Why seismic-to-well ties are difficult

Gary F. Margrave

It's Q's Fault

Gary F. Margrave

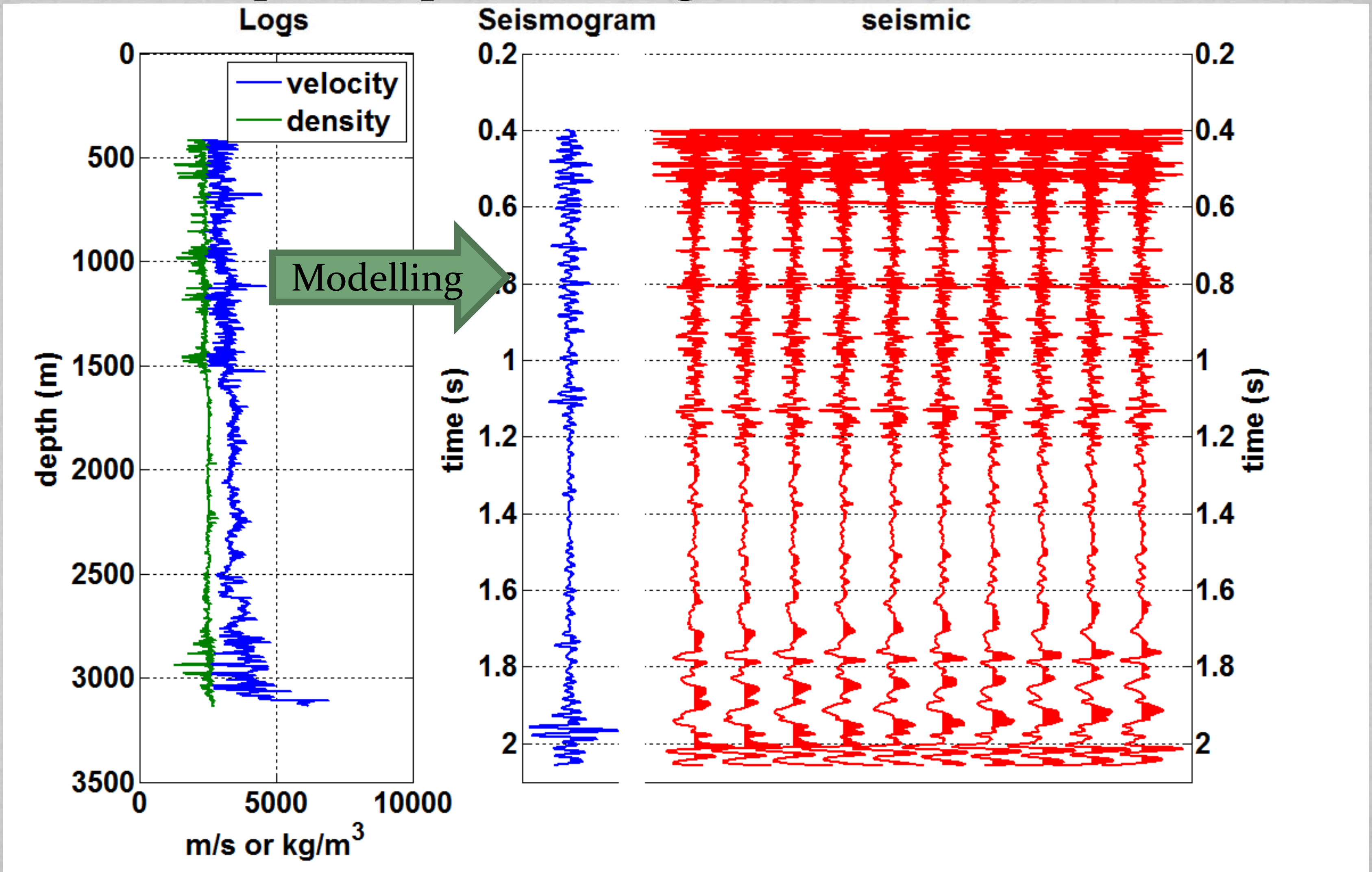
Outline

- Well tying: standard techniques
- The easy case that is mostly irrelevant.
- The nonstationary trace model
- Physical effects of attenuation (Q)
- Nonstationary seismogram from well logs
- Failure of stationary deconvolution
- Nonstationary deconvolution: Inverse Q filters and Gabor deconvolution
- Inclusion of noise
- Conclusions

Well Tying

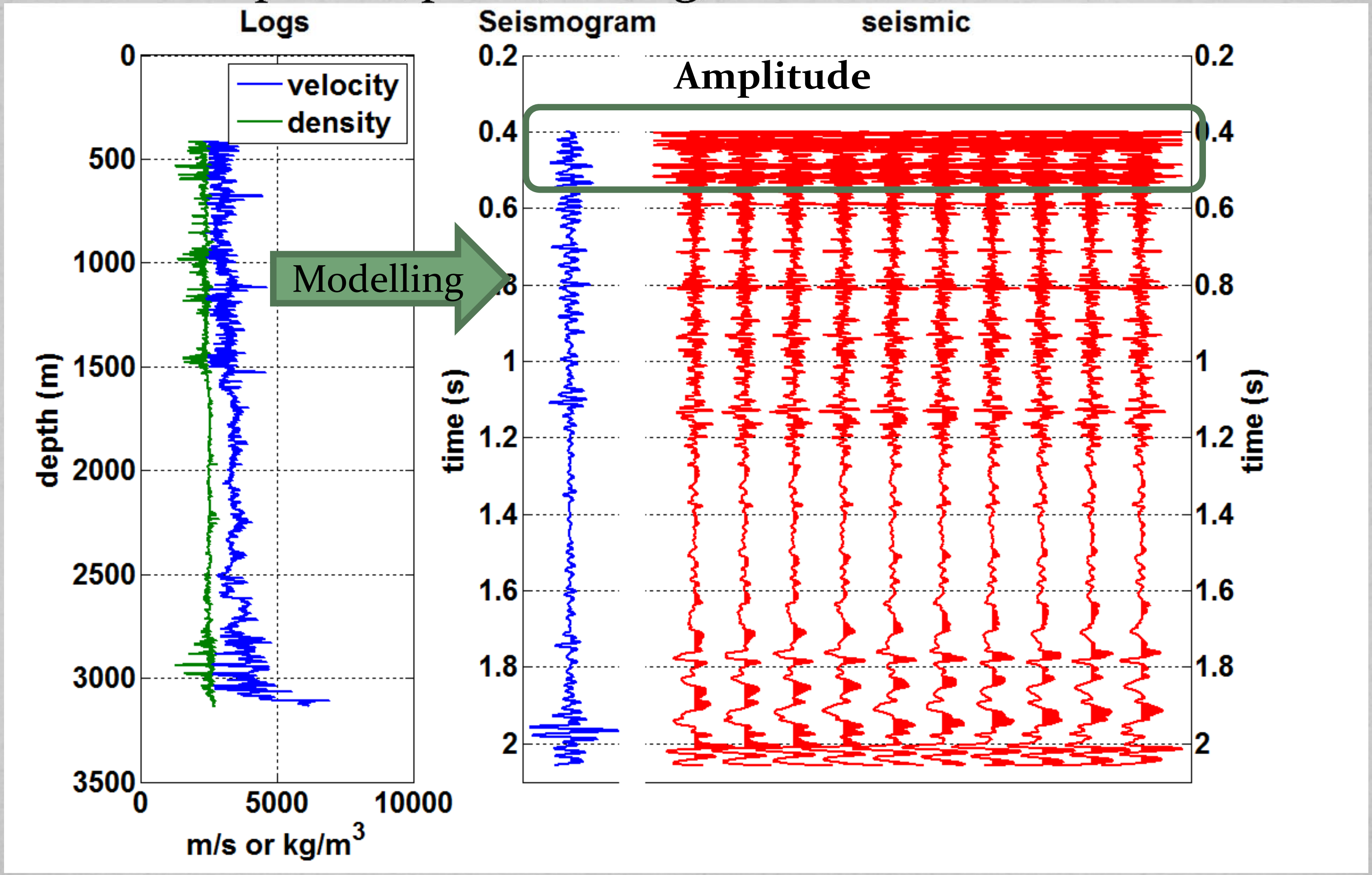
What does it mean for data and wells to “tie”?

Amplitude, phase, timing, bandwidth don’t match



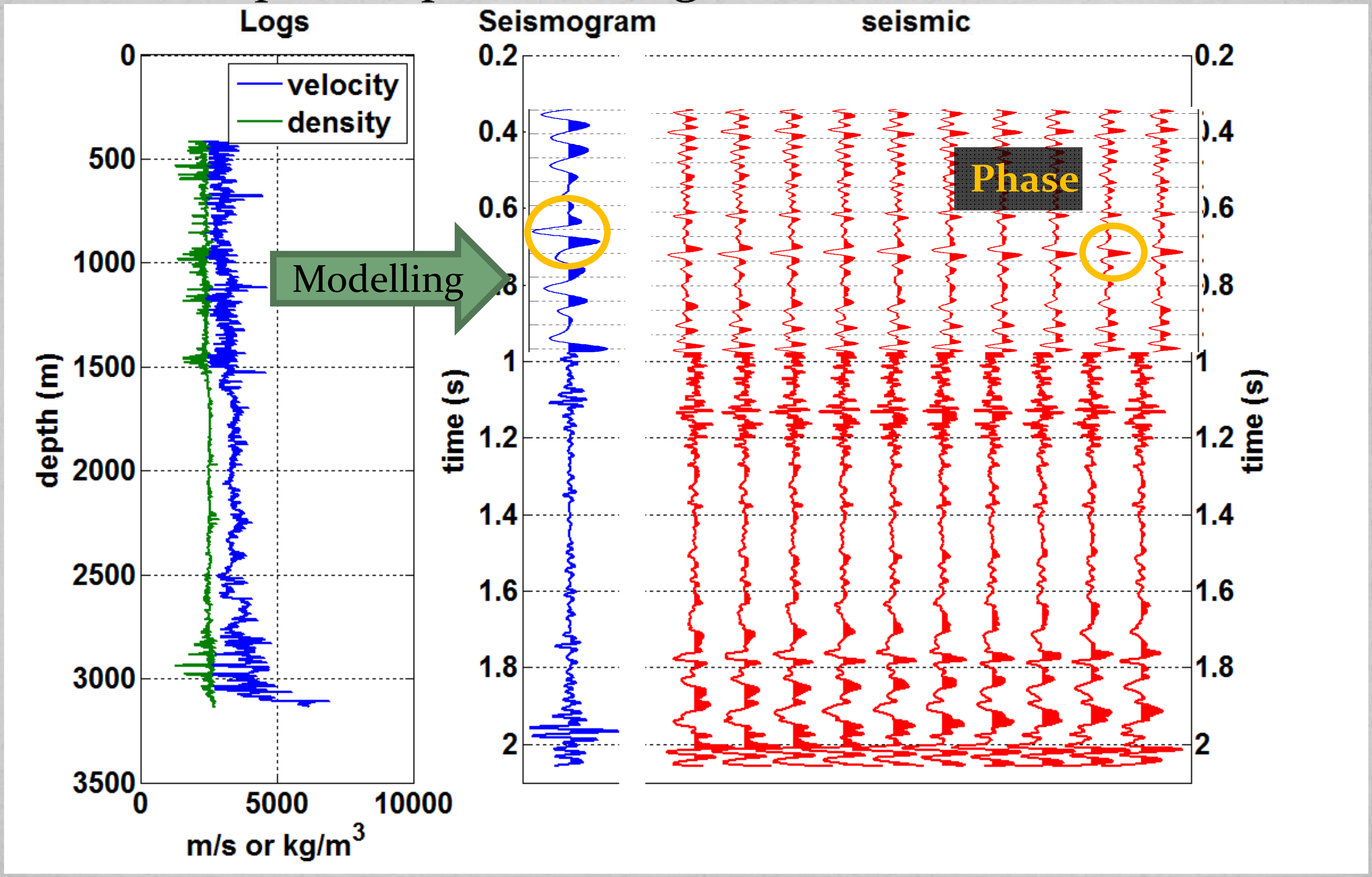
What does it mean for data and wells to "tie"?

Amplitude, phase, timing, bandwidth don't match



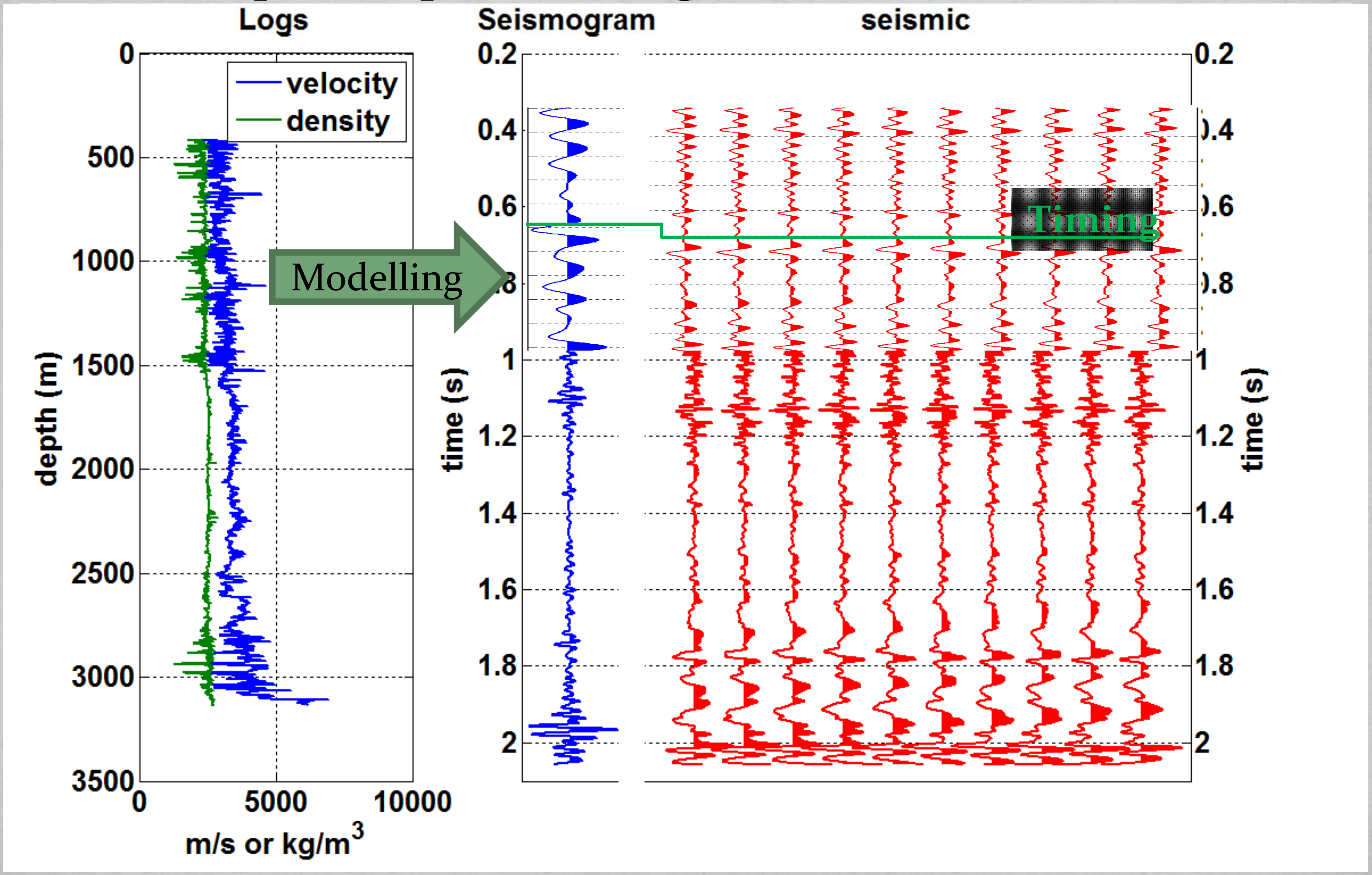
What does it mean for data and wells to “tie”?

Amplitude, phase, timing, bandwidth don’t match



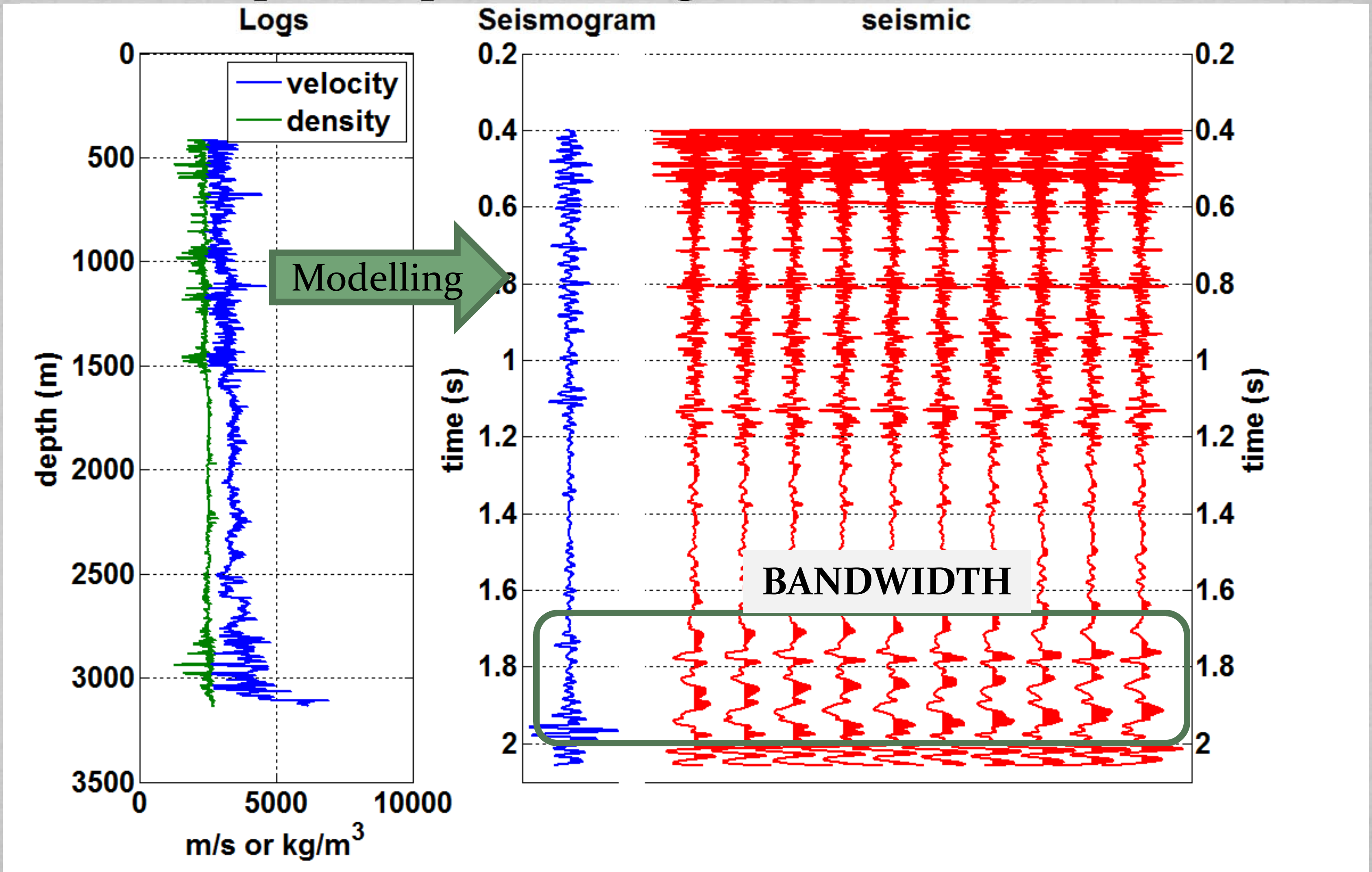
What does it mean for data and wells to "tie"?

