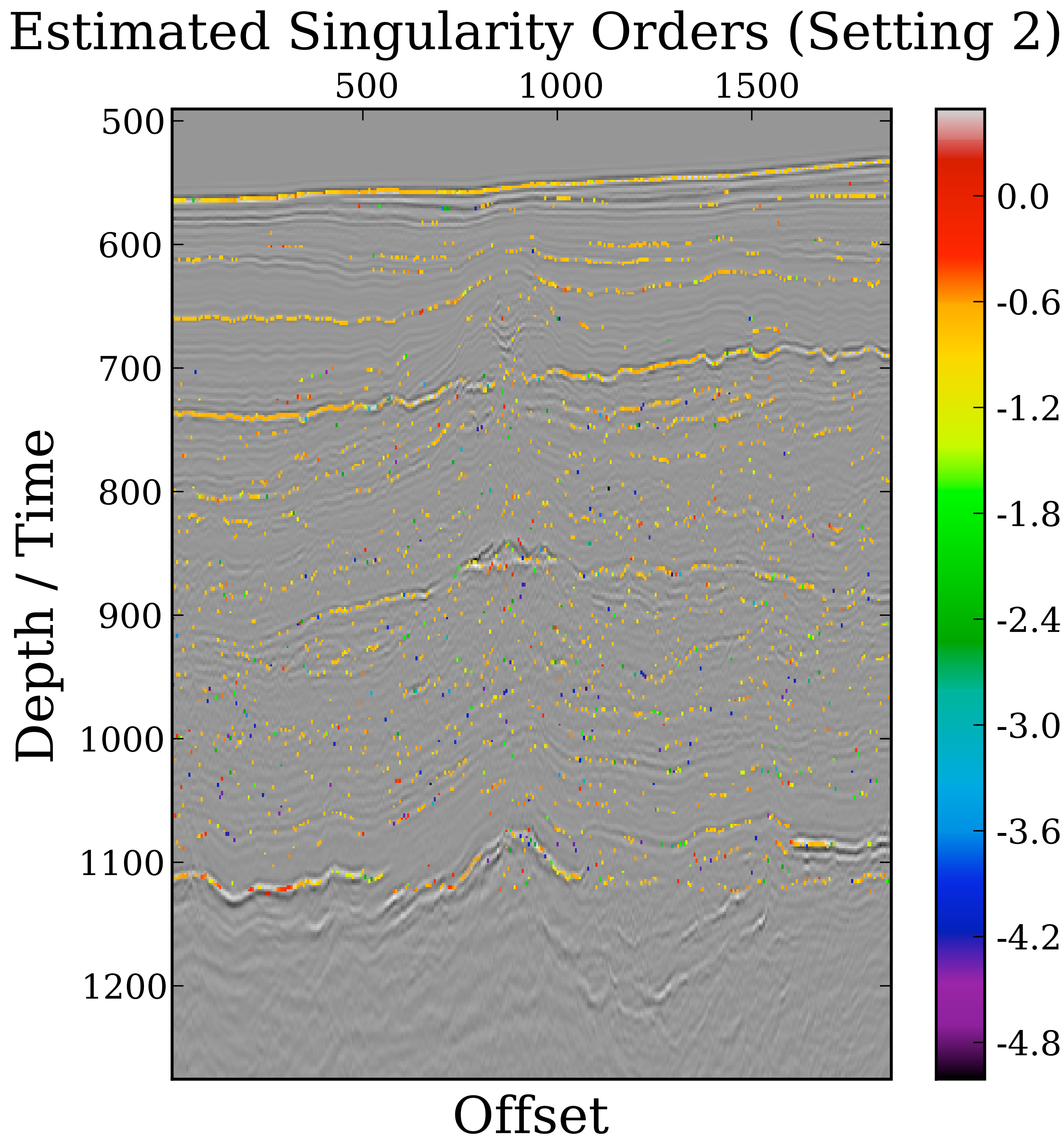




Results (setting 1)



Results (setting 2)