Amplitude, phase, timing, bandwidth don't match



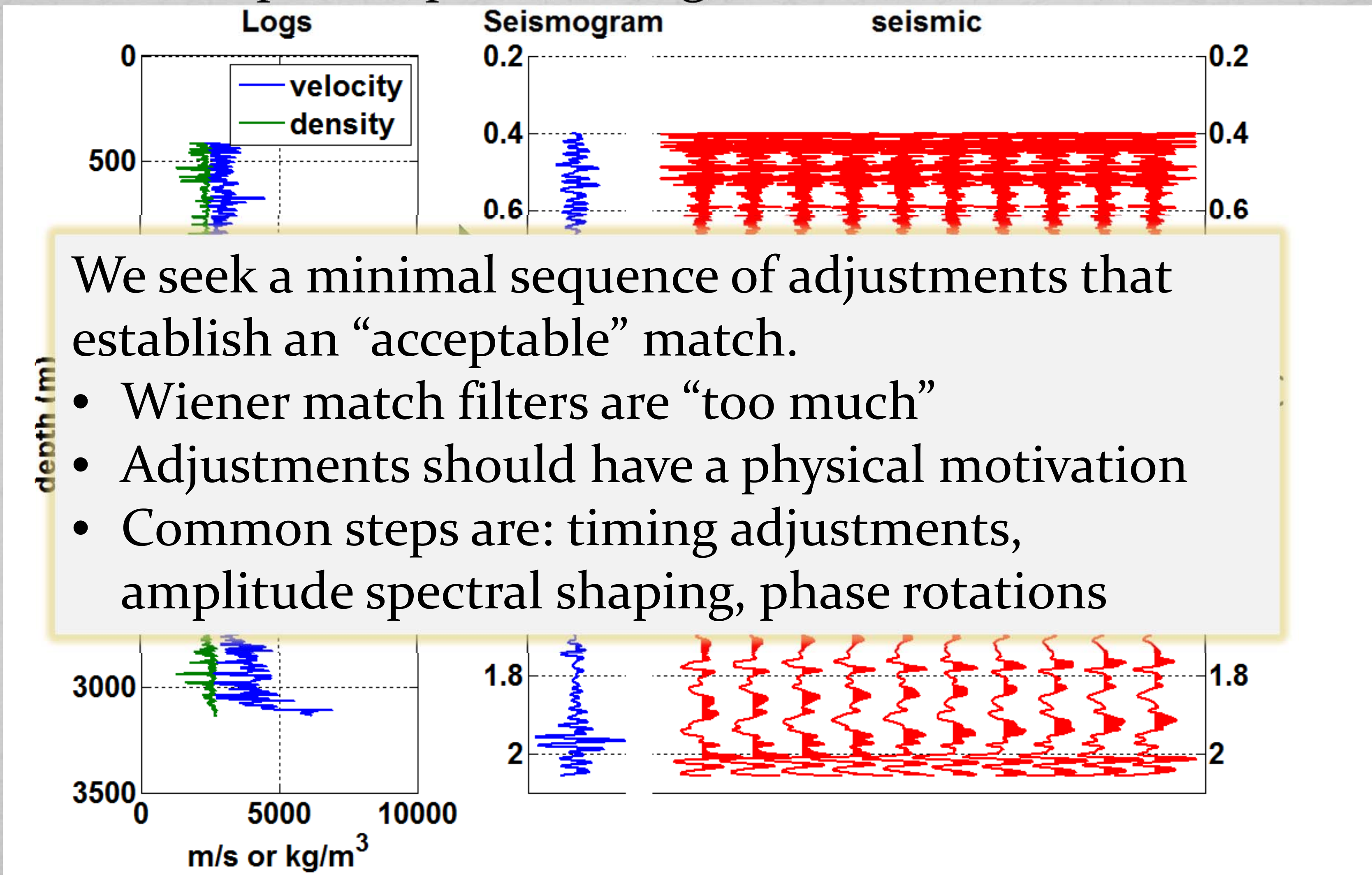
What does it mean for data and wells to "tie"?

Amplitude, phase, timing, bandwidth don't match



What does it mean for data and wells to "tie"?

Amplitude, phase, timing, bandwidth don't match

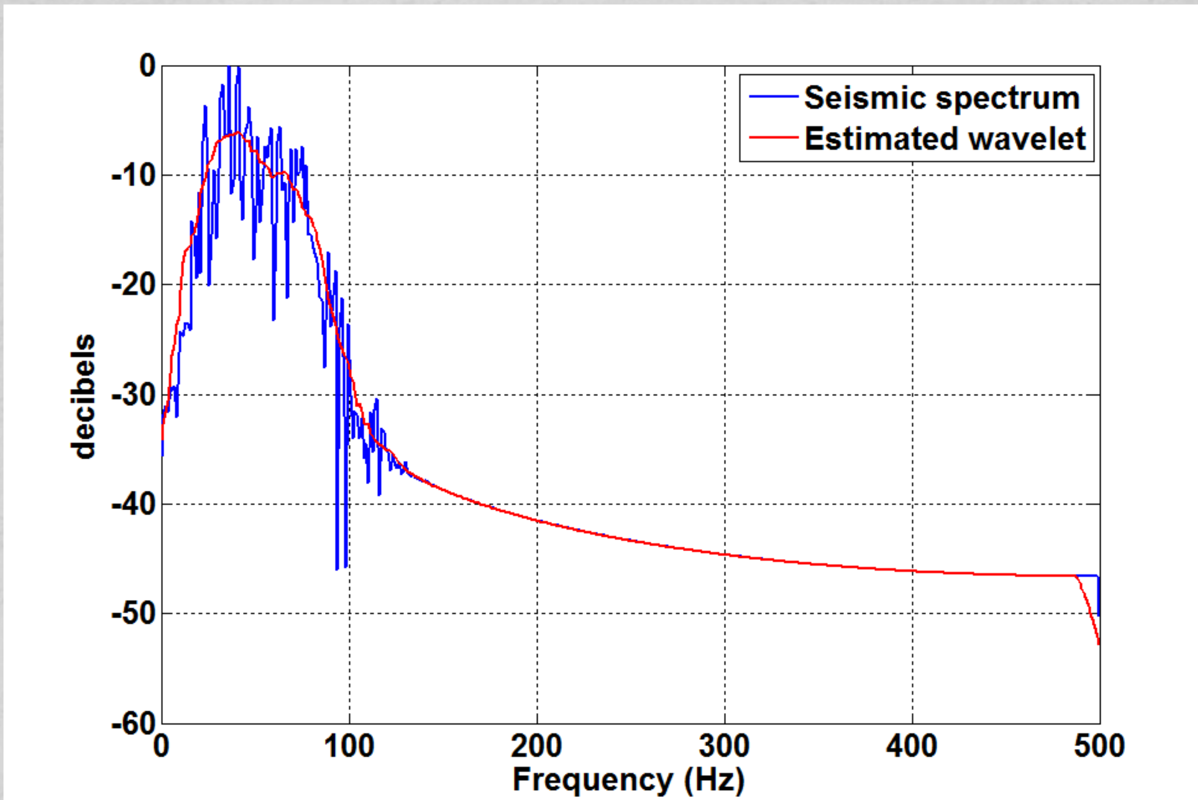


We seek a minimal sequence of adjustments that establish an "acceptable" match.

- Wiener match filters are "too much"
- Adjustments should have a physical motivation
- Common steps are: timing adjustments, amplitude spectral shaping, phase rotations

Wavelet Estimation: Amplitude spectrum

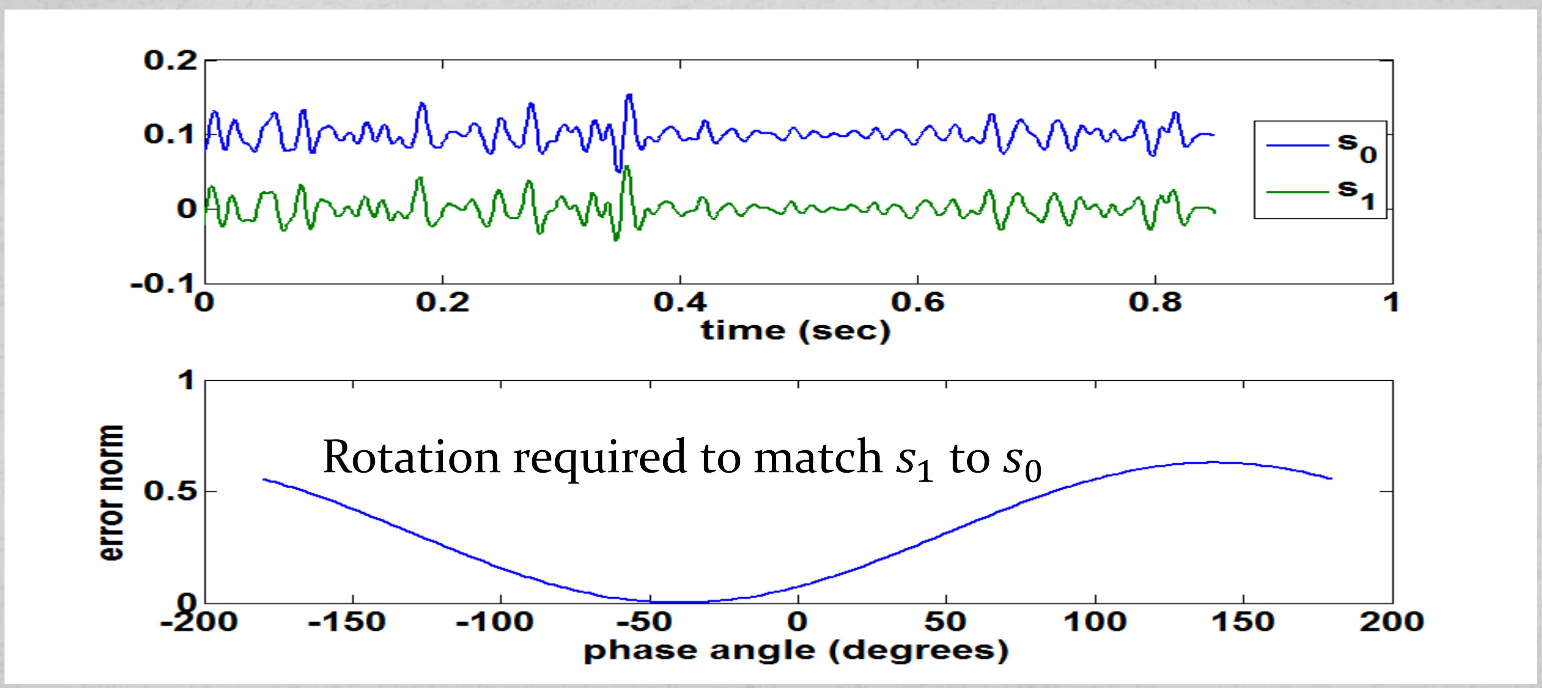
Estimate amplitude spectrum of wavelet by smoothing the spectrum of the seismic data.



Wavelet Estimation: phase spectrum

Assume a simple phase: constant phase, minimum phase, or time-variant constant phase.

Example: Constant phase scan: $\mathrm{err}(\theta) = \sum(s_0 - phsrot(s_1, \theta))^2$

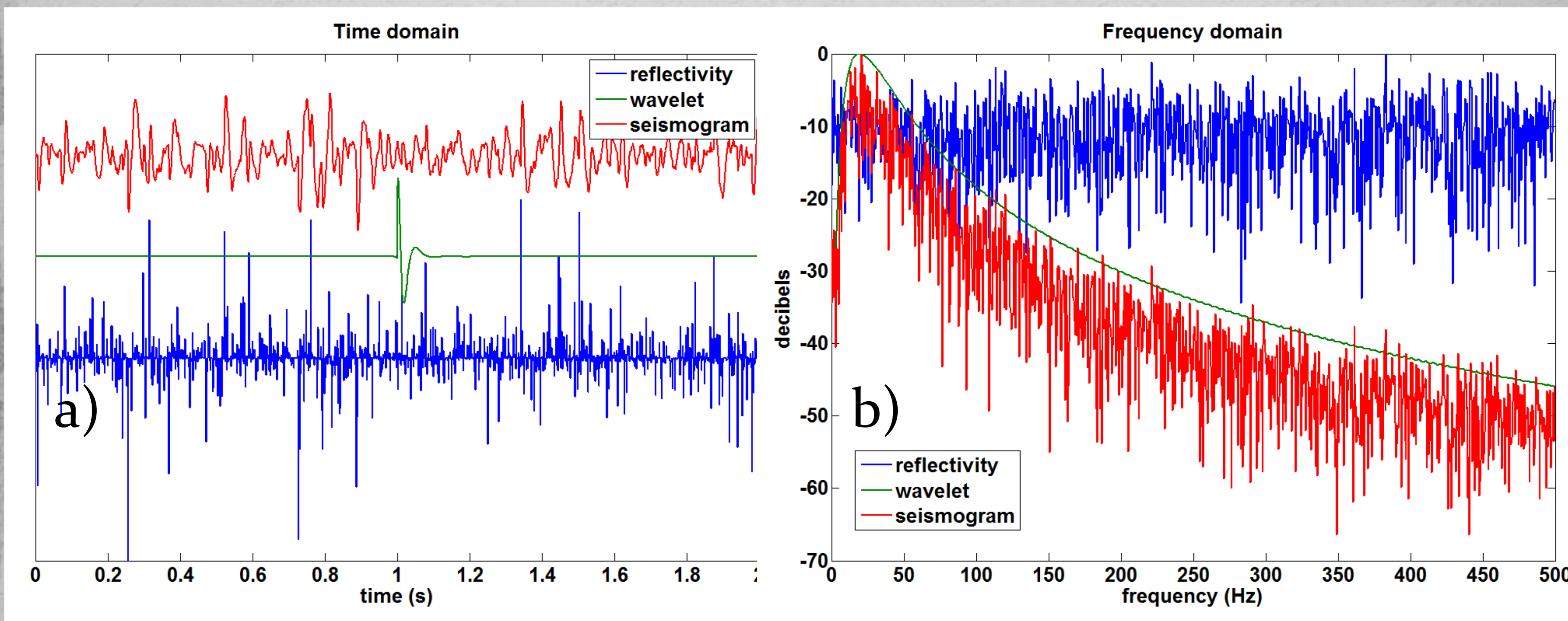


The Easy, Nonphysical Case

The easy but nonphysical case

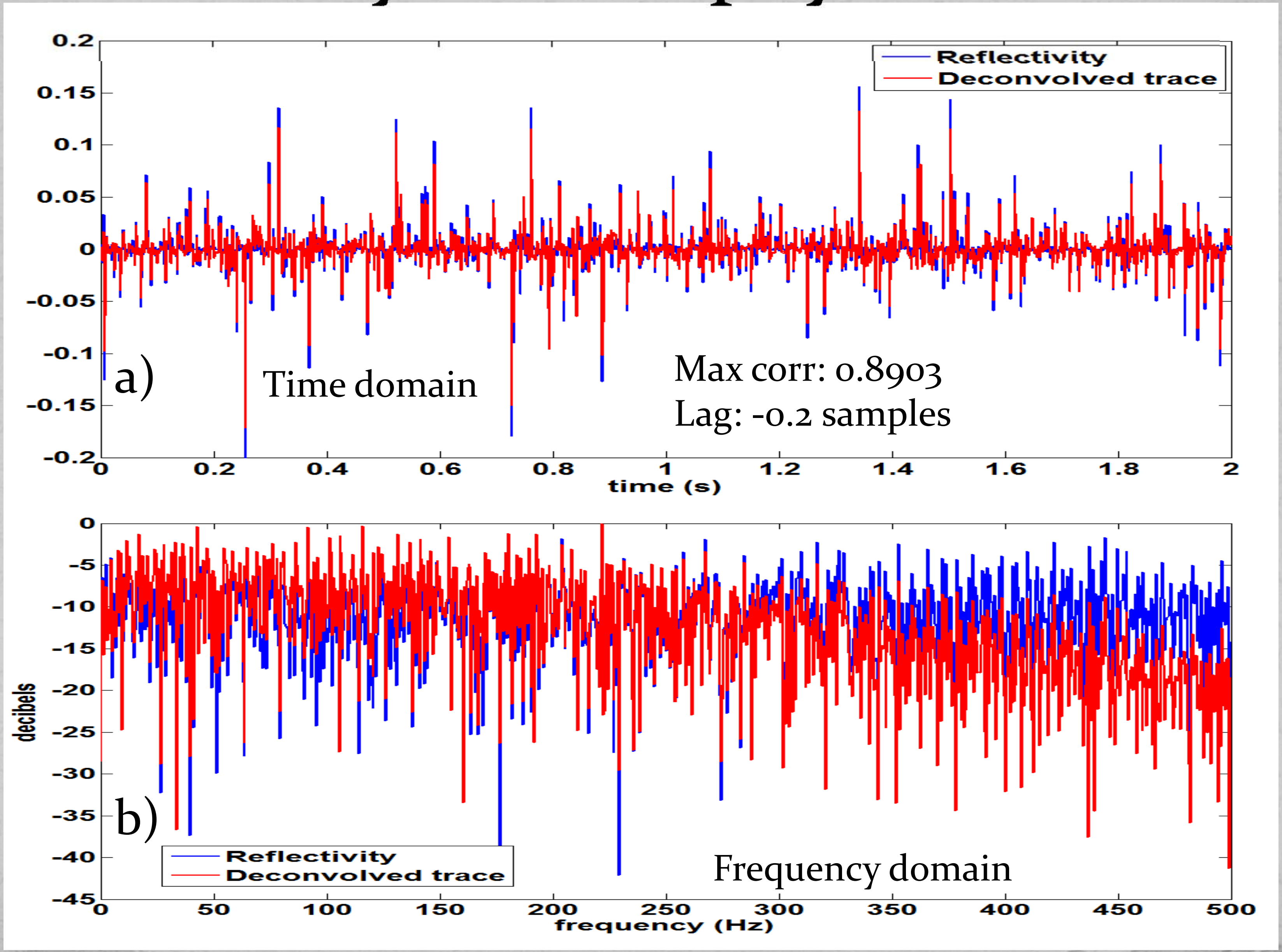
Noise-free convolutional seismogram
with a minimum phase wavelet and white reflectivity

$$s(t) = w(t) * r(t)$$



The deconvolved seismogram will tie the reflectivity almost exactly.

The easy but nonphysical case



What's wrong with this?

$$s(t) = w(t) \ast r(t)$$

A: Almost everything!

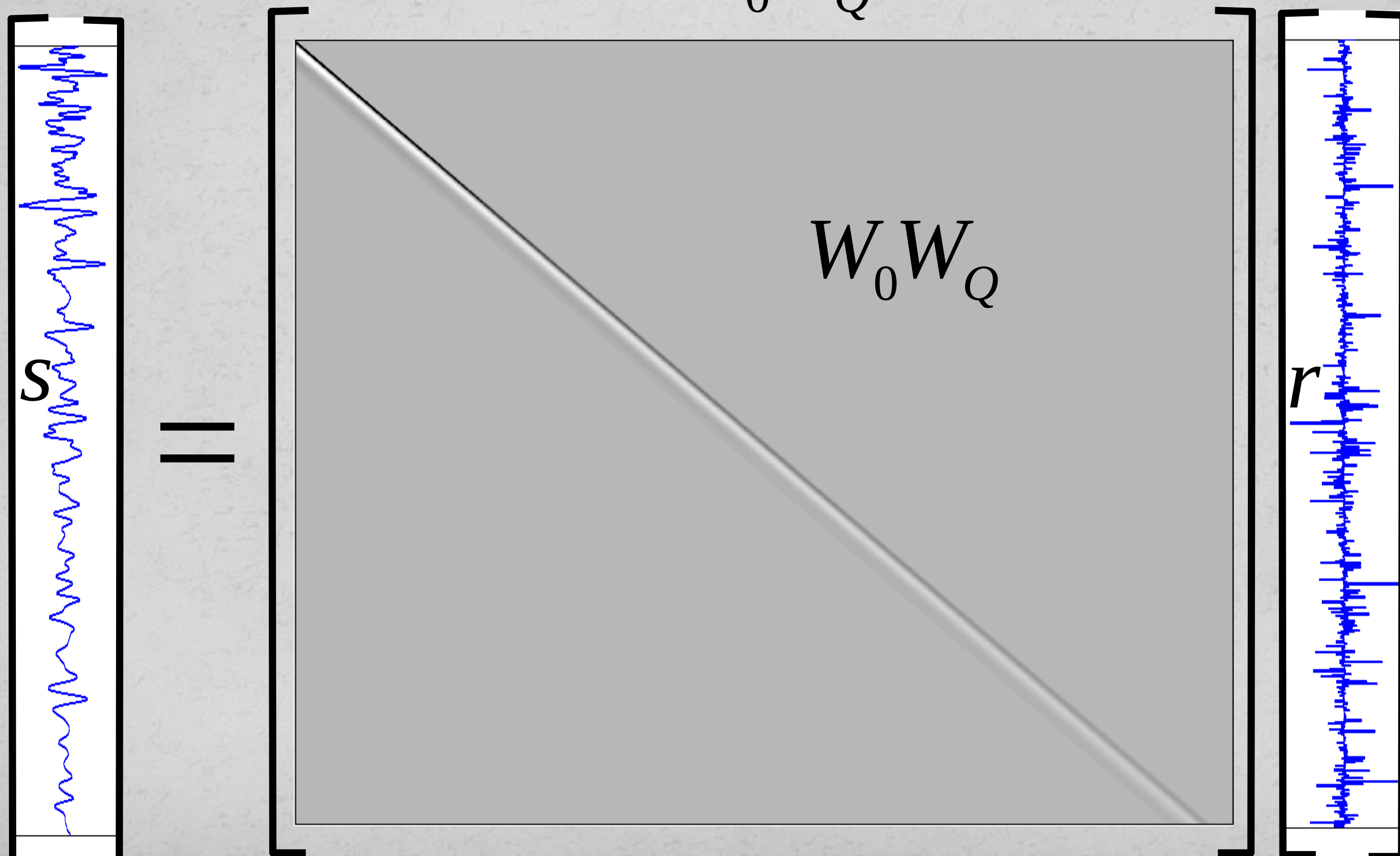
- Real reflectivity is not white
- The wavelet, while possibly minimum phase, evolves continuously
- Convolution cannot be stationary
- Noise is fundamentally important

Nonstationary trace model (CREWES q_tools)

Nonstationary Convolution Model

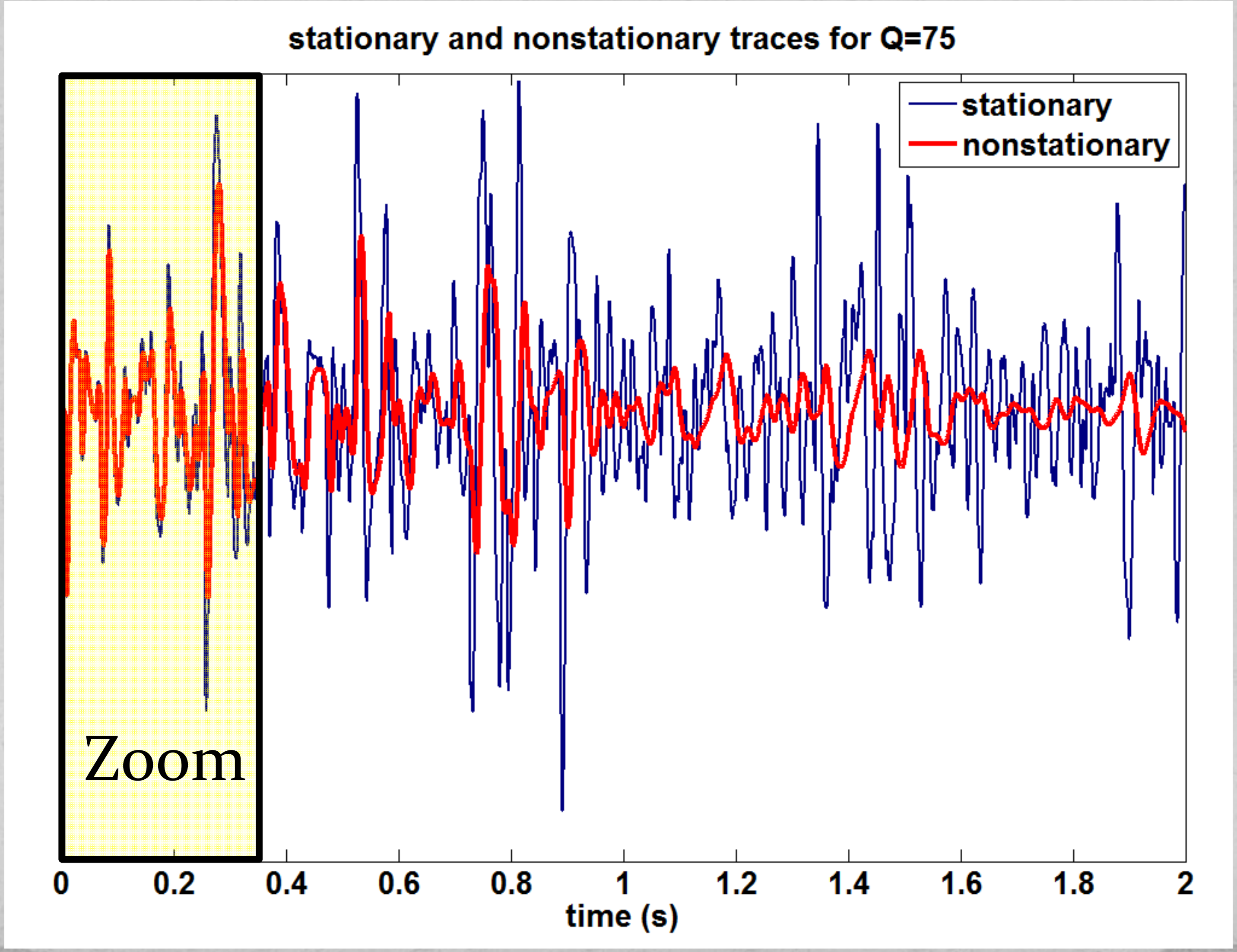
Better trace model

$$s = W_0 W_Q r$$



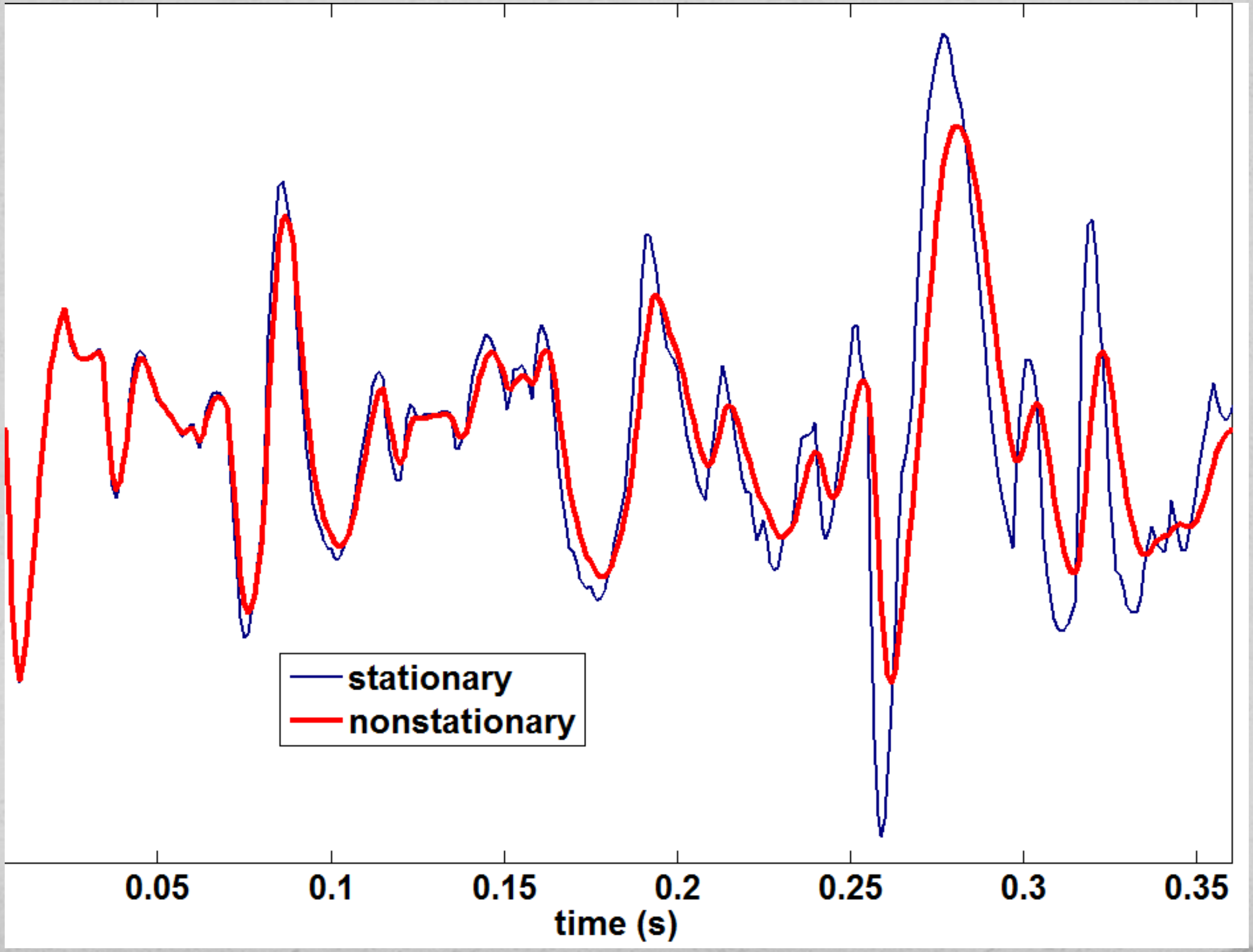
Nonstationary Convolution Model

Better trace model

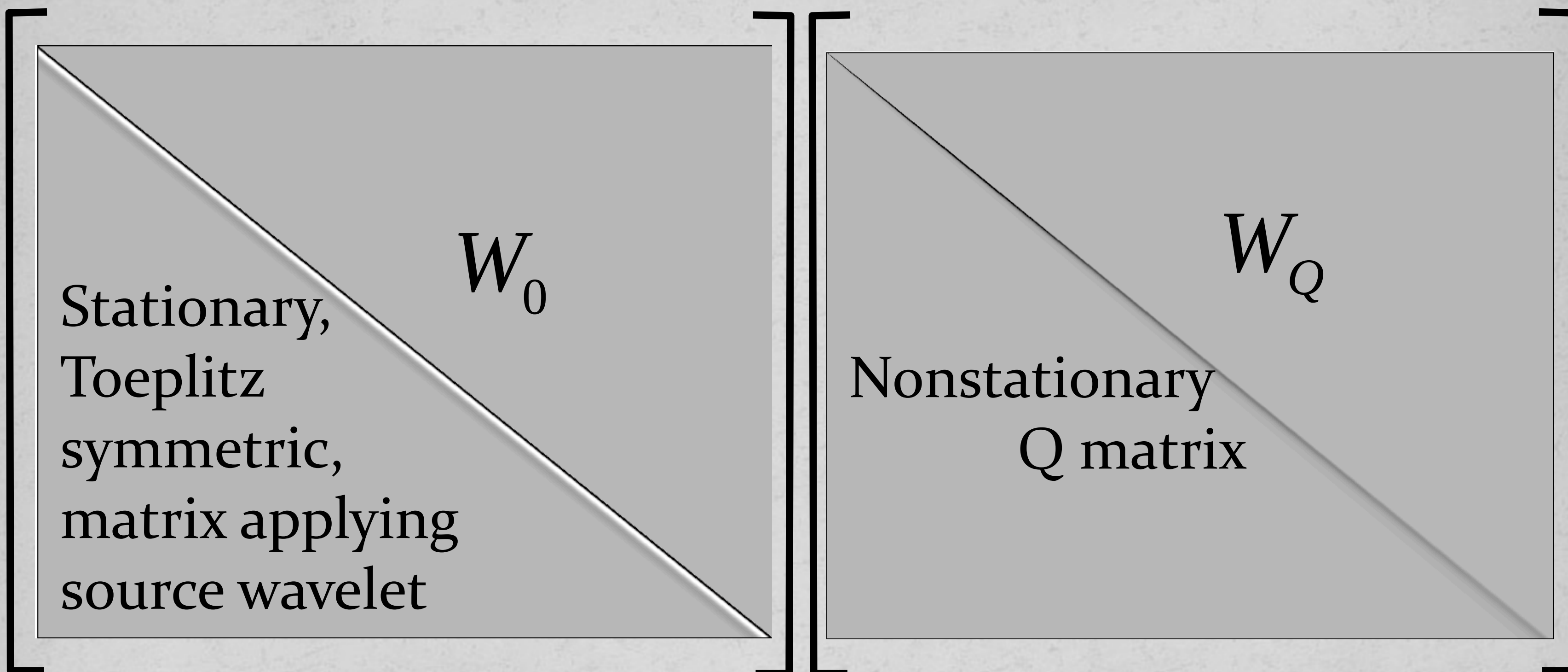


Nonstationary Convolution Model

Better trace model



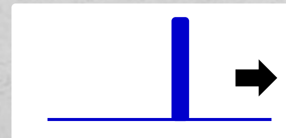
Factoring $W_0 W_Q$



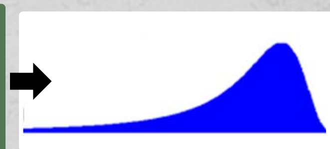
Note: $W_0 W_Q - W_Q W_0 \neq 0$ but is usually very small

Physical Effects of Anelastic Attenuation (CREWES q_tools)

Wavelet evolution

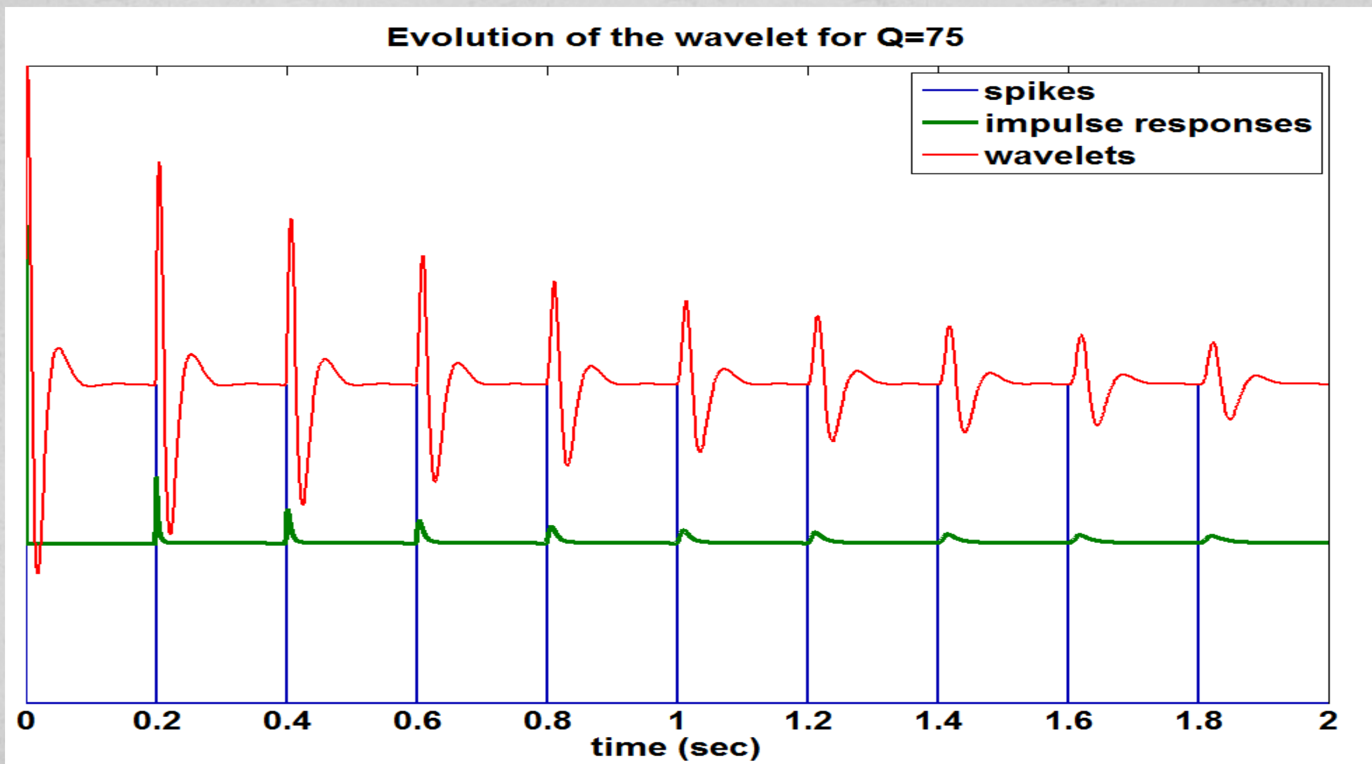


1D attenuating earth



Impulse in

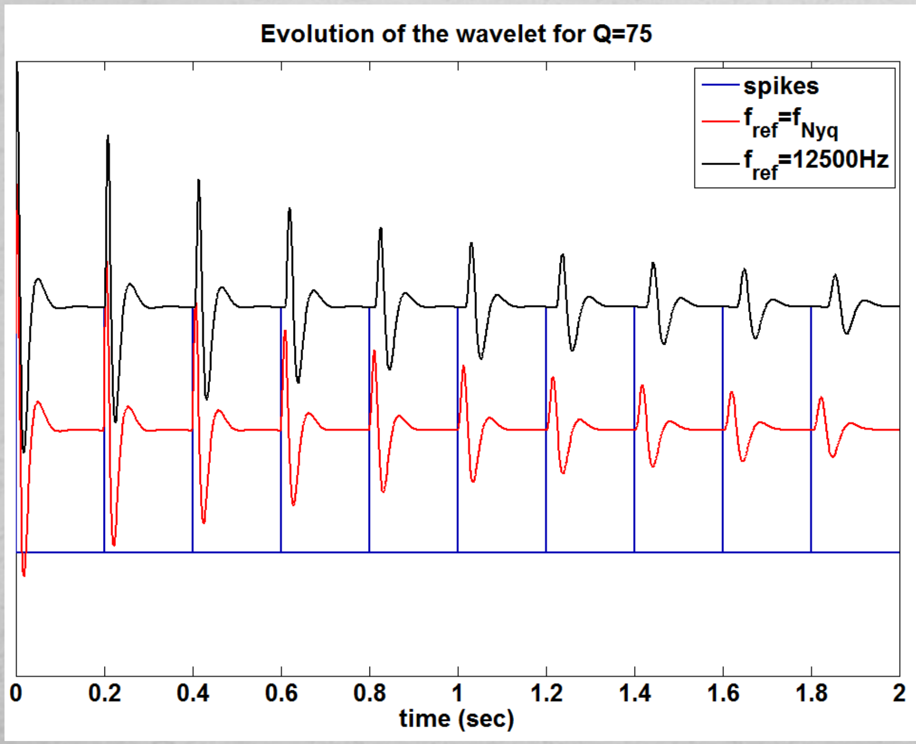
Blob out

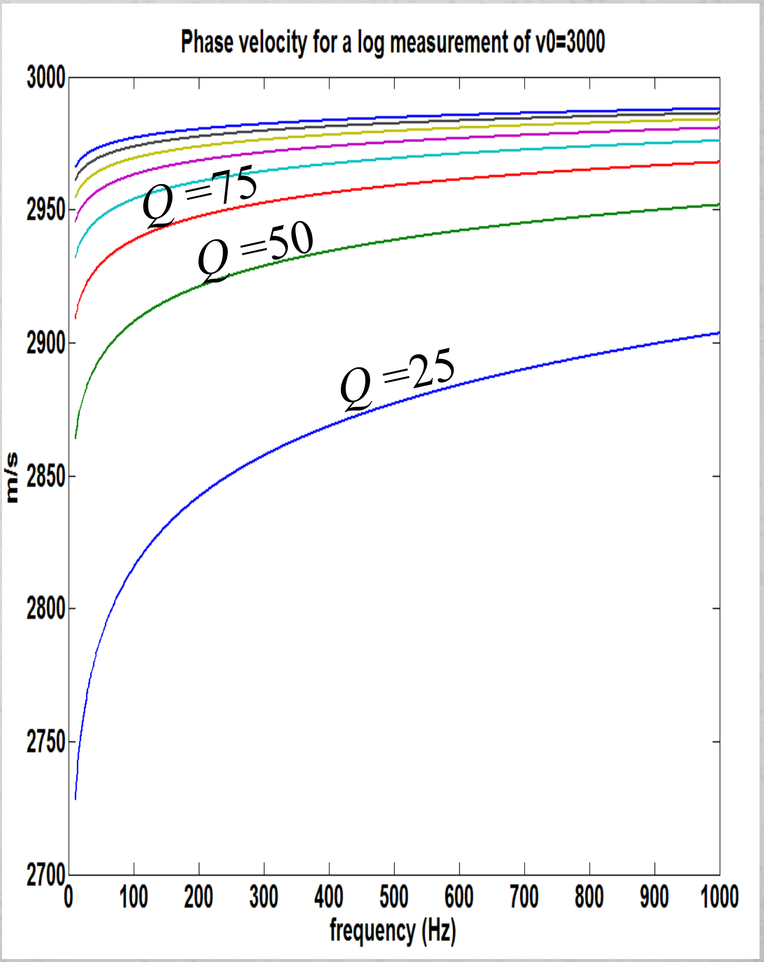


Wavelet evolution and drift

Frequency dependence of phase velocity leads to "drift"

$$v(f) = v(f_{ref})\left(1 + \frac{1}{\pi Q}\log\left(\frac{f}{f_{ref}}\right)\right)$$