Conclusion

- new characterization method
  - allows for the estimation of fractional-order discontinuities.
  - suited for the estimation of the scale exponent attributes from bandwidth limited data. As opposed to wavelet coefficient decay based methods, our method does not lead to possibly ambiguous estimates since we do not rely on ’infinite’ bandwidth.
  - may lead in improvement of geological interpretation from the seismic trace.different groups of events
  - has flexibility to aim for estimation of a specific group of reflectors
  - that has potential for parallel implementation

Future plan

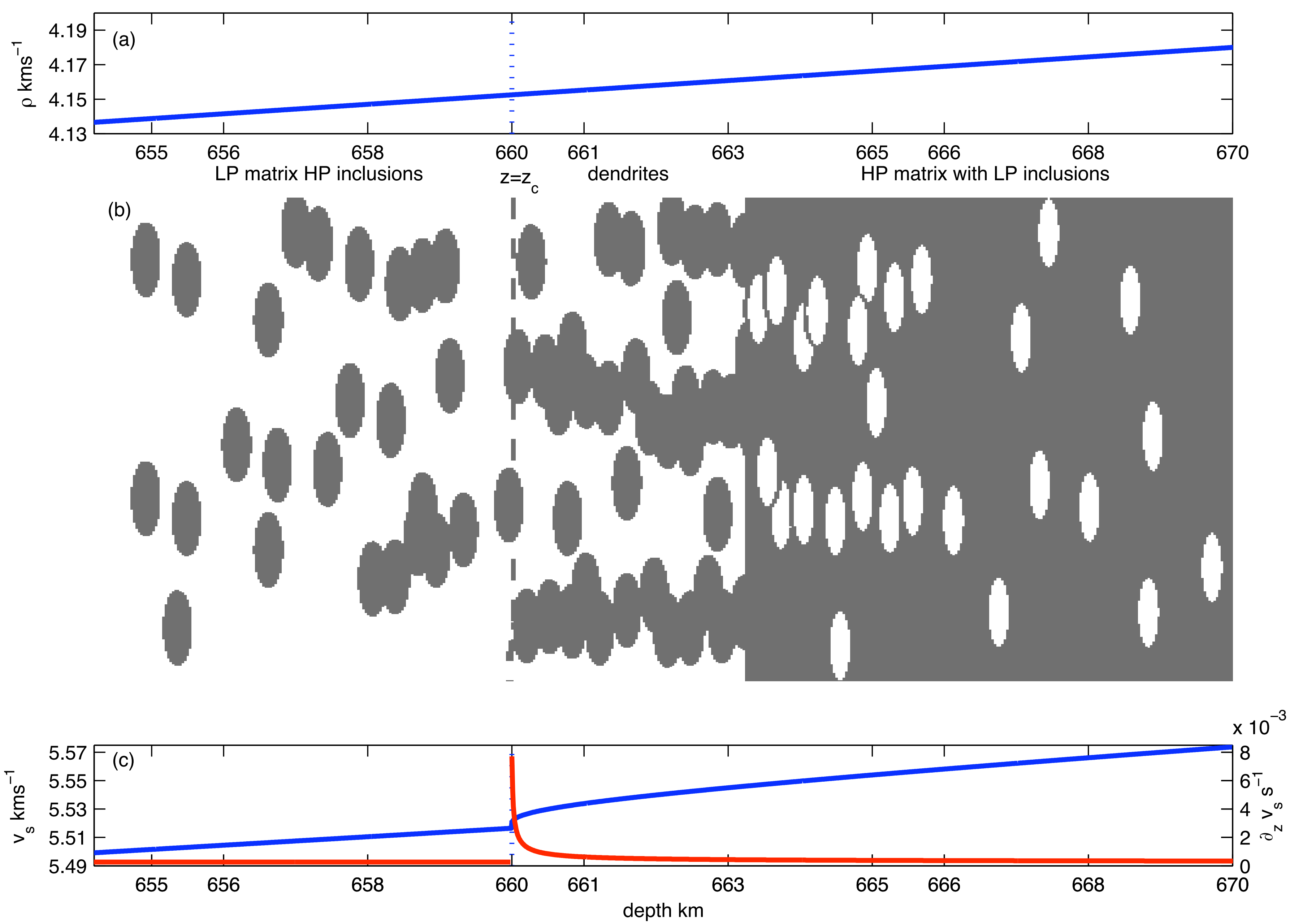
- Improve accuracy of method in estimation part
  - Look into other solvers

- Extend to well data and and find well tie to seismic data

- Provide new insights in the well-seismic tie

- Look into application of this model in Studying well-defined binary mixtures (e.g. Opal, gas-hydrates etc.)