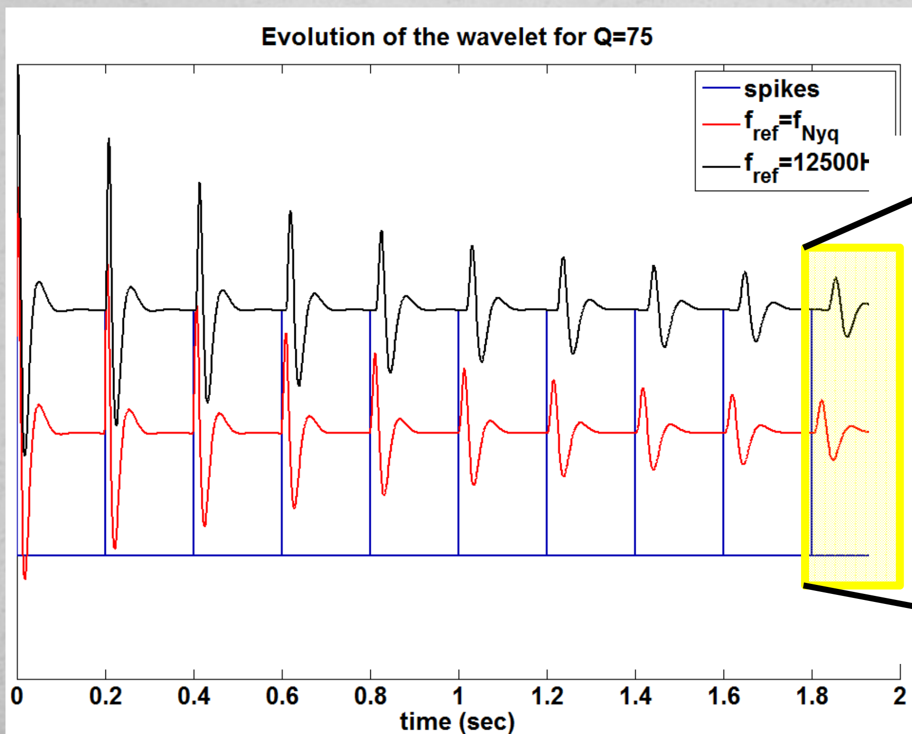


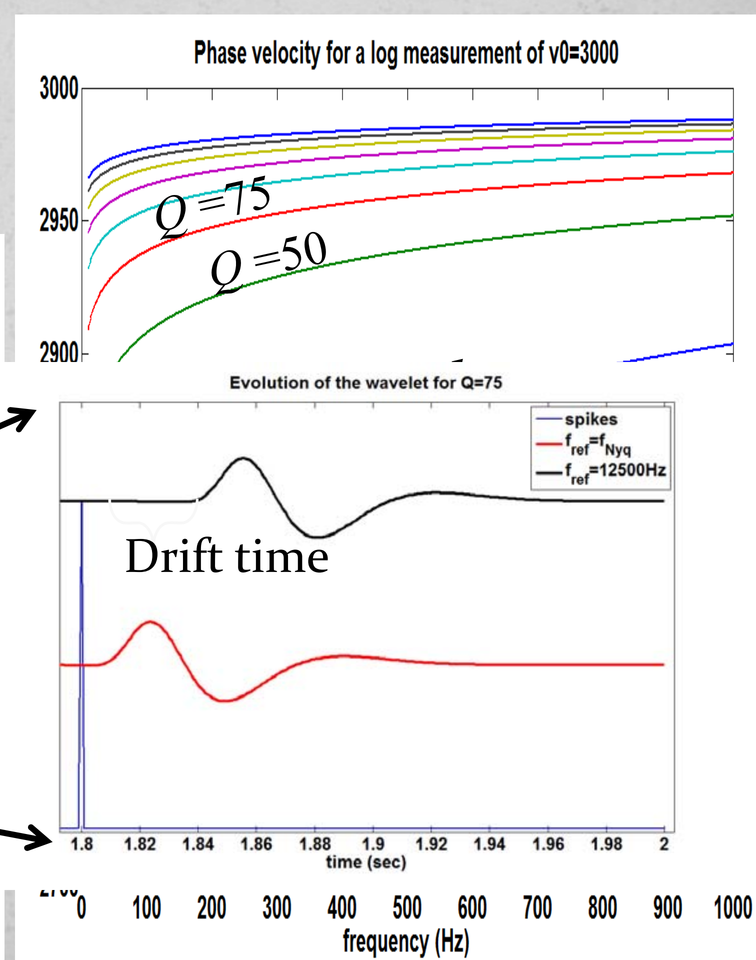


Wavelet evolution and drift

Frequency dependence of phase velocity leads to "drift"

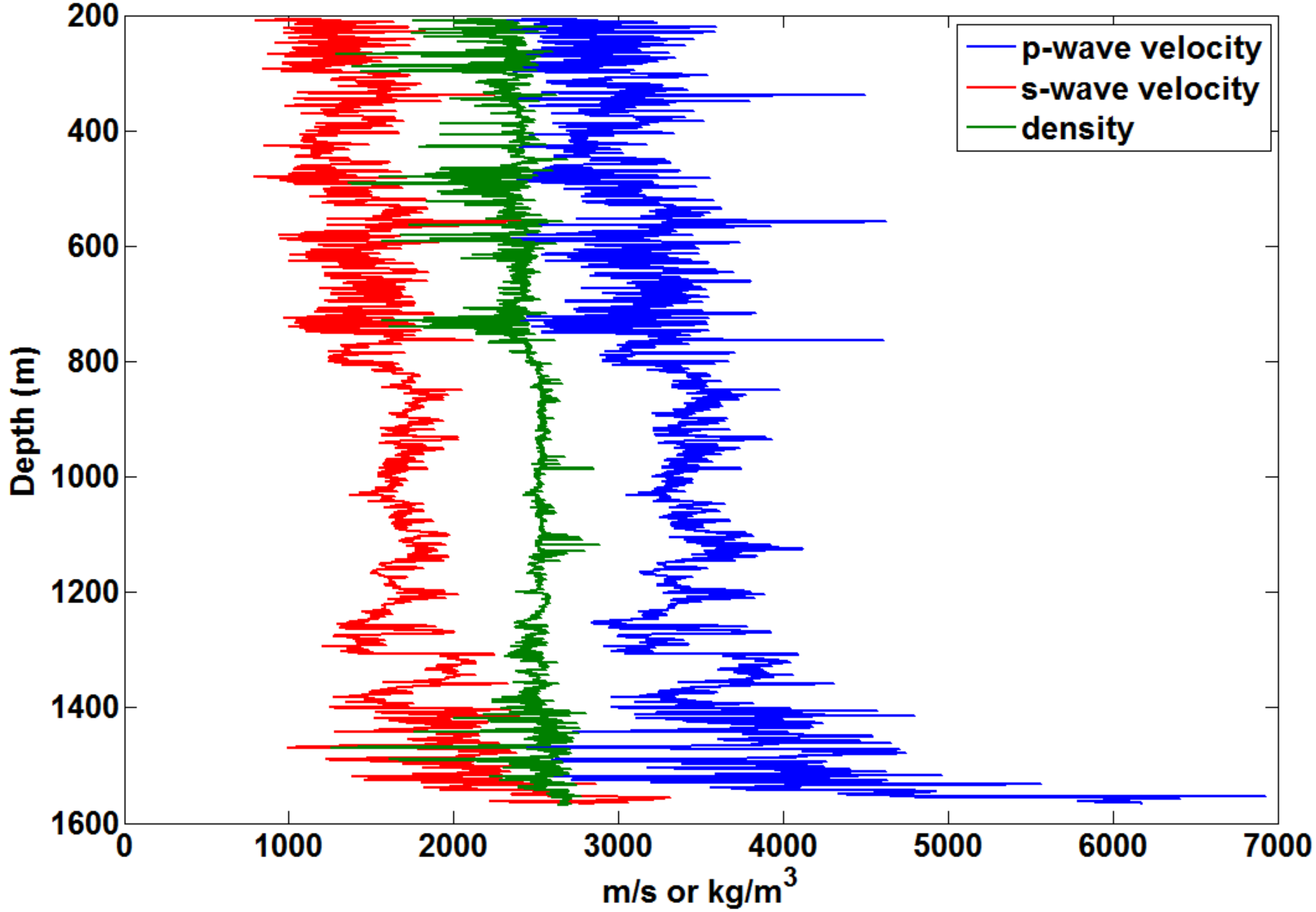
$$v(f) = v(f_{ref})\left(1 + \frac{1}{\pi Q}\log\left(\frac{f}{f_{ref}}\right)\right)$$



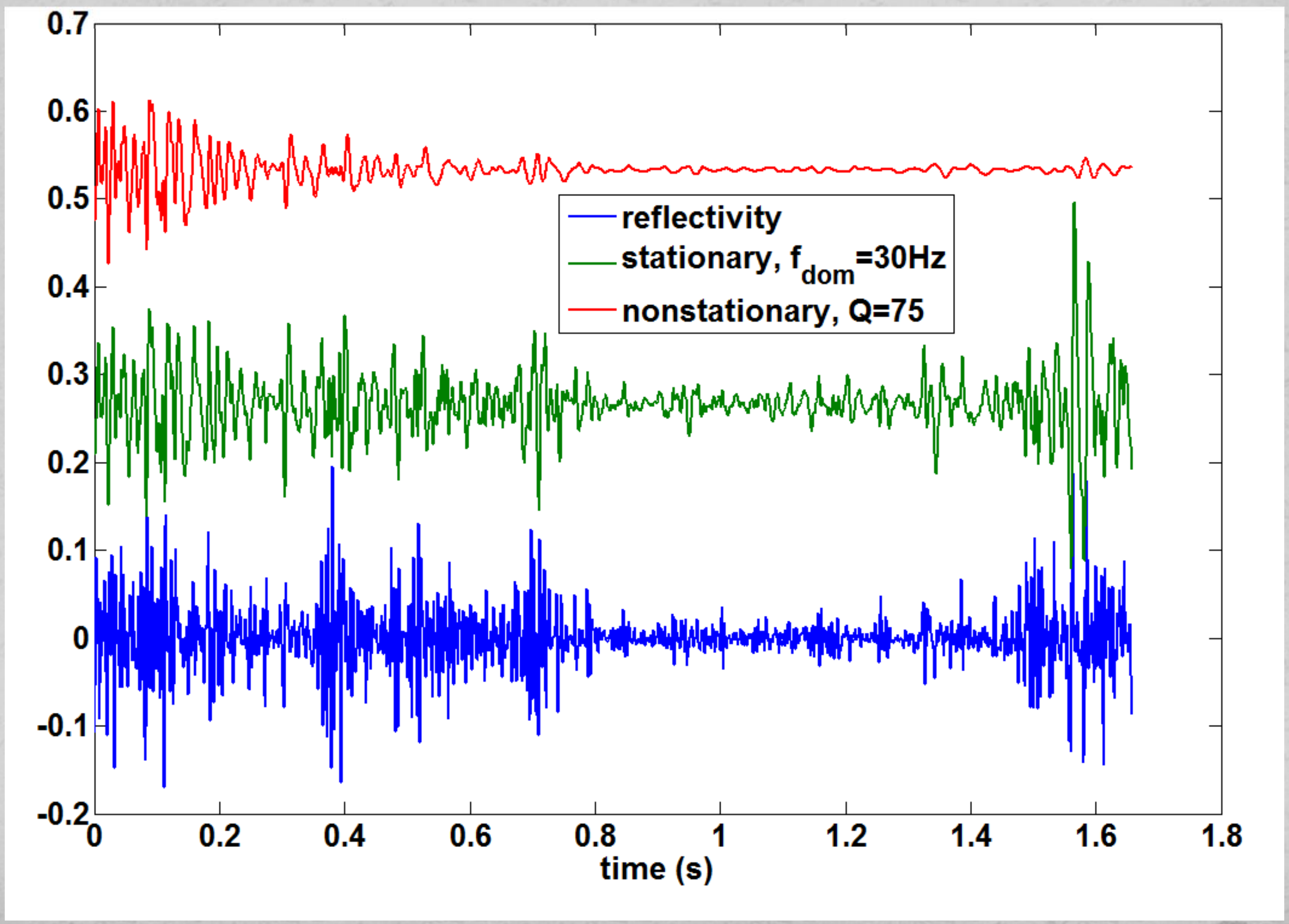


Nonstationary seismogram from well logs

Hussar 12-27 Logs

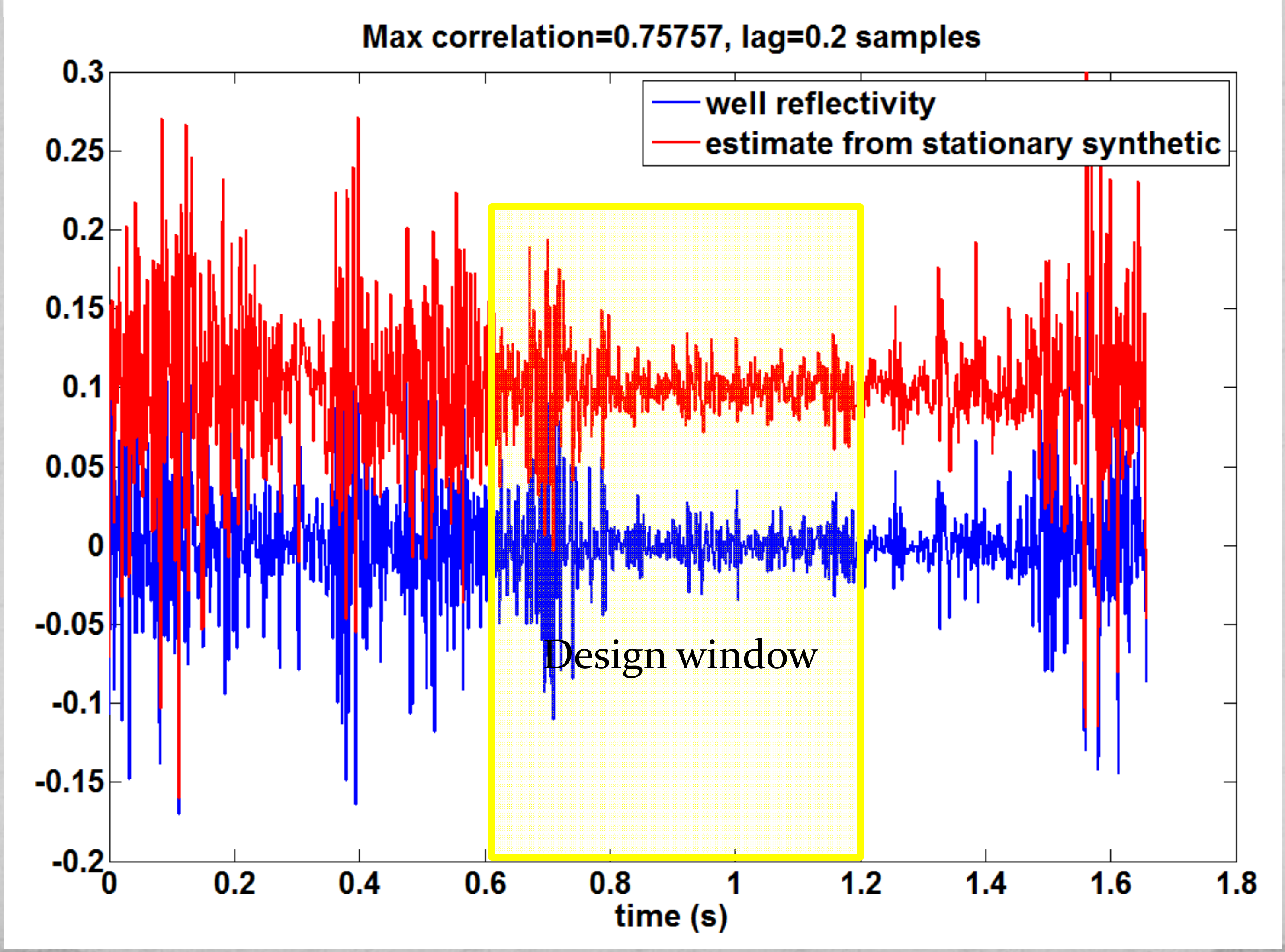


Synthetic seismograms from
Hussar 12-27 Logs, logging depths doubled

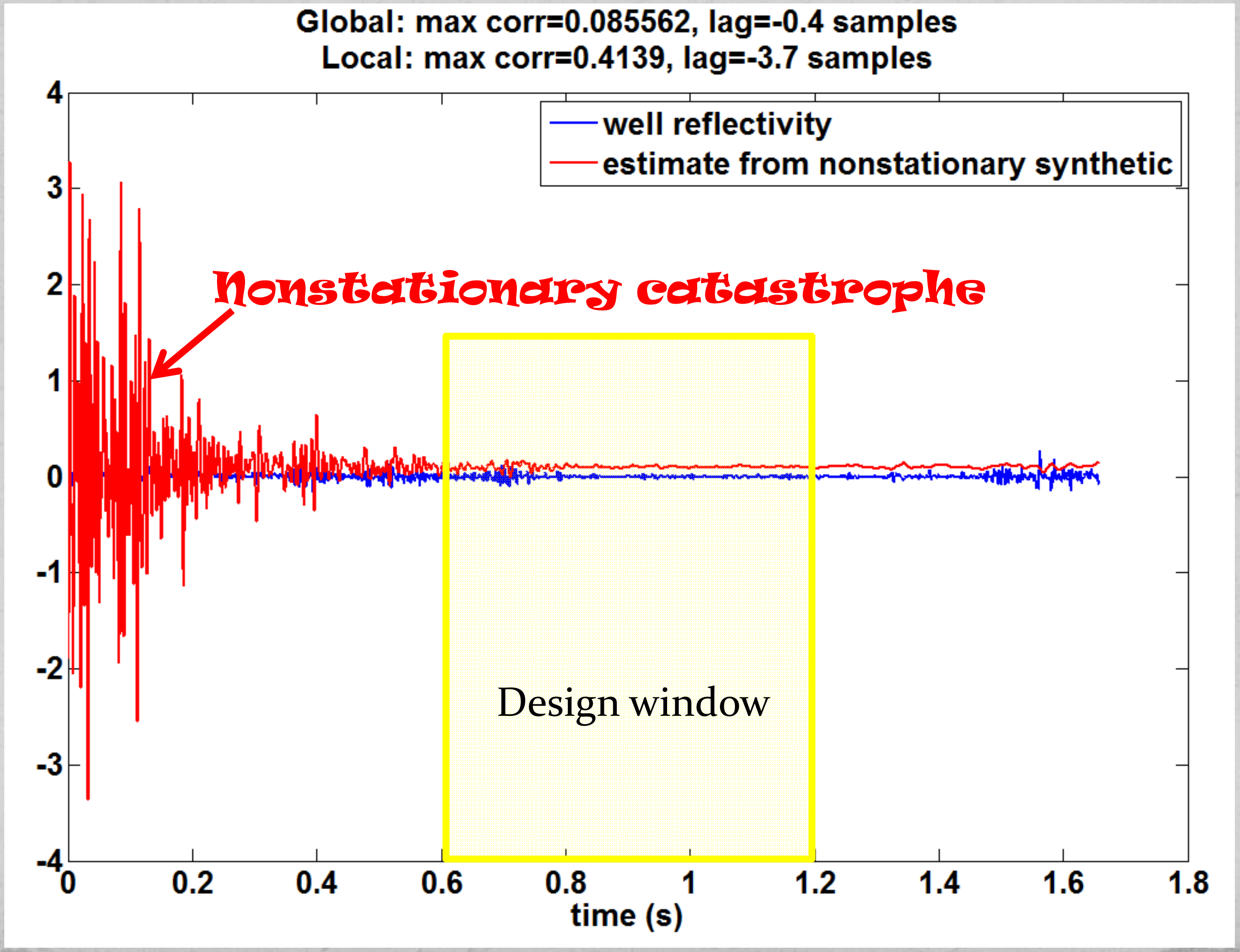


Failure of
Stationary Deconvolution

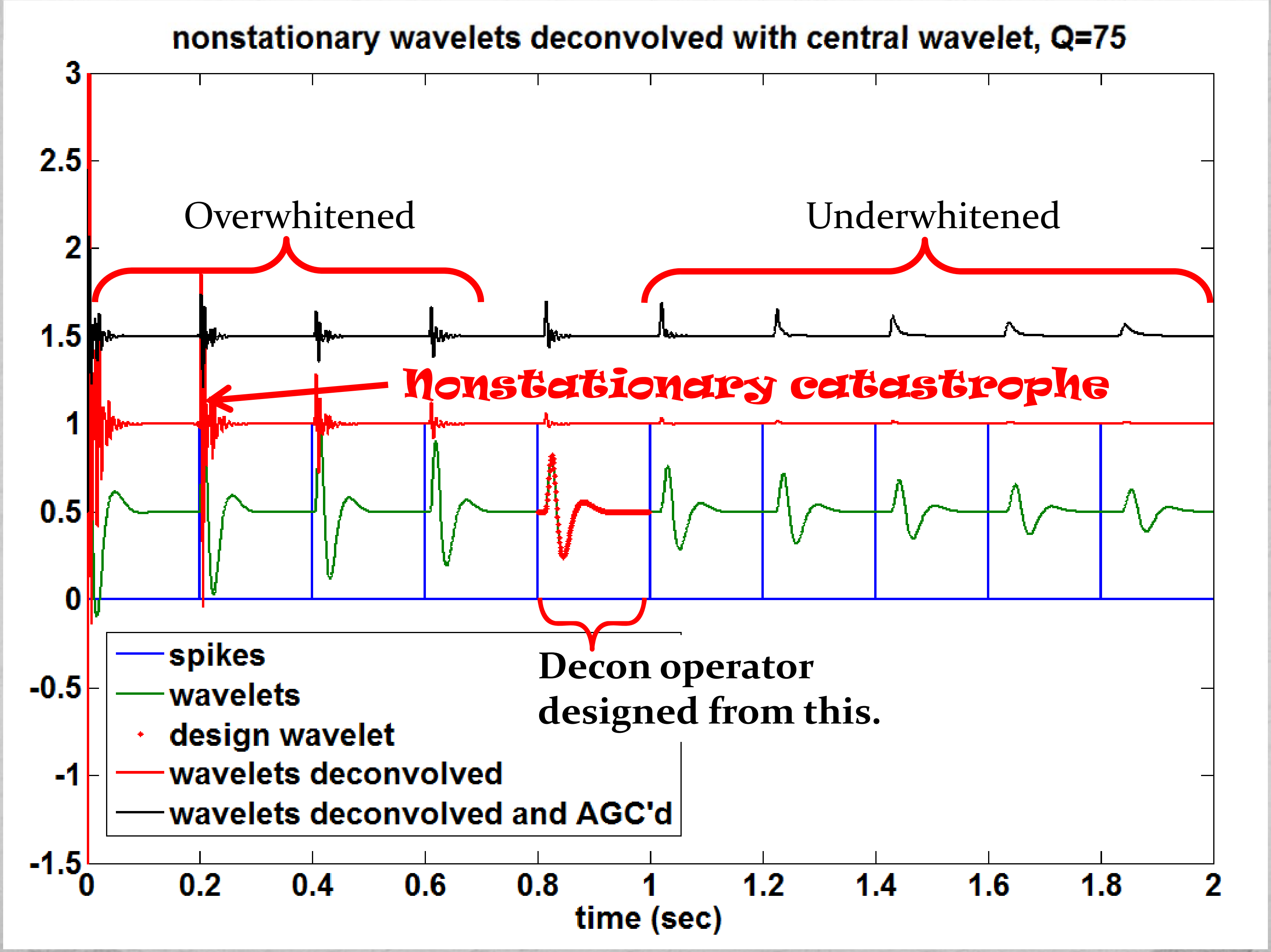
Stationary decon of stationary seismogram
the unphysical case



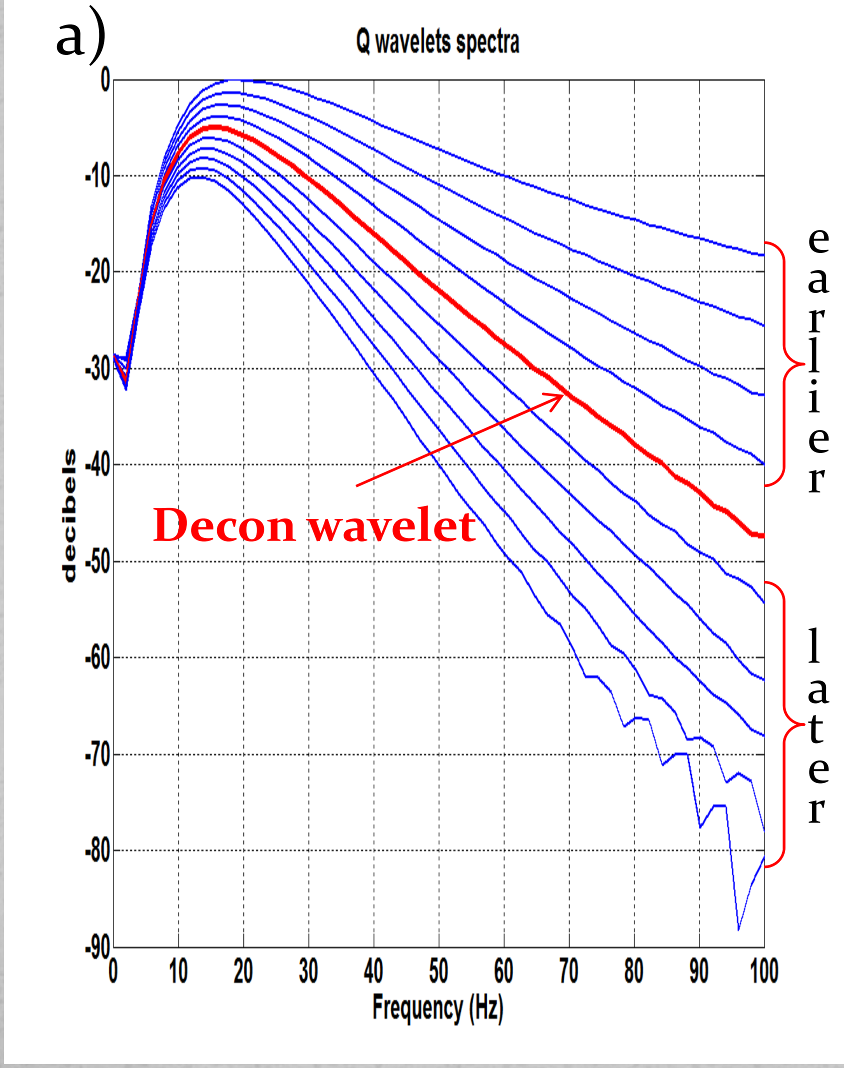
Stationary decon of nonstationary seismogram

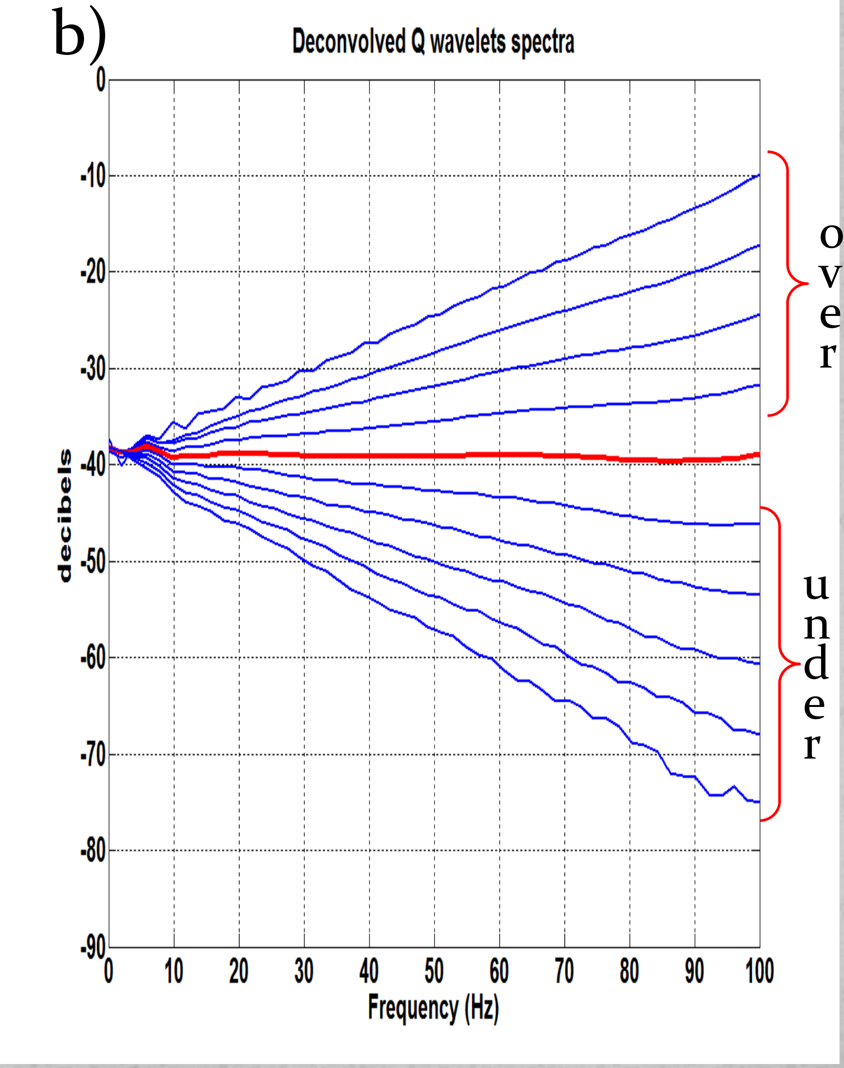


Nonstationary catastrophe



Understanding the
Nonstationary catastrophe

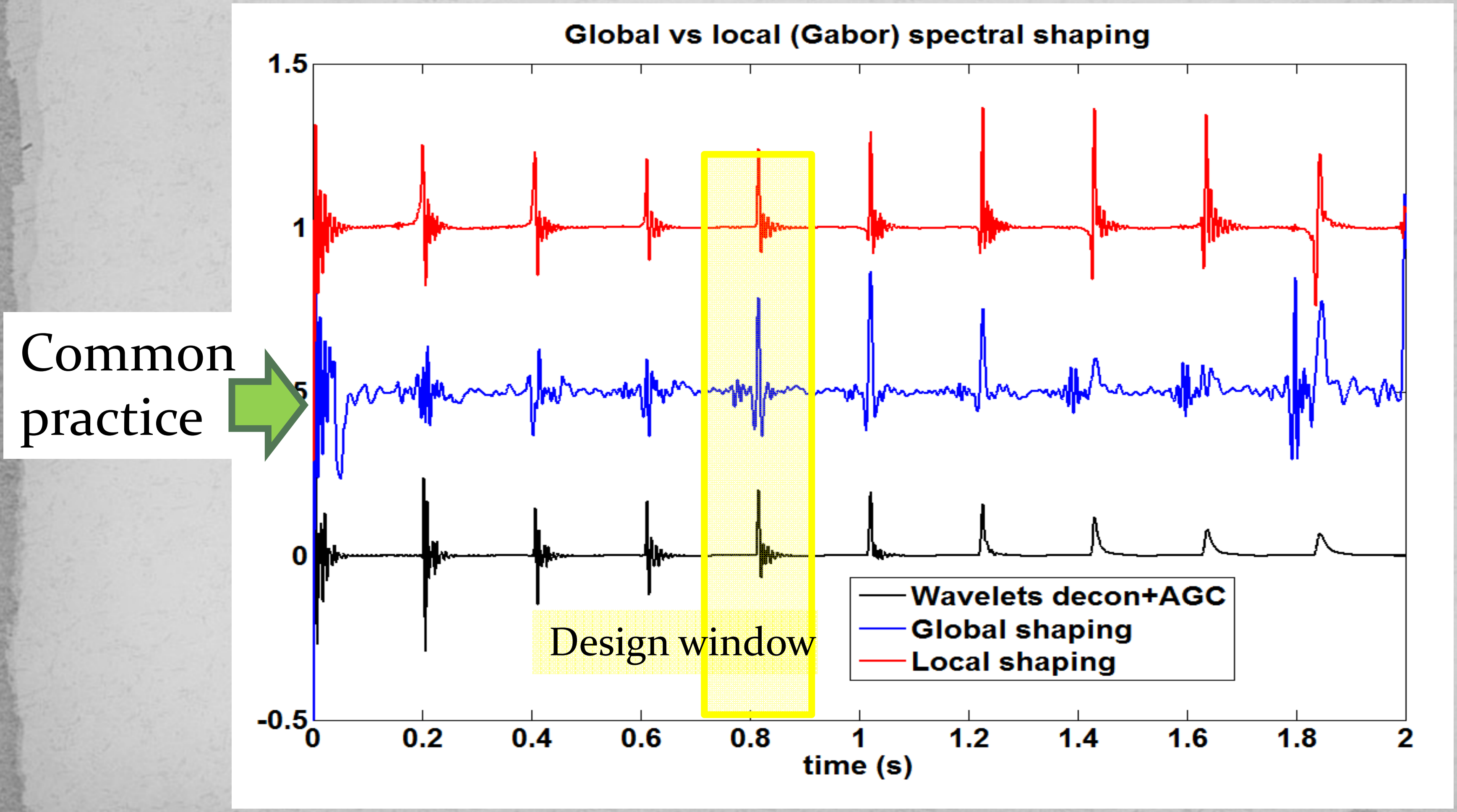




Nonstationary catastrophe

Can spectral shaping help?

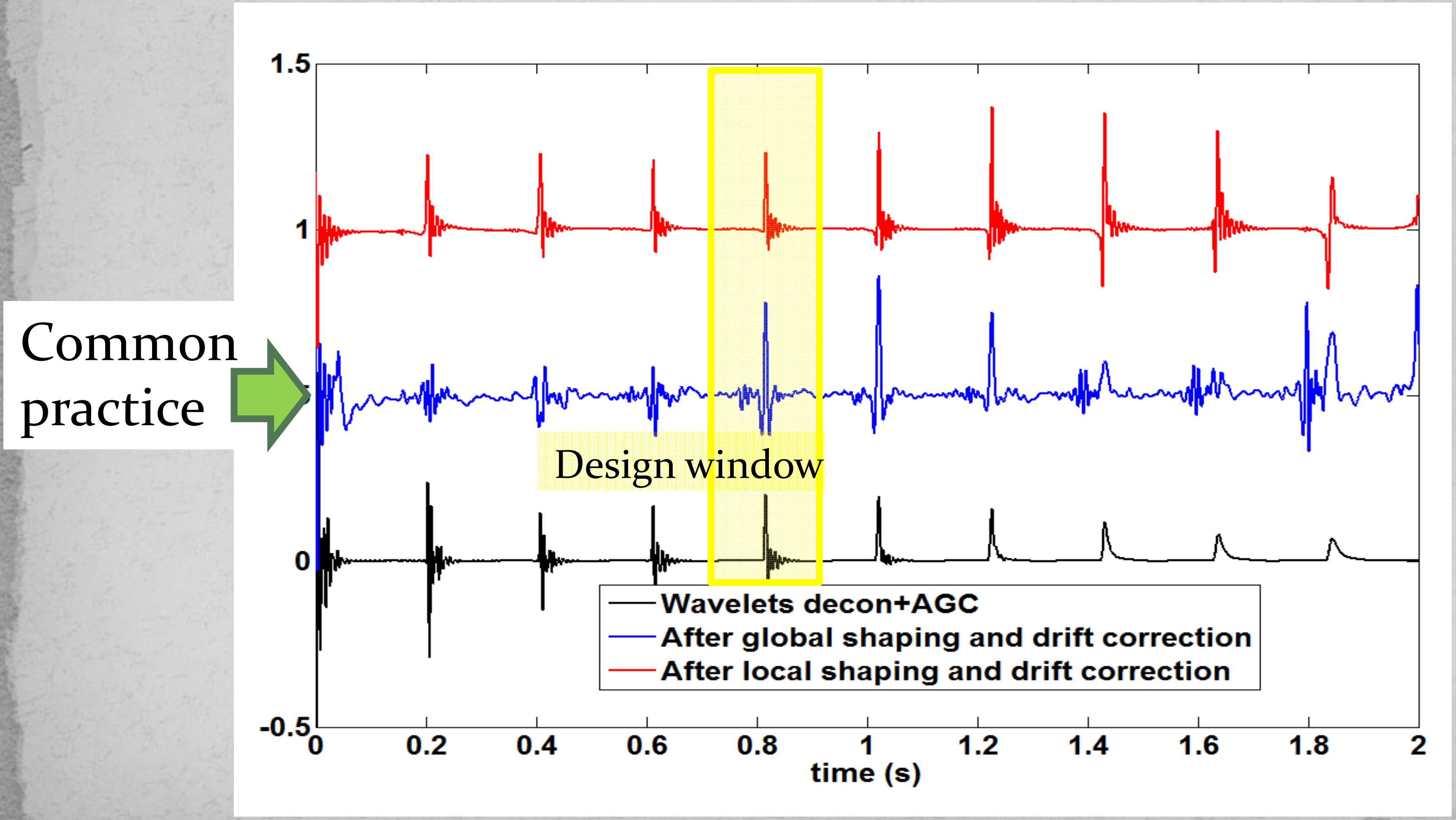
Impose the amplitude spectrum from the ideal case



Nonstationary catastrophe

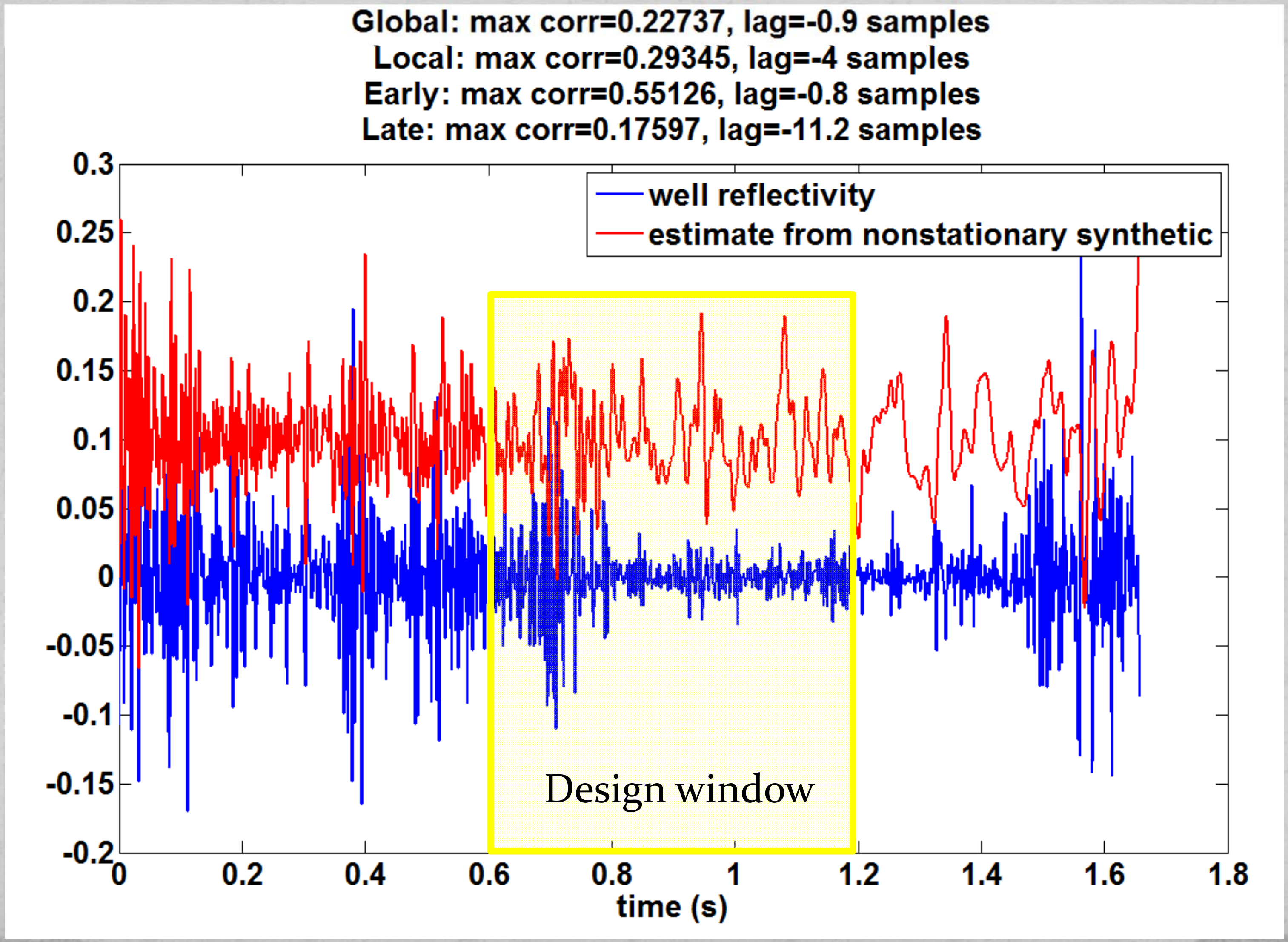
Can phase rotations help?

Find best constant phase rotation in local Gabor windows (drift correction should be done first)



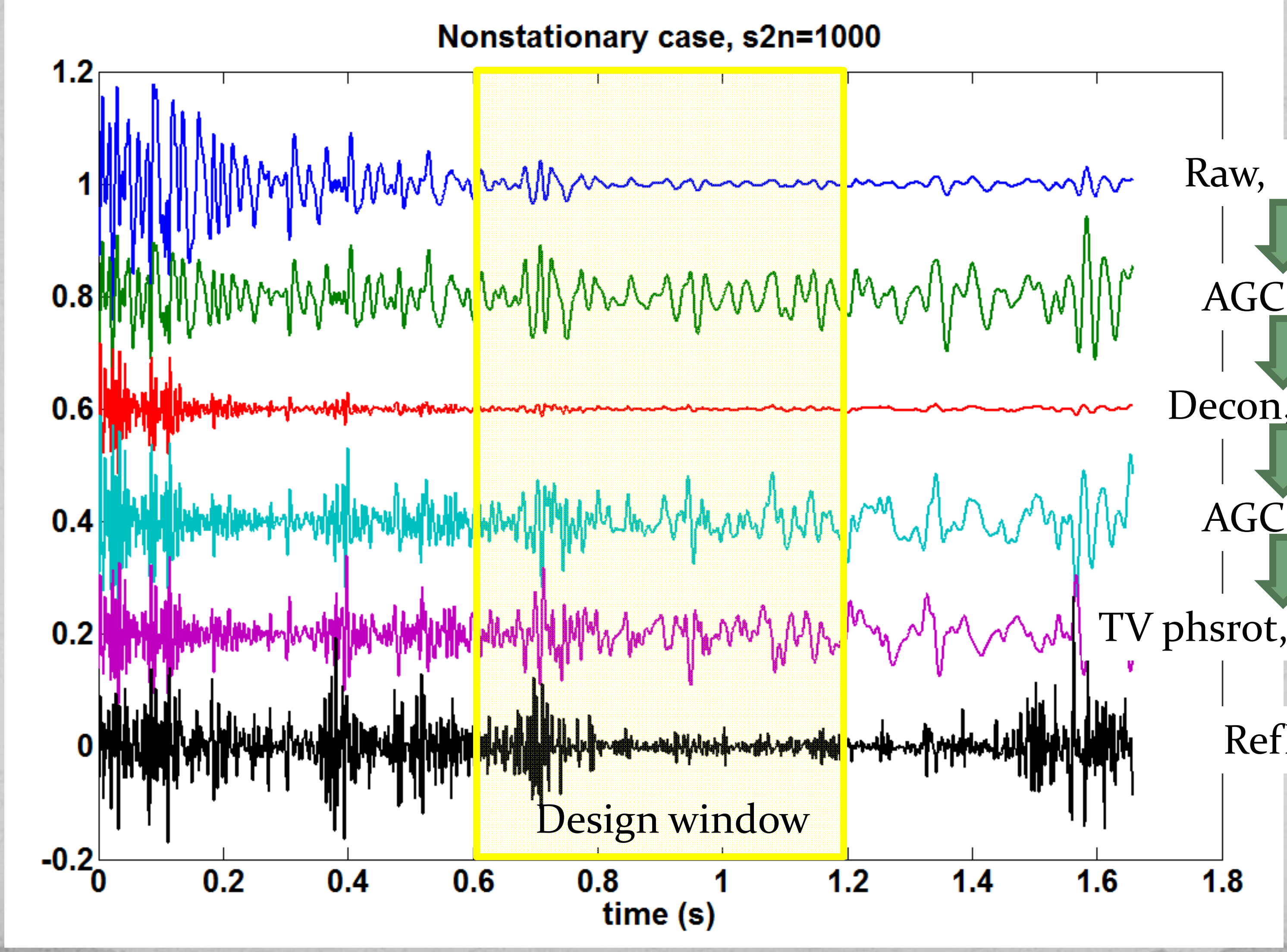
Nonstationary catastrophe

Can AGC help?