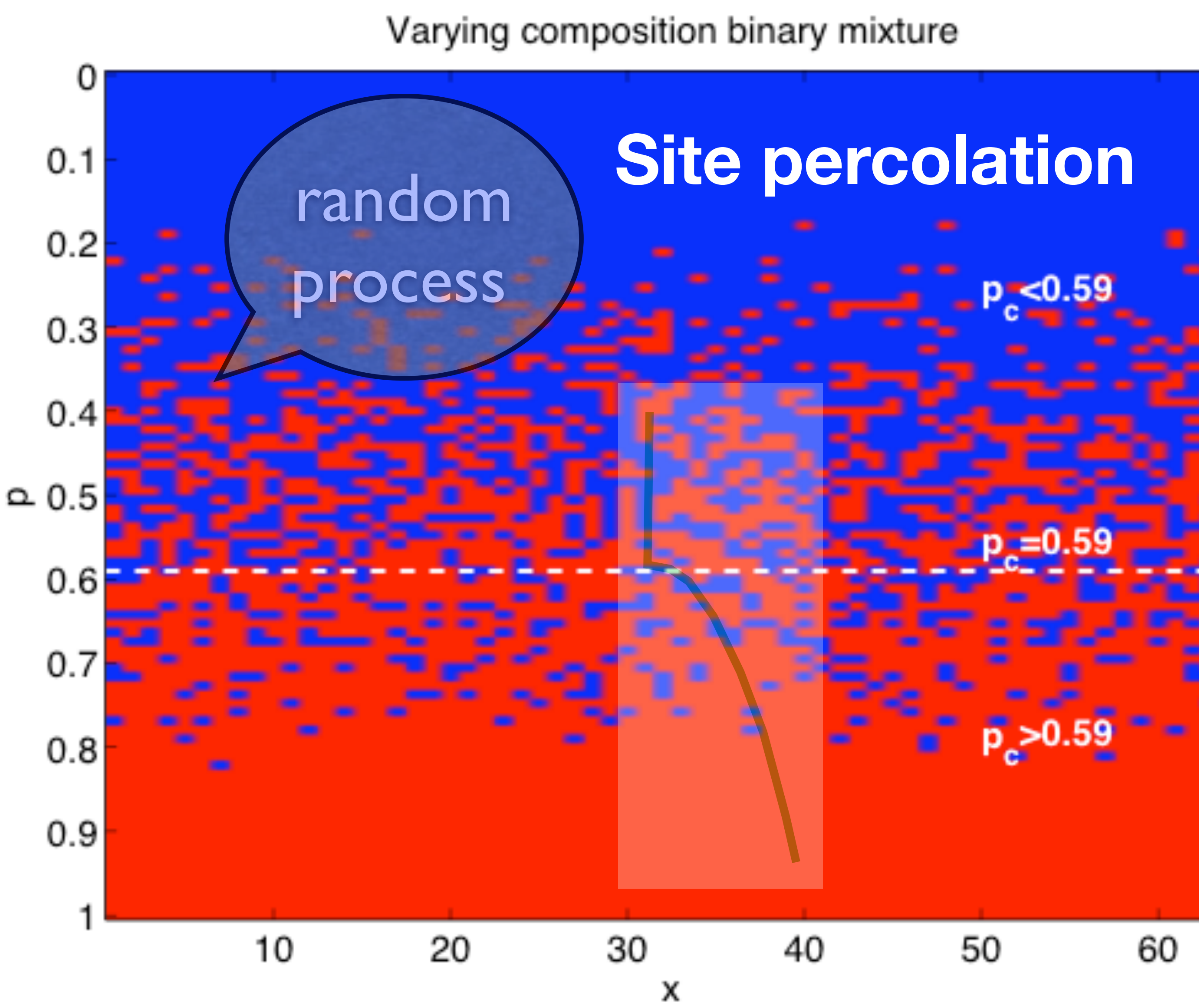
Discontinuity modeling
Percolation model [Herrmann-Bernabe 04]