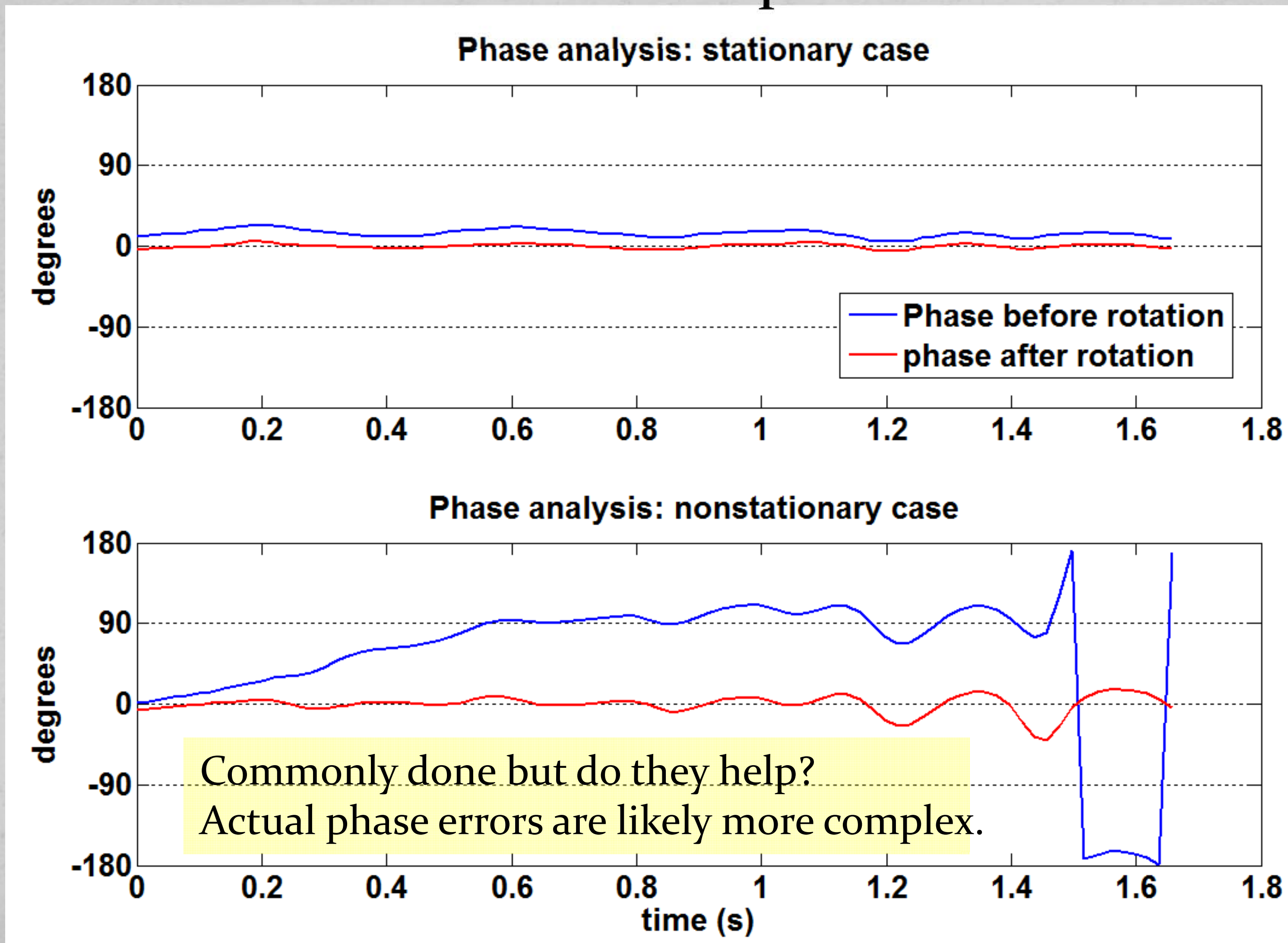
Stationary deconvolution

Nonstationary band-aid



Phase error analysis

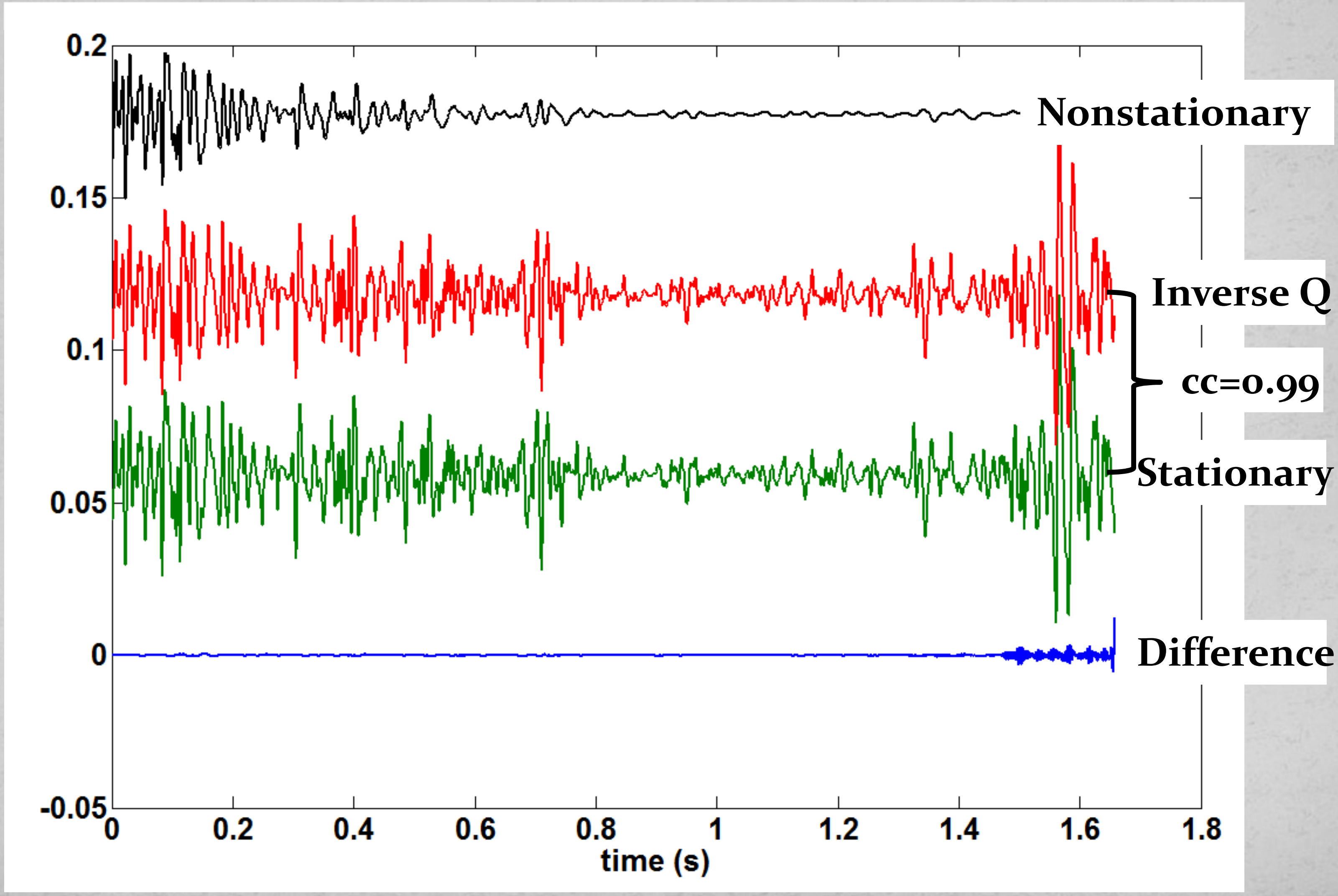
time-variant constant phase estimates



Commonly done but do they help?
Actual phase errors are likely more complex.

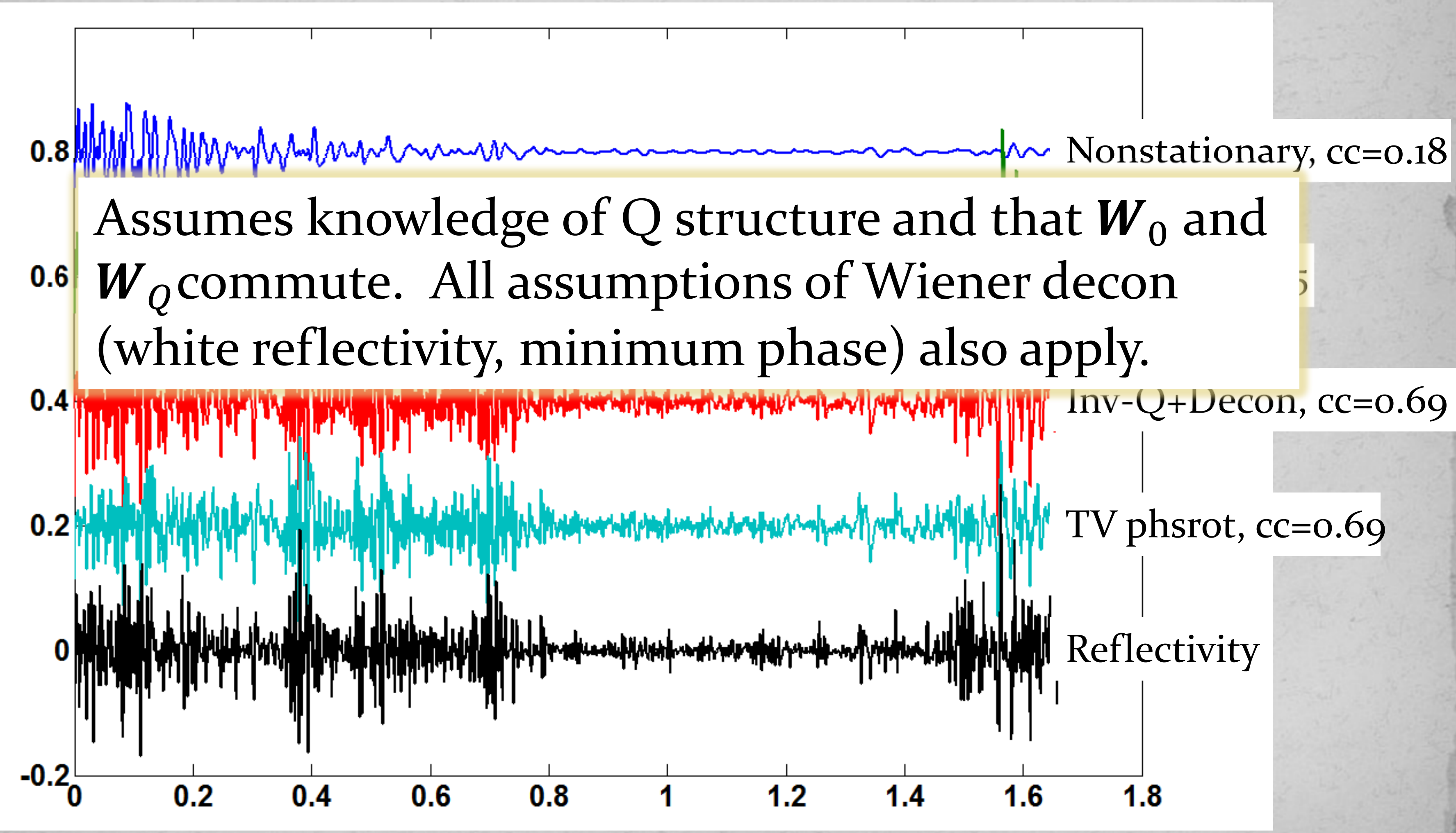
Inverse Q filter
and
Gabor deconvolution

Inverse Q filter renders the nonstationary trace stationary



Inverse Q filter then Wiener decon

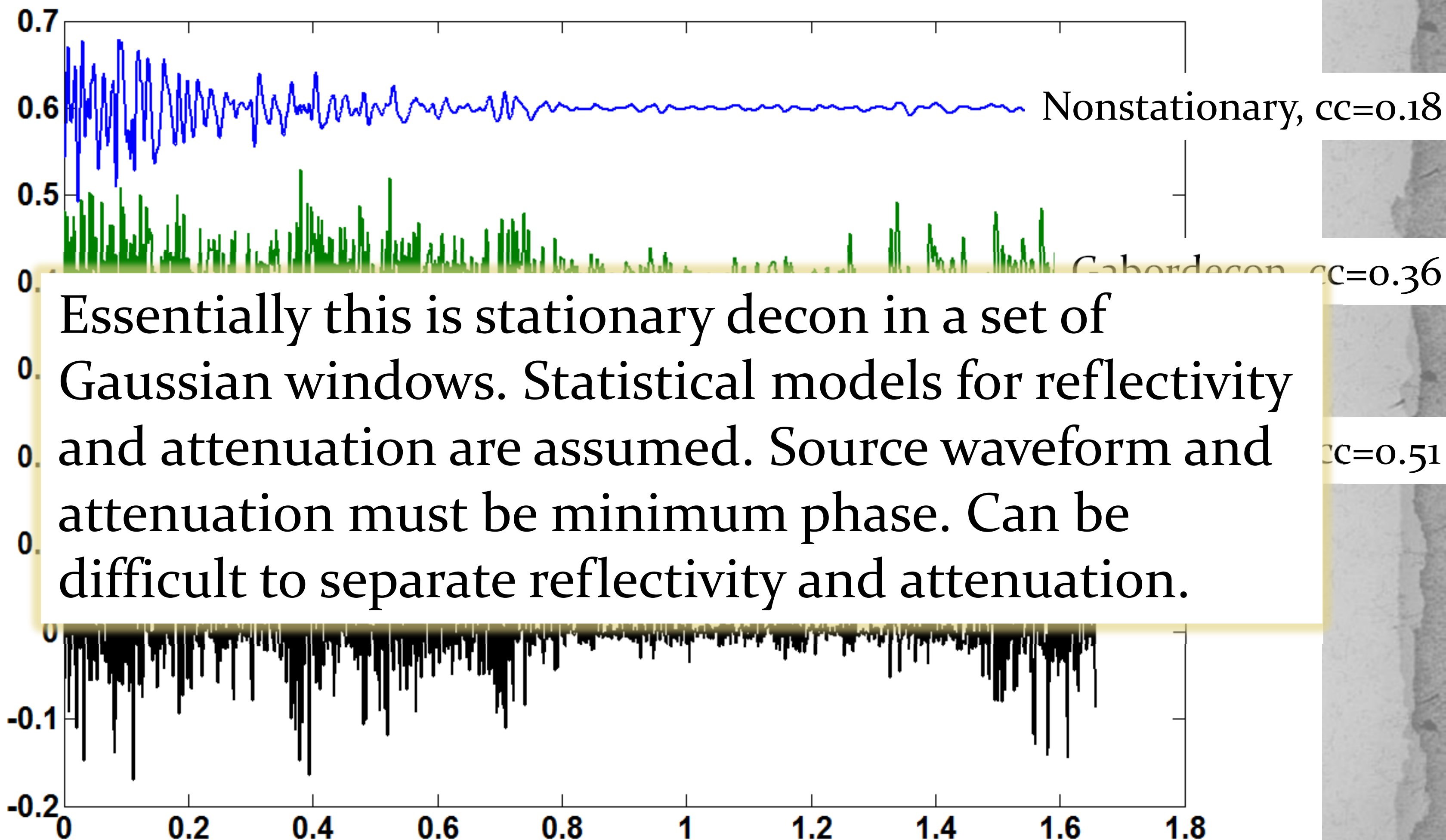
avoiding the nonstationary catastrophe



Assumes knowledge of Q structure and that $\boldsymbol{W}_0$ and $\boldsymbol{W}_Q$ commute. All assumptions of Wiener decon (white reflectivity, minimum phase) also apply.

Gabor decon

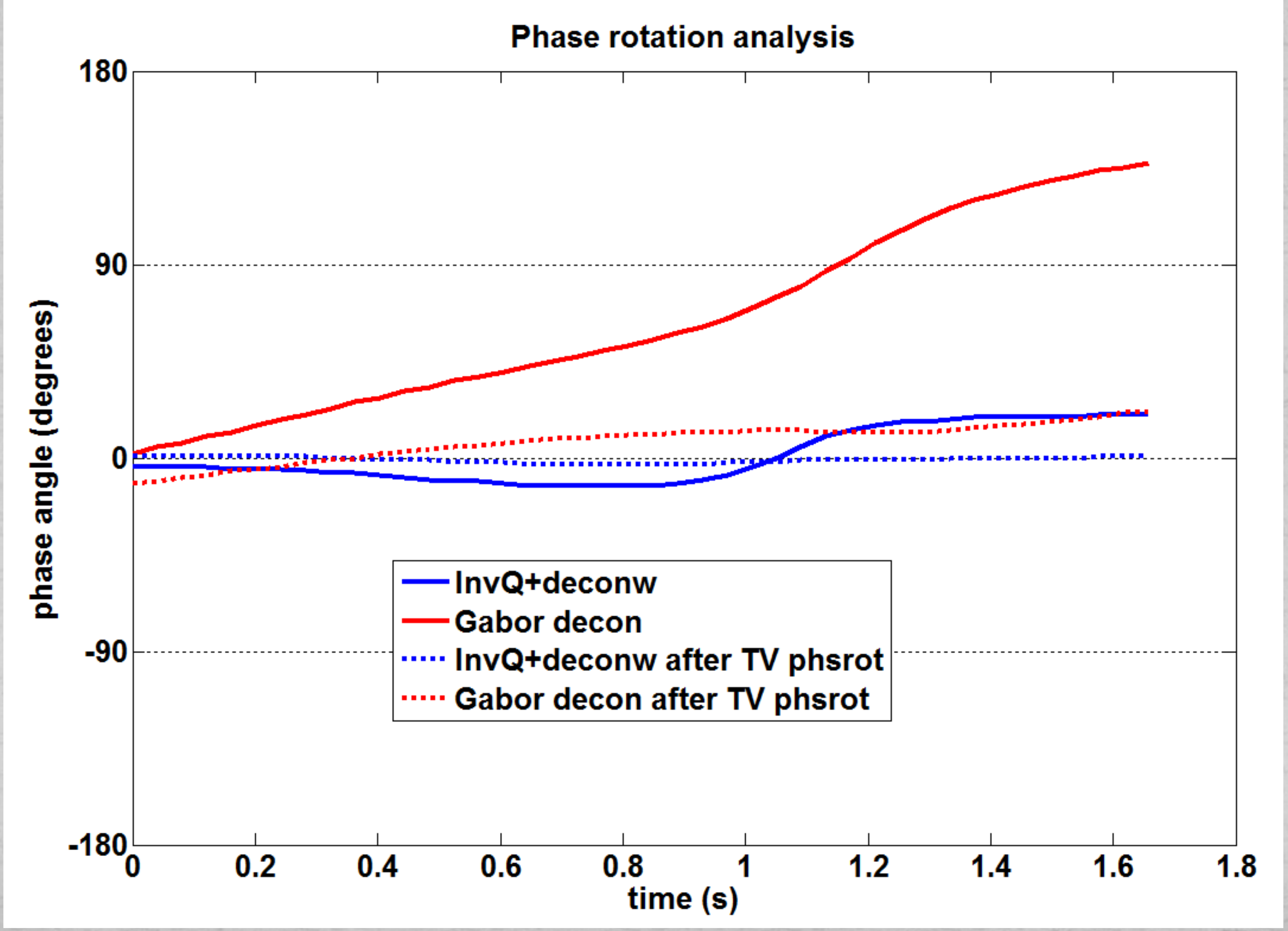
avoiding the nonstationary catastrophe



Essentially this is stationary decon in a set of Gaussian windows. Statistical models for reflectivity and attenuation are assumed. Source waveform and attenuation must be minimum phase. Can be difficult to separate reflectivity and attenuation.

Phase rotation analysis

Inverse Q->deconw compared to Gabor decon

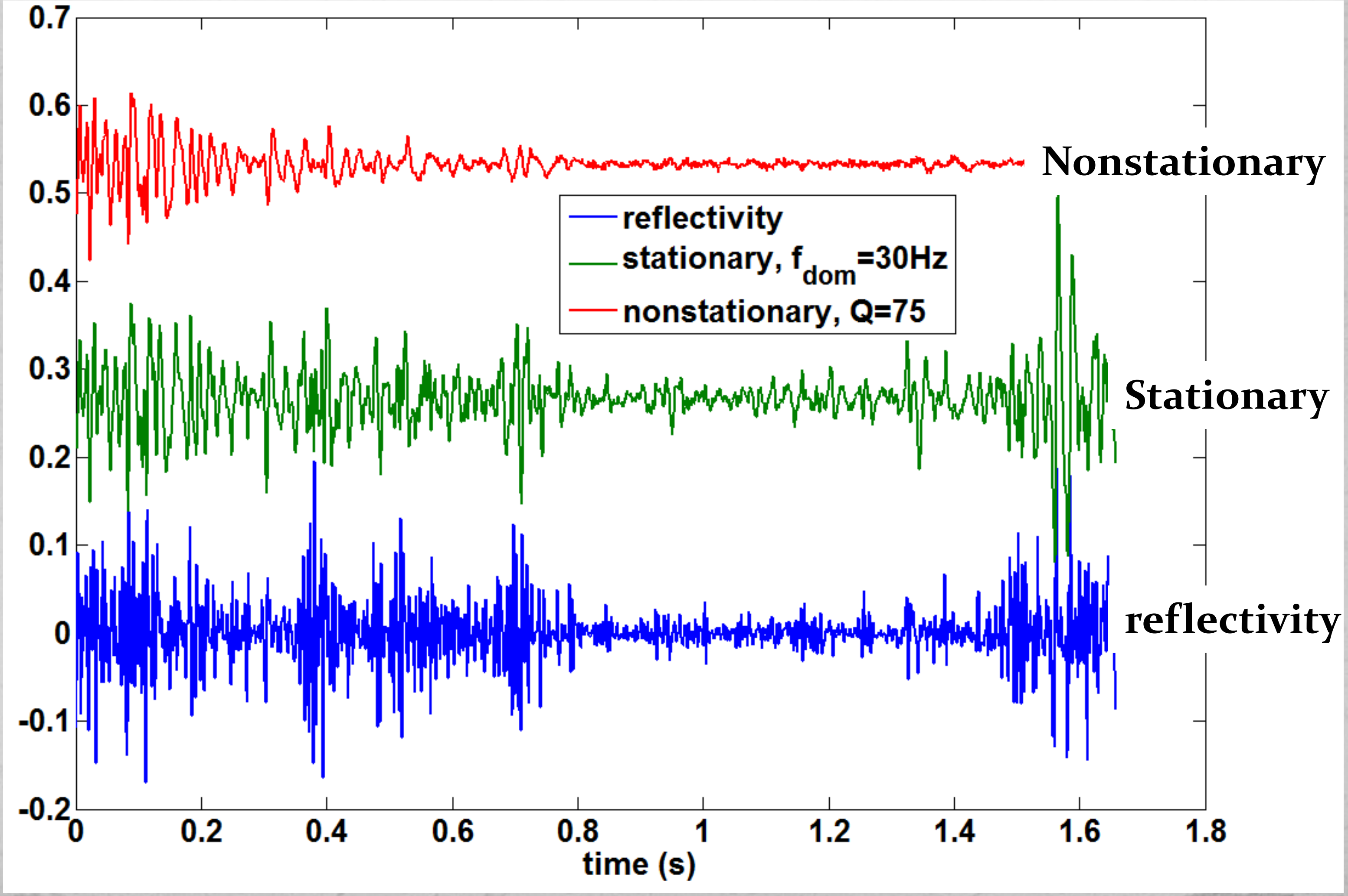


Inclusion of noise

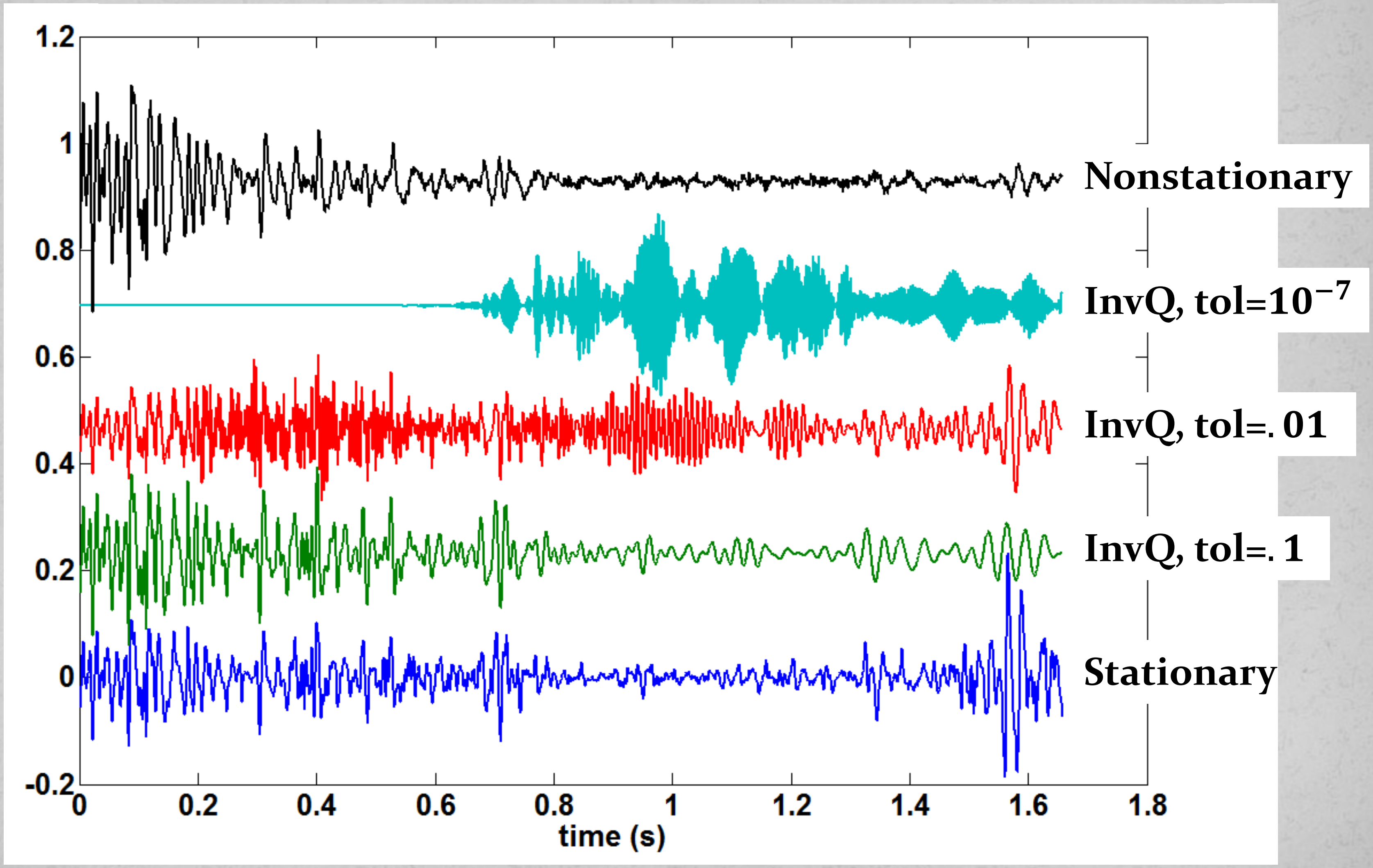
Noisy seismograms

S2N=2 in design window of nonstationary trace

Identical noise added to both seismograms

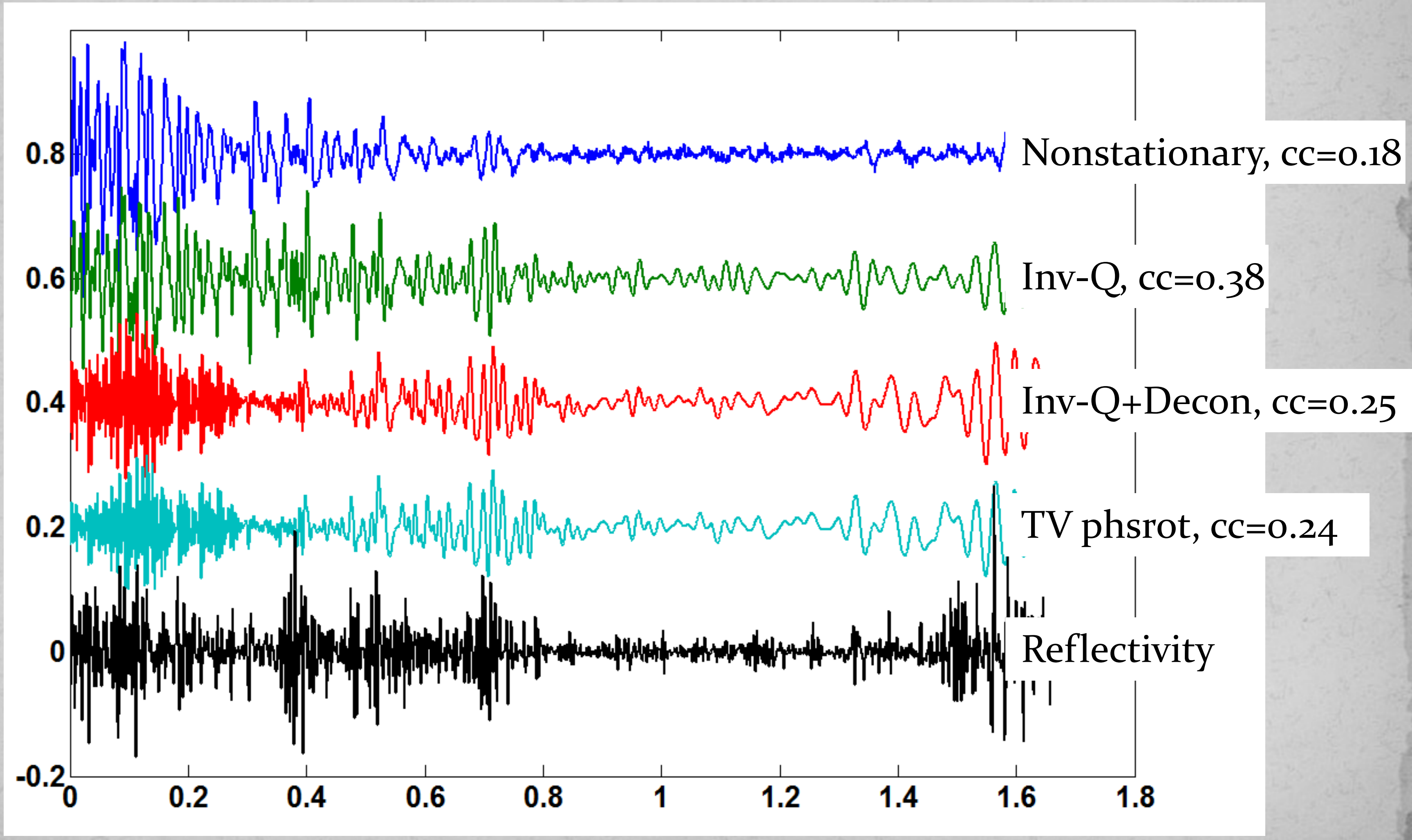


Inverse Q filter on noisy data



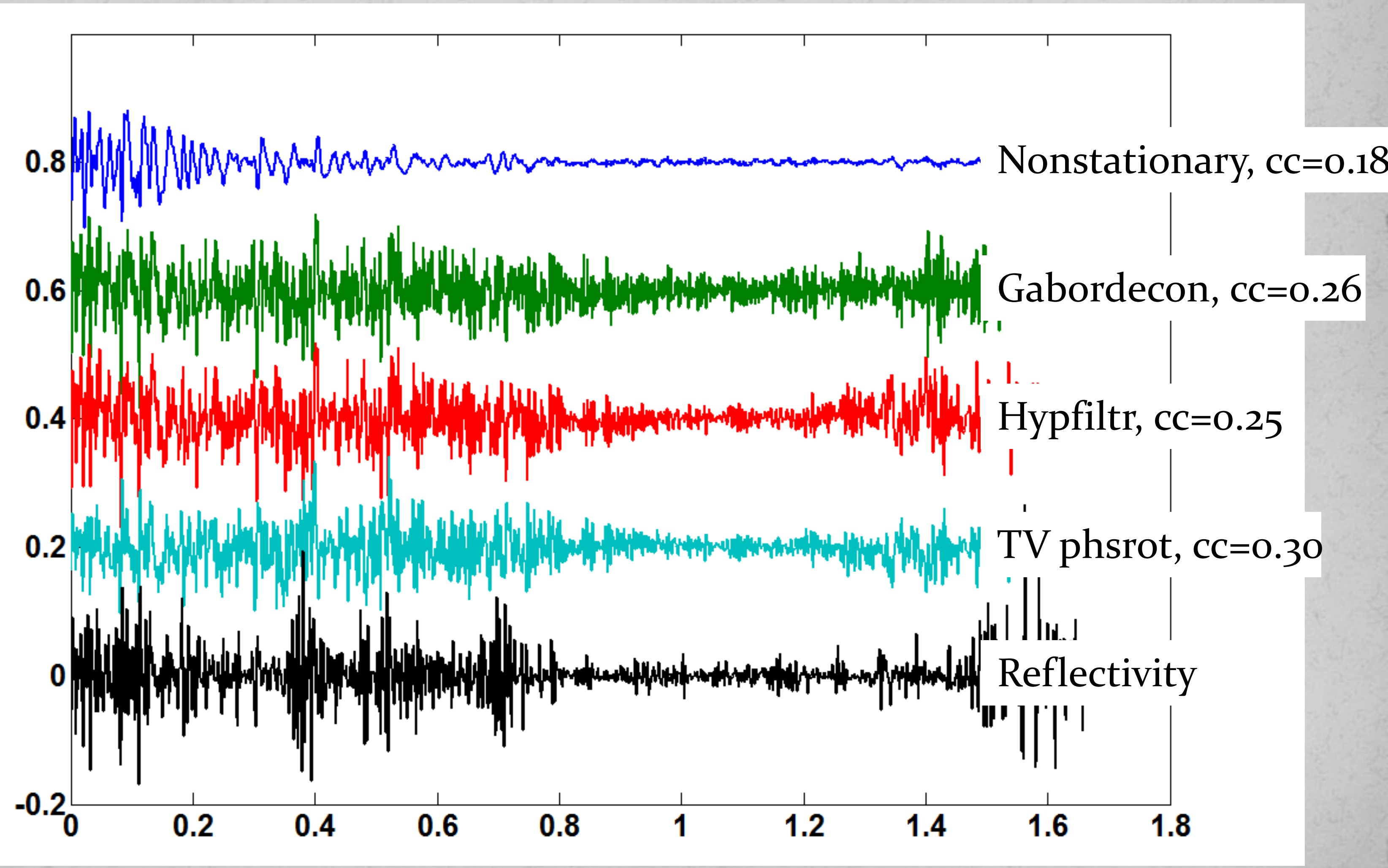
Inverse Q filter then Wiener decon

on noisy data



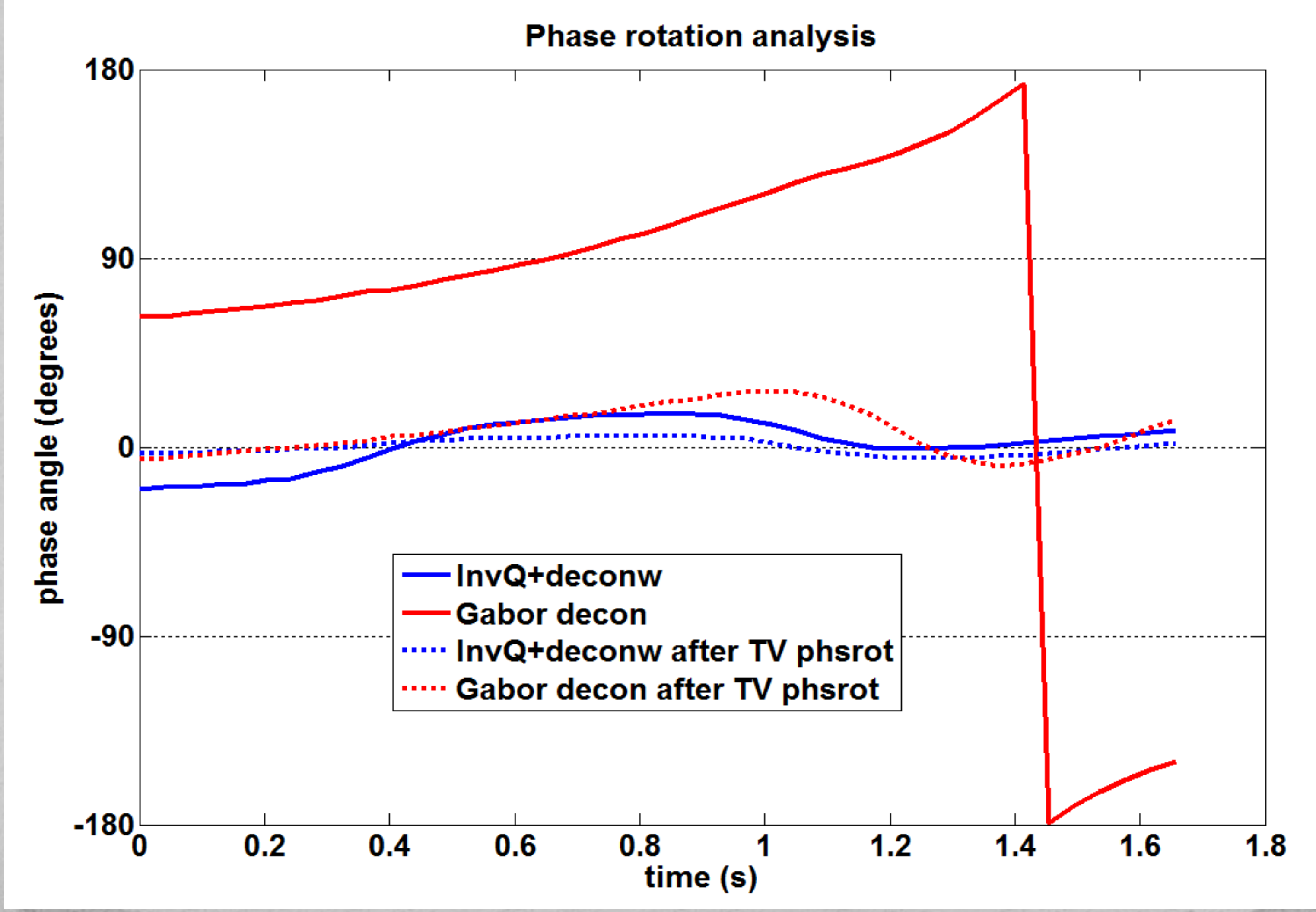
Gabor deconvolution

on noisy data



Phase rotation analysis

Inverse Q->deconw compared to Gabor decon on noisy data



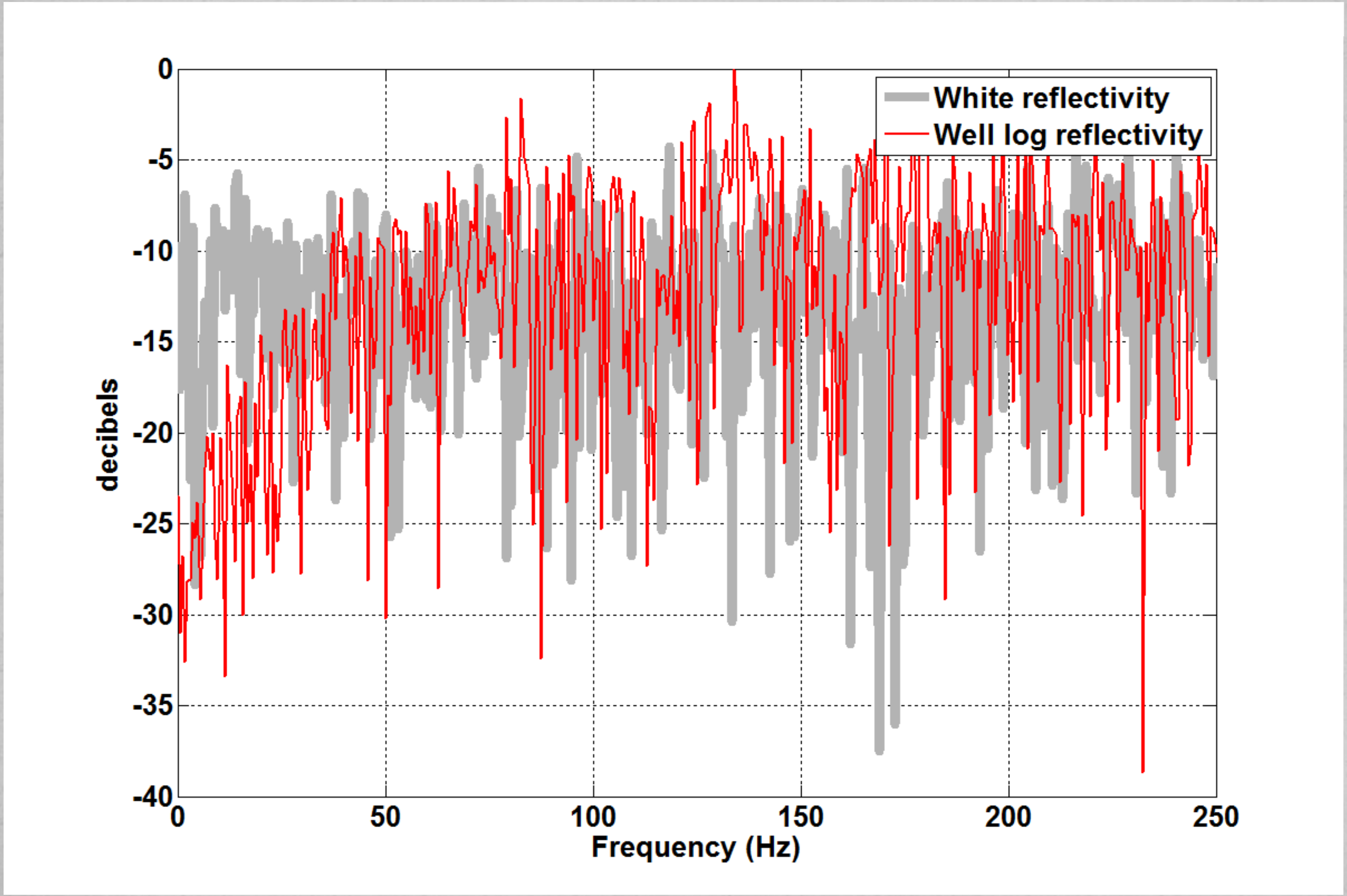
Conclusions

- **Anelastic attenuation, which is always present, ensures that the convolutional model is approximate at best.**
- **Real seismic data does not have a single “wavelet” but rather an evolving wavelet determine by the Q structure.**
- **The nonstationary convolutional model captures the first-order effects of the evolving wavelet.**
- **Applying stationary deconvolution to a nonstationary seismogram is reasonable in the design widow but produces severe distortions elsewhere.**
- **Standard well-tying procedures of wavelet shaping and phase rotation have limited success outside the design window.**
- **Nonstationary deconvolution processes are required for better results but have their own problems.**
- **Noise affects the nonstationary trace severely and ensures that the signal band is time-variant.**