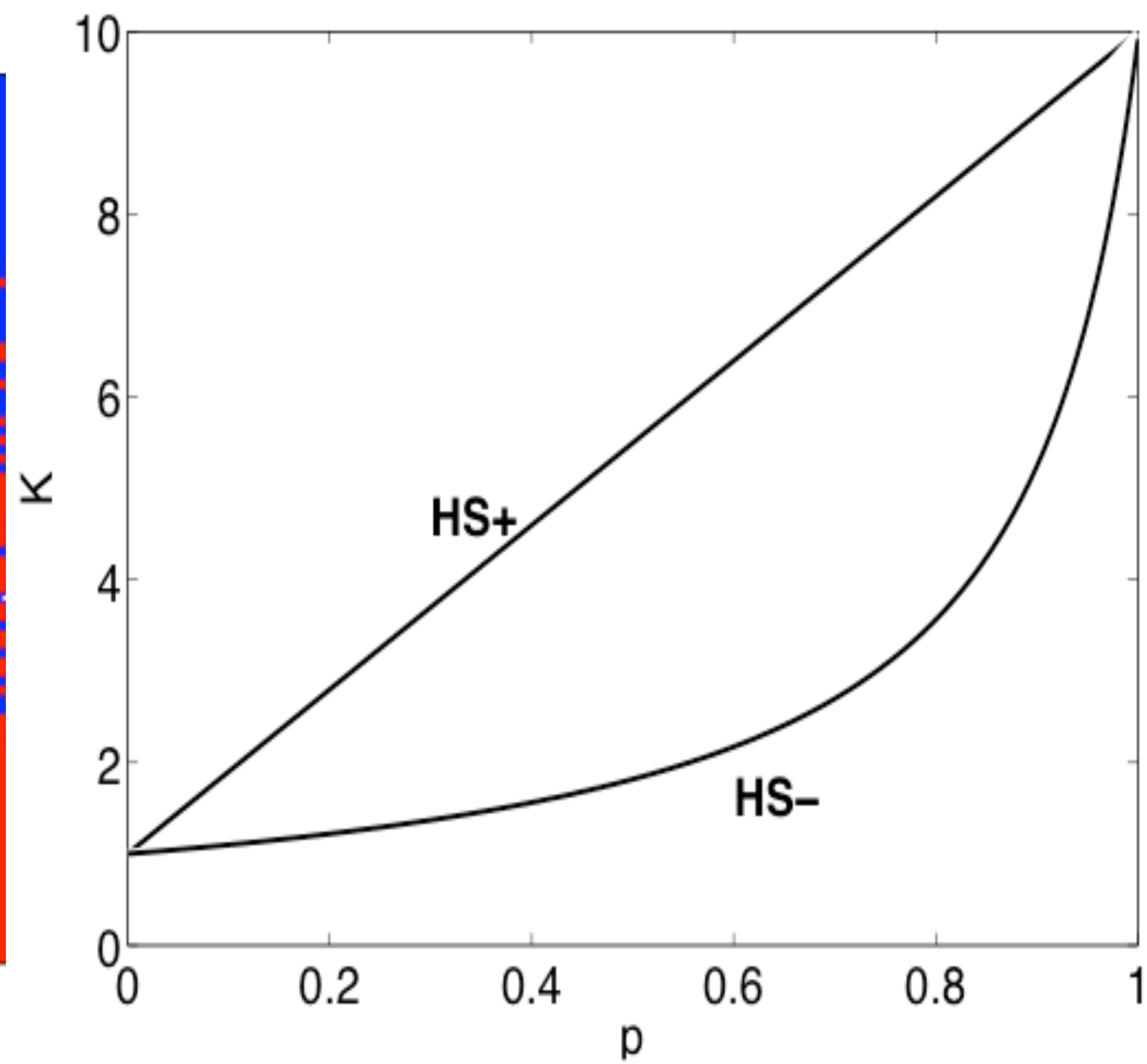


Discontinuity modeling
binary mixtures

LP olivine HP β-spinel

elastic properties





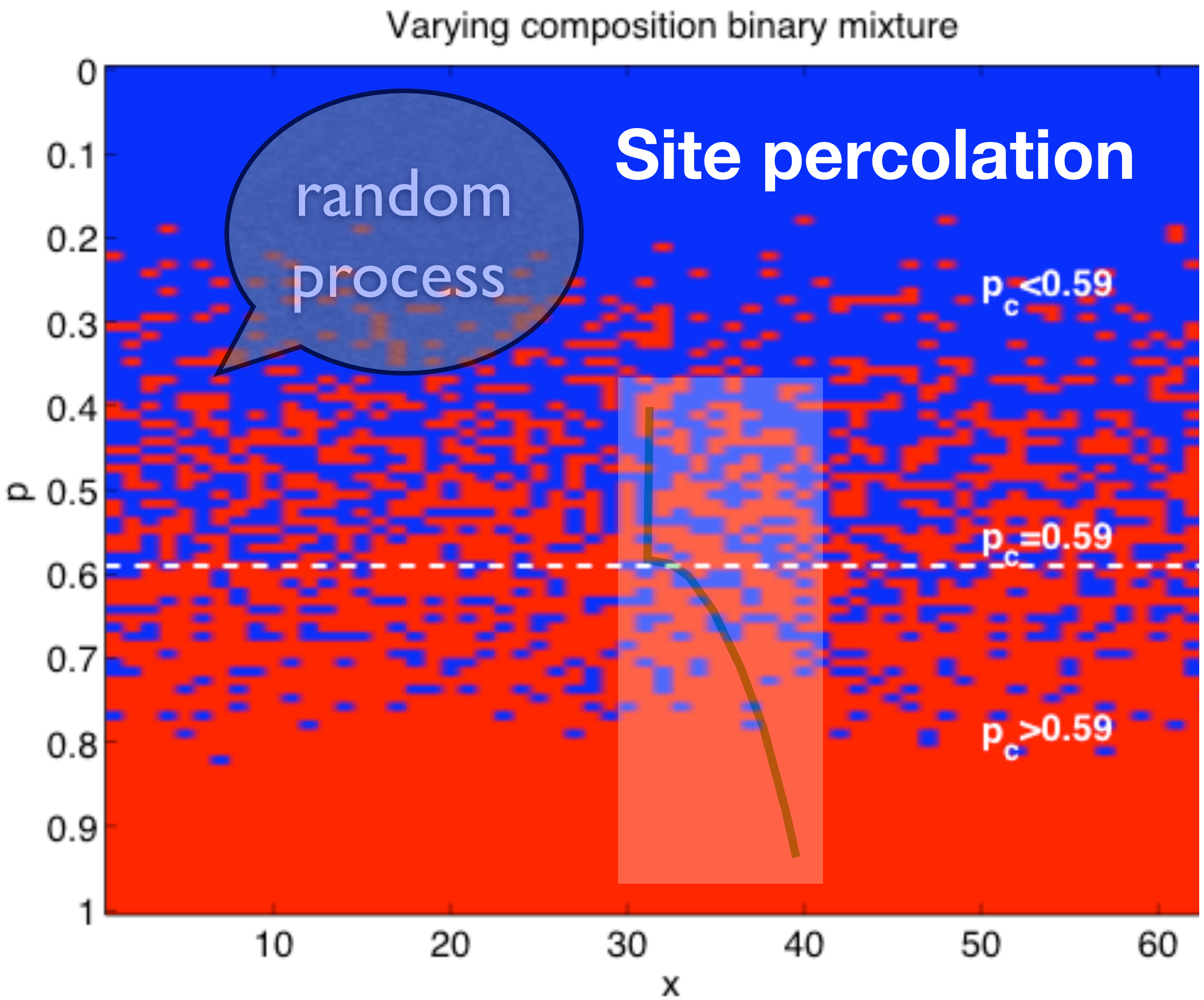