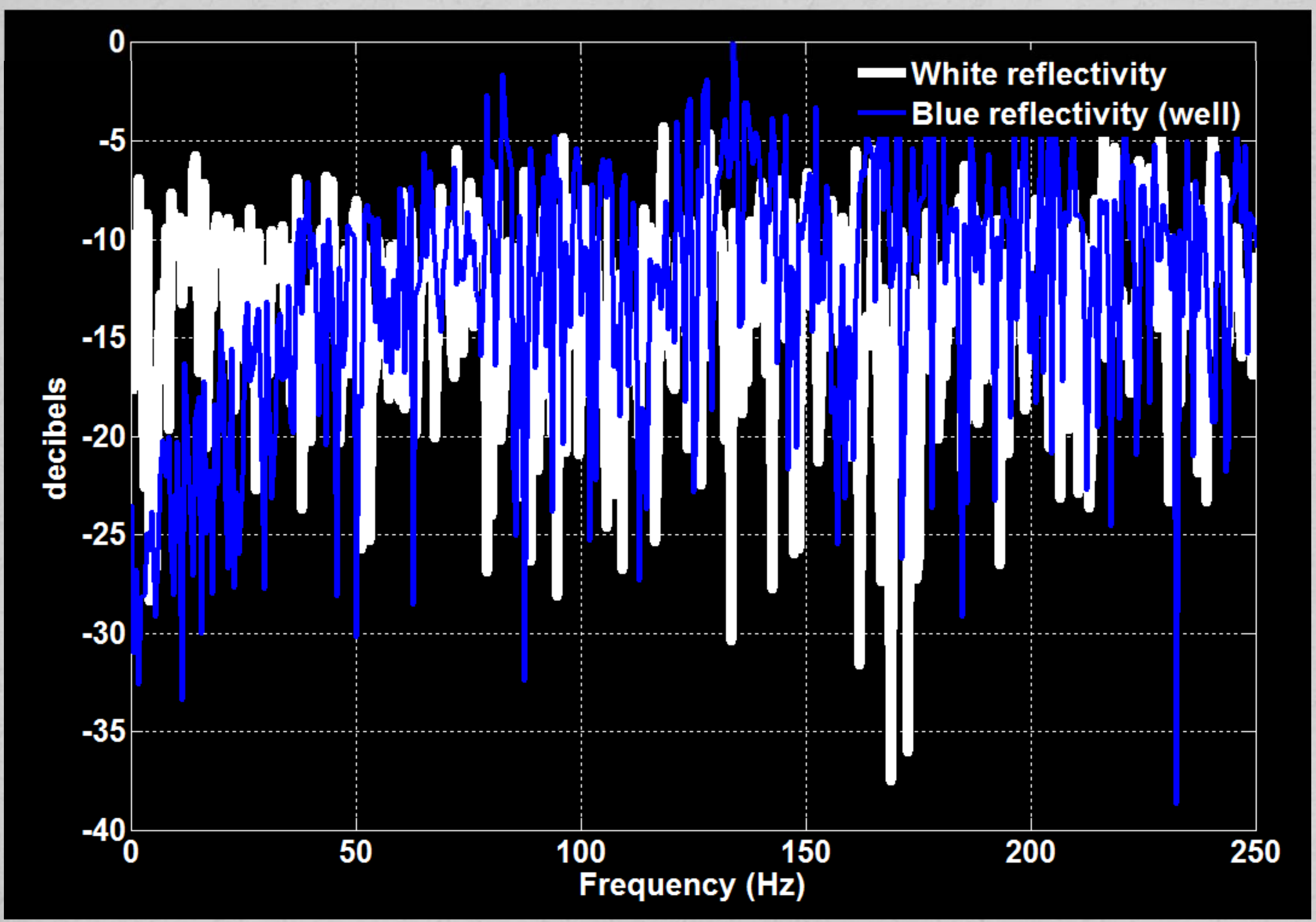
Acknowledgements

My thanks to all CREWES sponsors for supporting this research. Thanks also the NSERC, CMC, and the UofC for additional support.

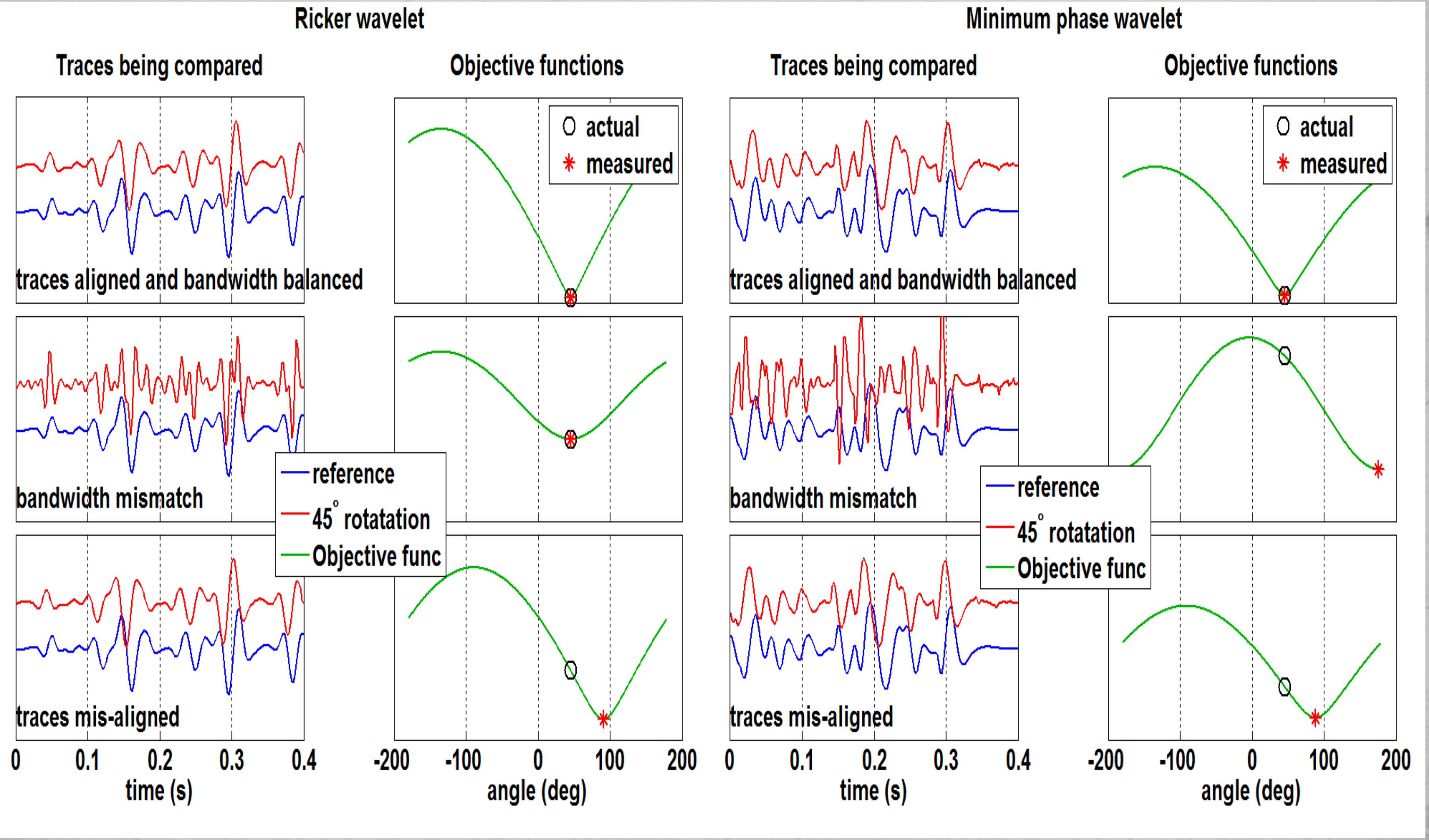
Well versus synthetic reflectivities



Well versus synthetic reflectivities

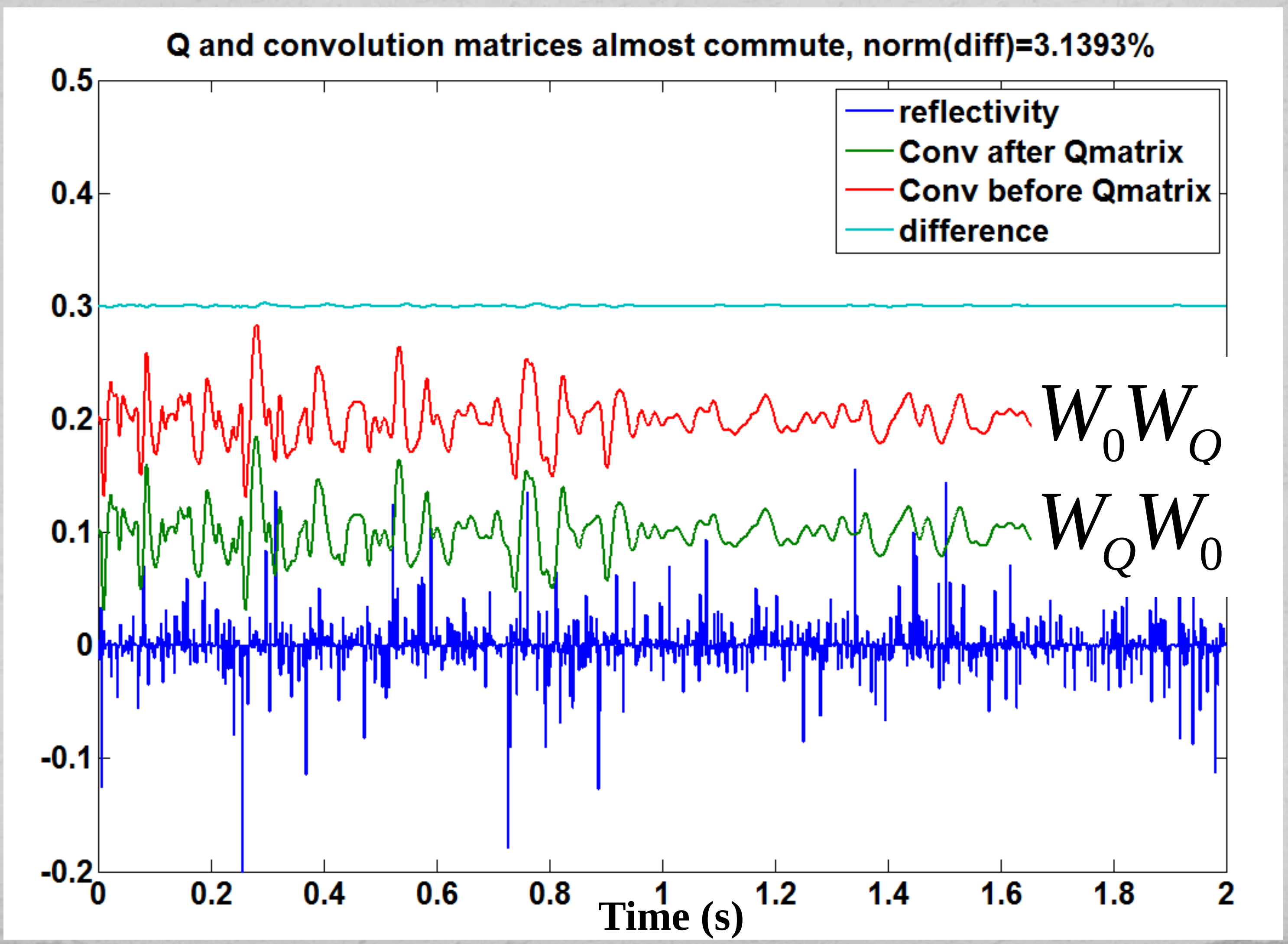


Wavelet Estimation: Constant phase rotations

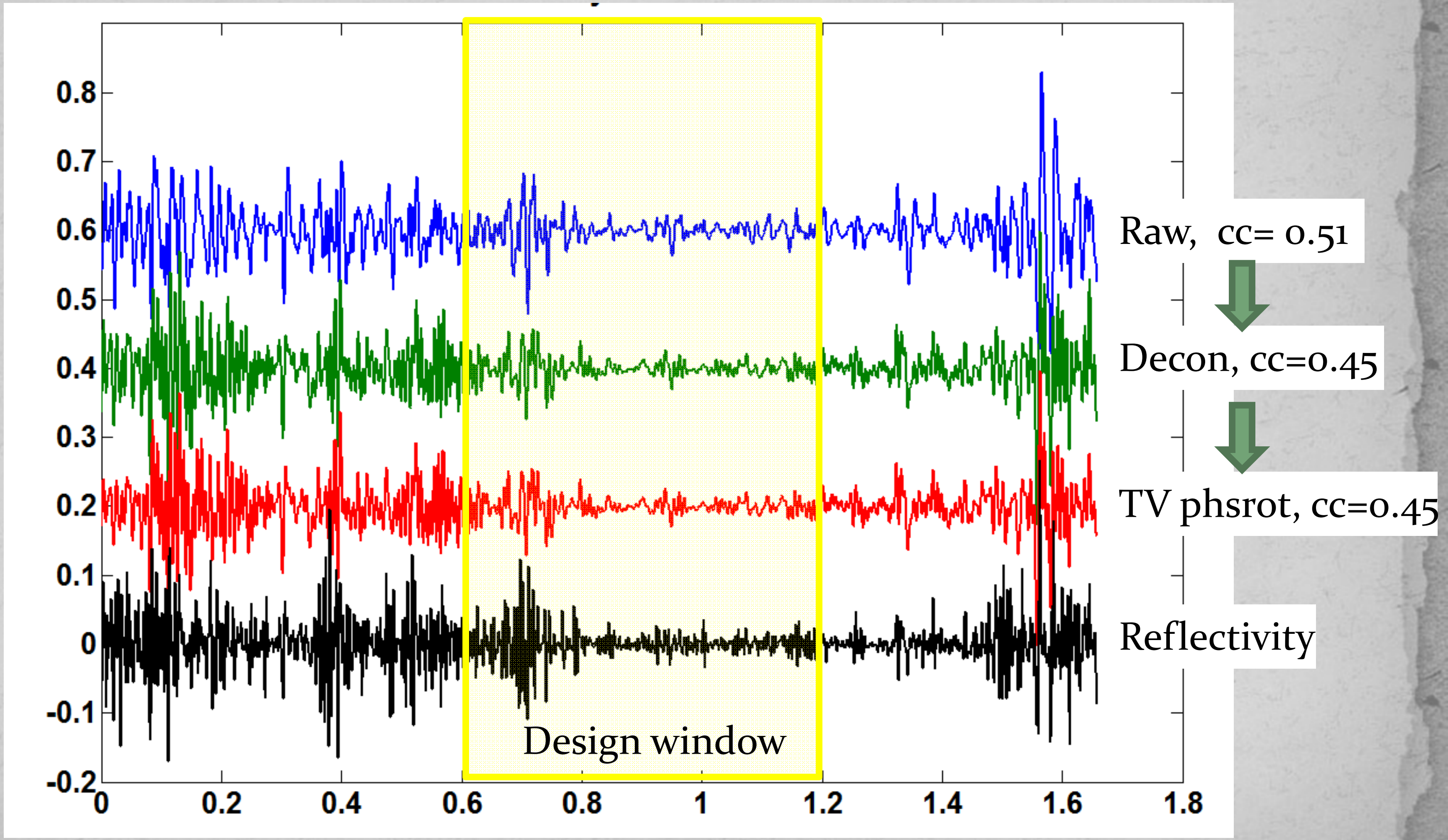


$$W_0 W_Q \sim W_Q W_0$$

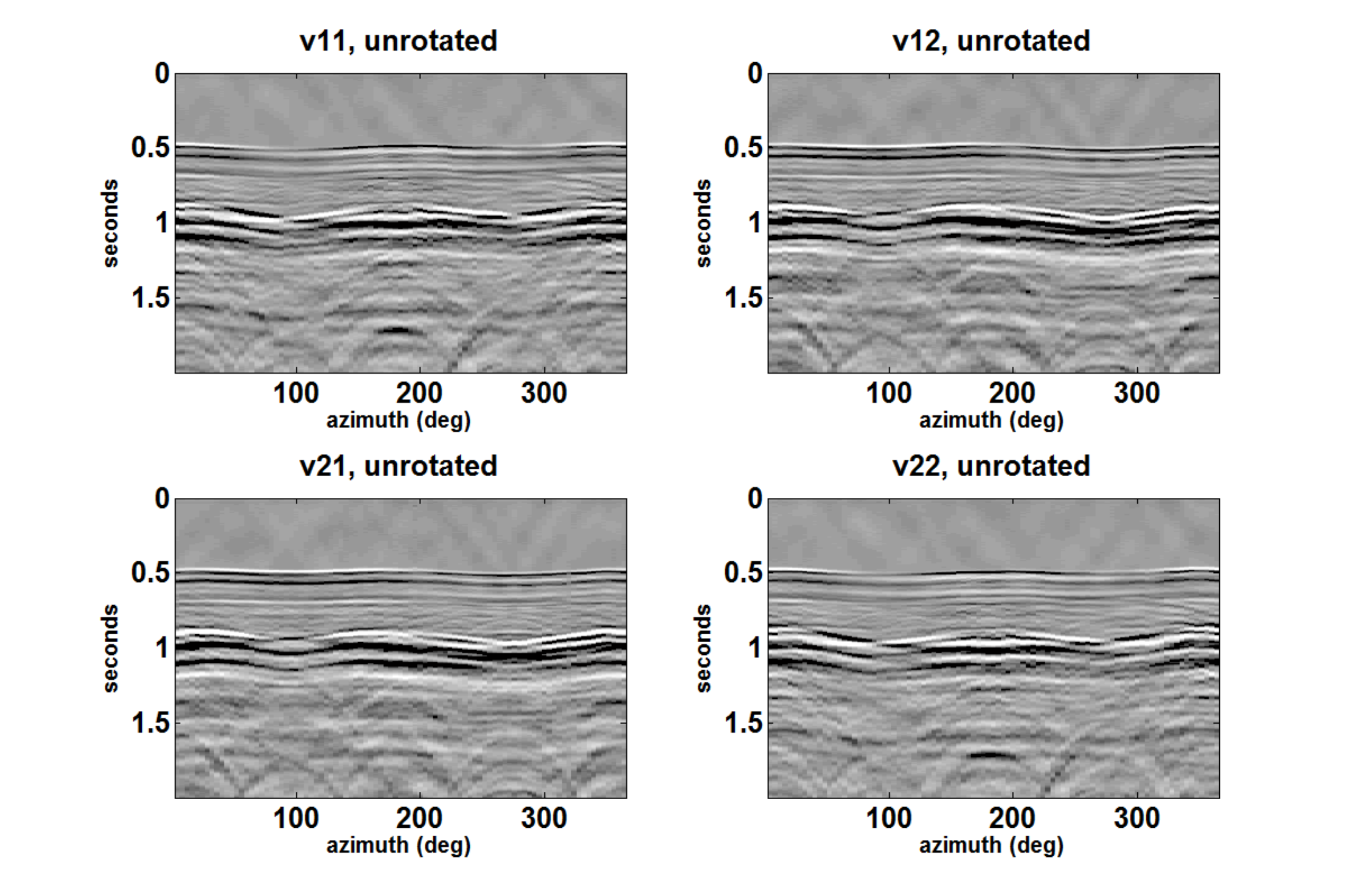
Almost commutative



Stationary decon of stationary seismogram for reference



Stationary decon of stationary seismogram for reference



Stationary decon of stationary seismogram for reference