HP: high porosity

LP: low porosity

volume fraction

Discontinuity modeling
binary mixtures

LP olivine HP β-spinel



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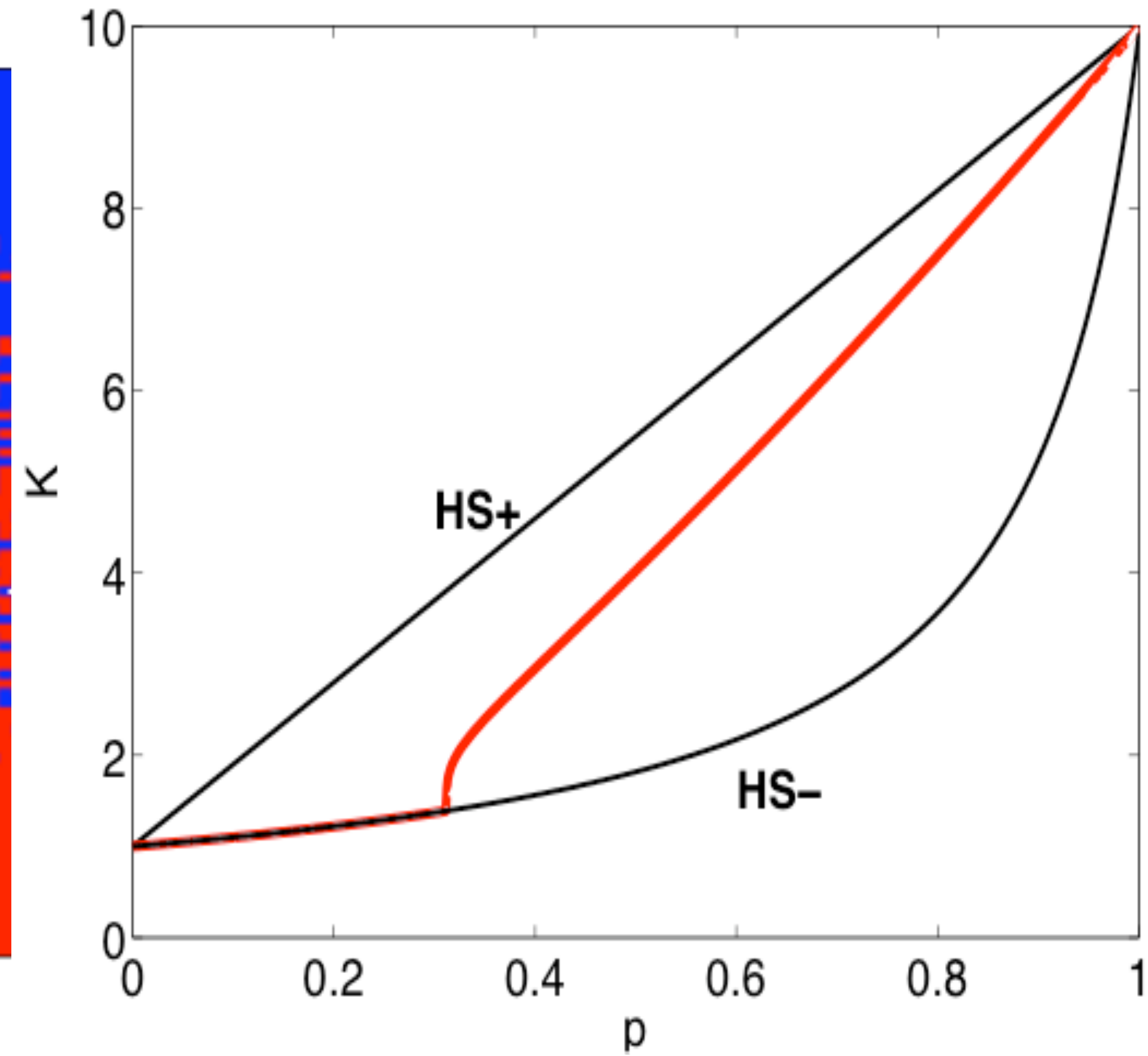

volume fraction

HP: high porosity

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