Sparsity decon in the log domain with variable gain

Jon Claerbout, Qiang Fu, and Antoine Guitton

SEG
Las Vegas
November 2012

Ricker compliant decon; and Sparsity decon in the log domain with variable gain

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Polarity revealing decon is Ricker compliant decon; and Sparsity decon in the log domain with variable gain

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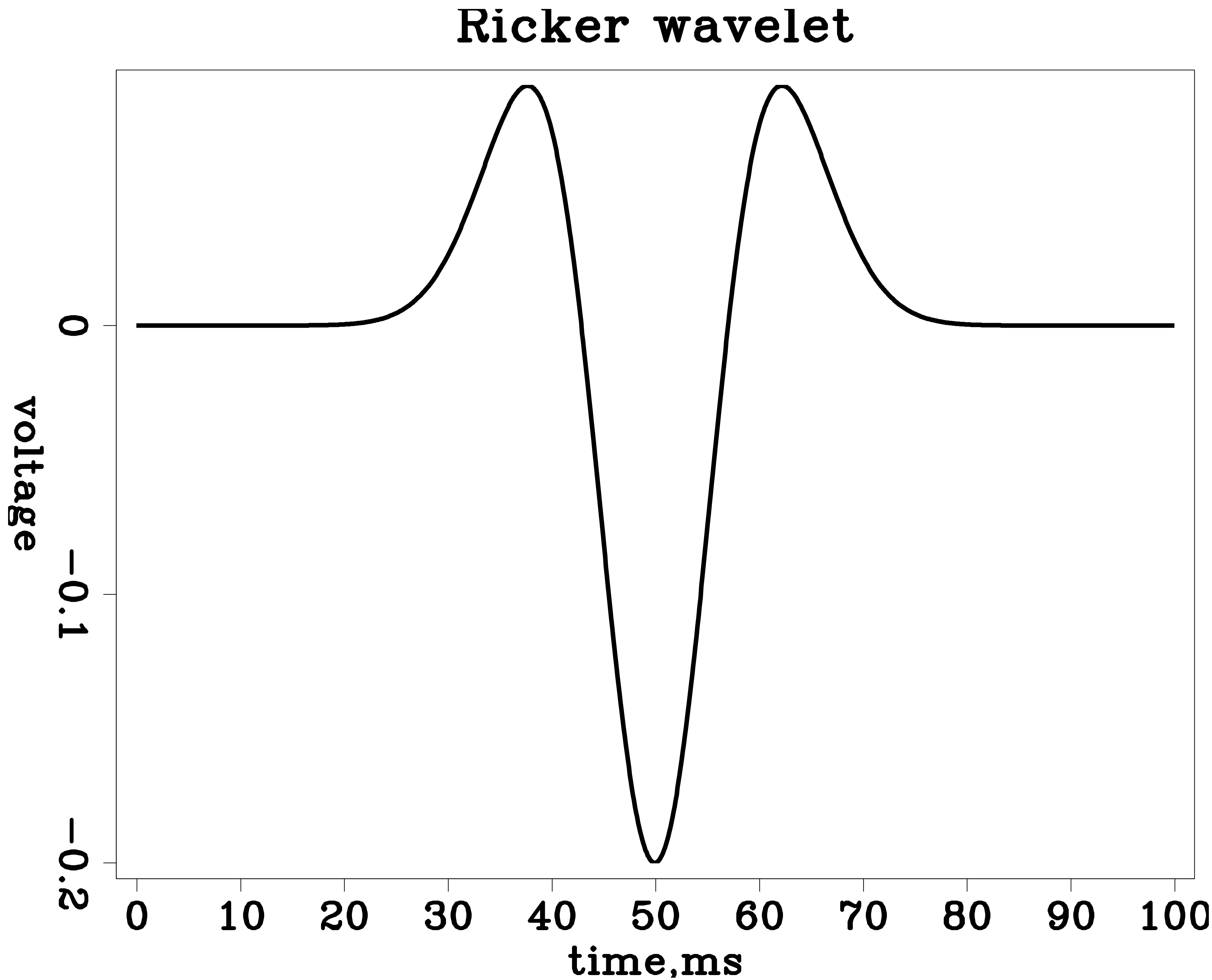
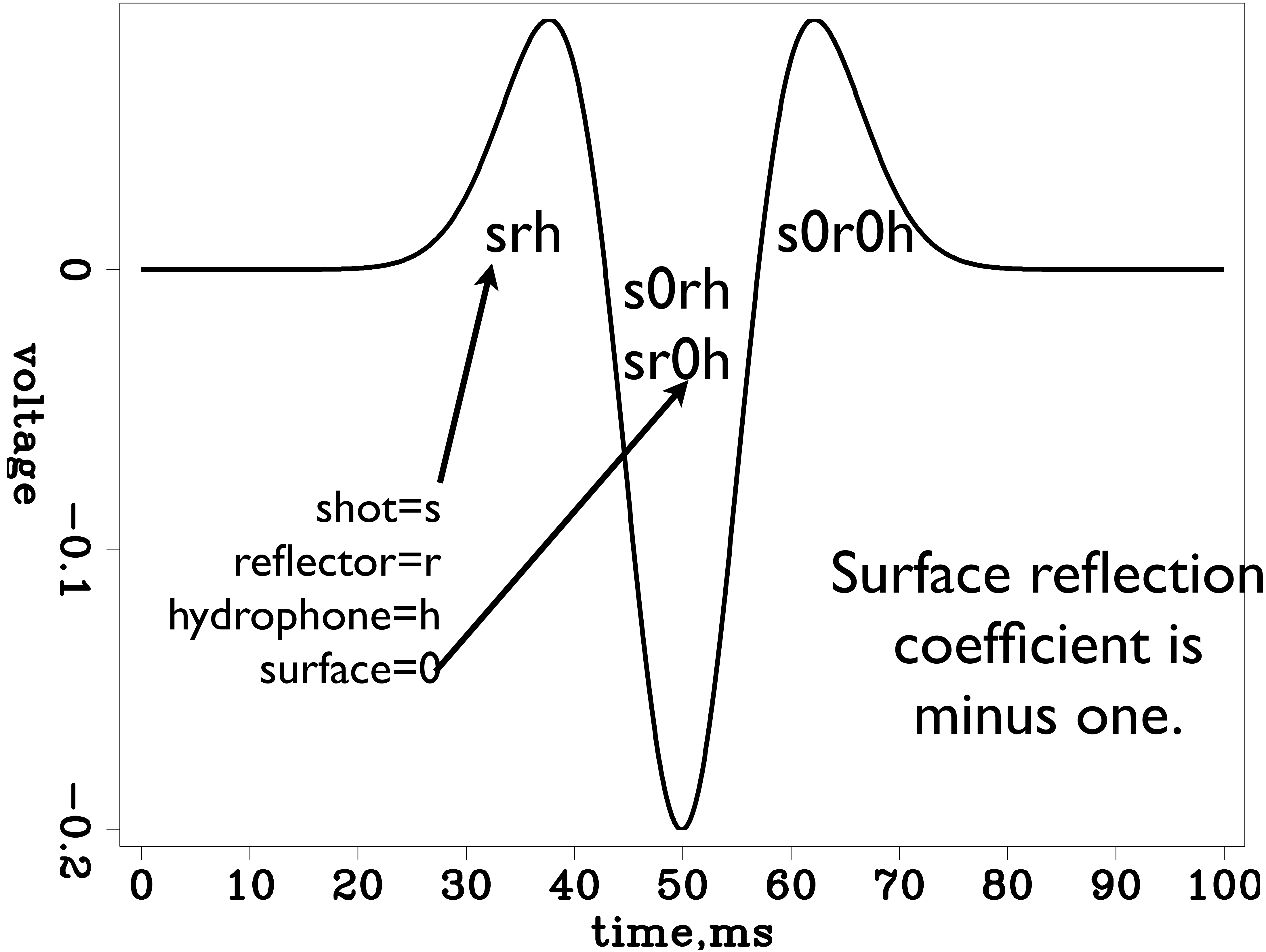
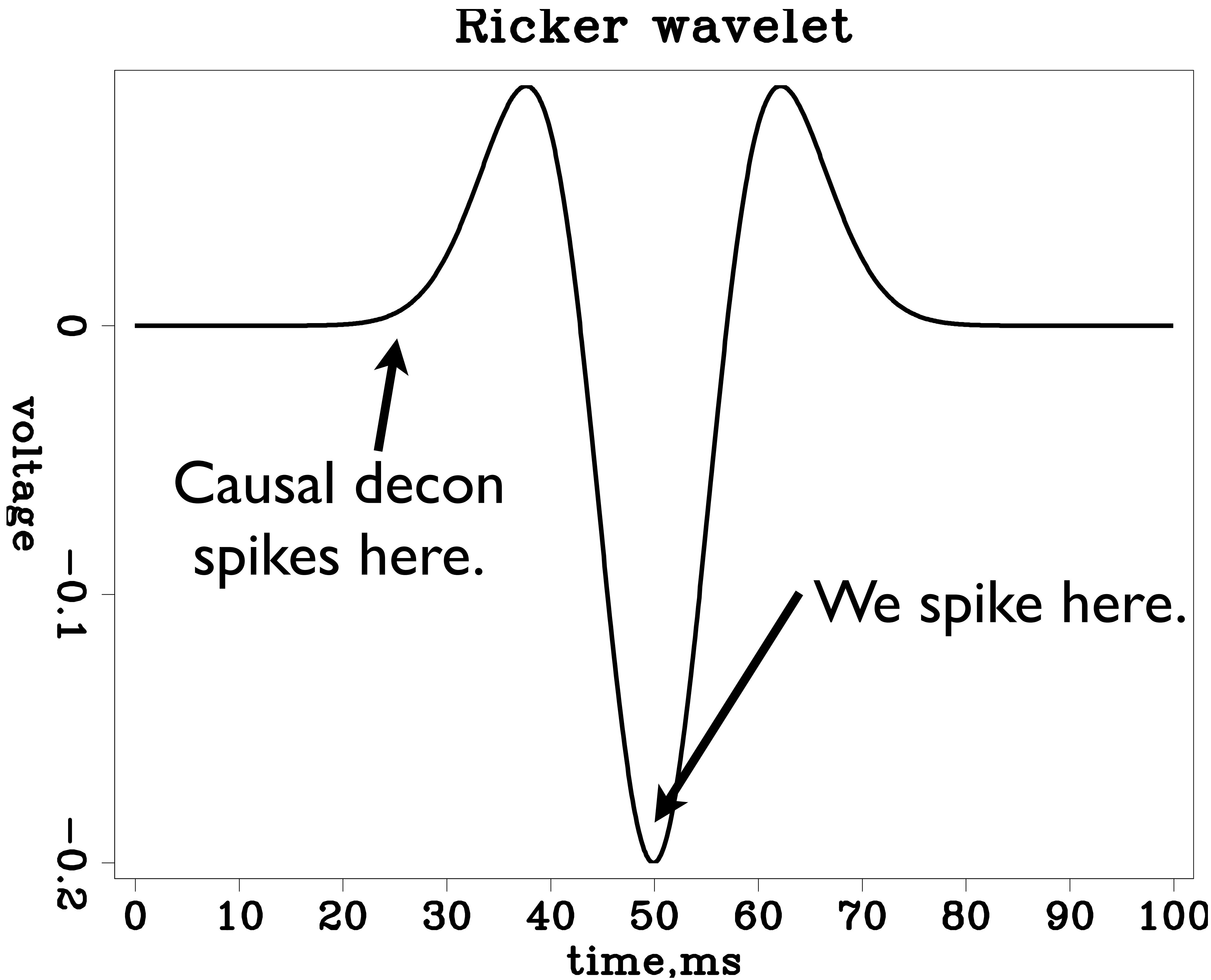
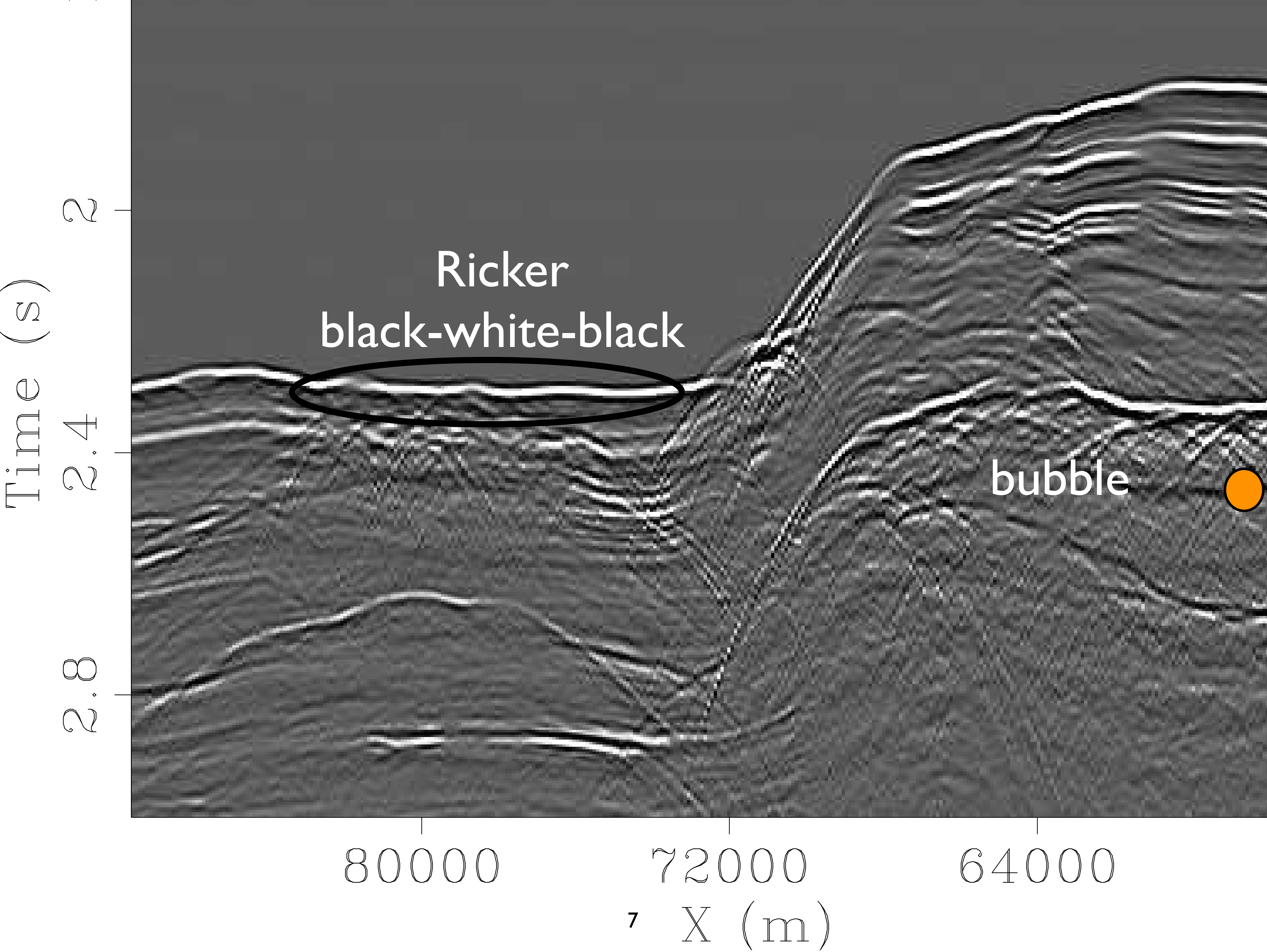
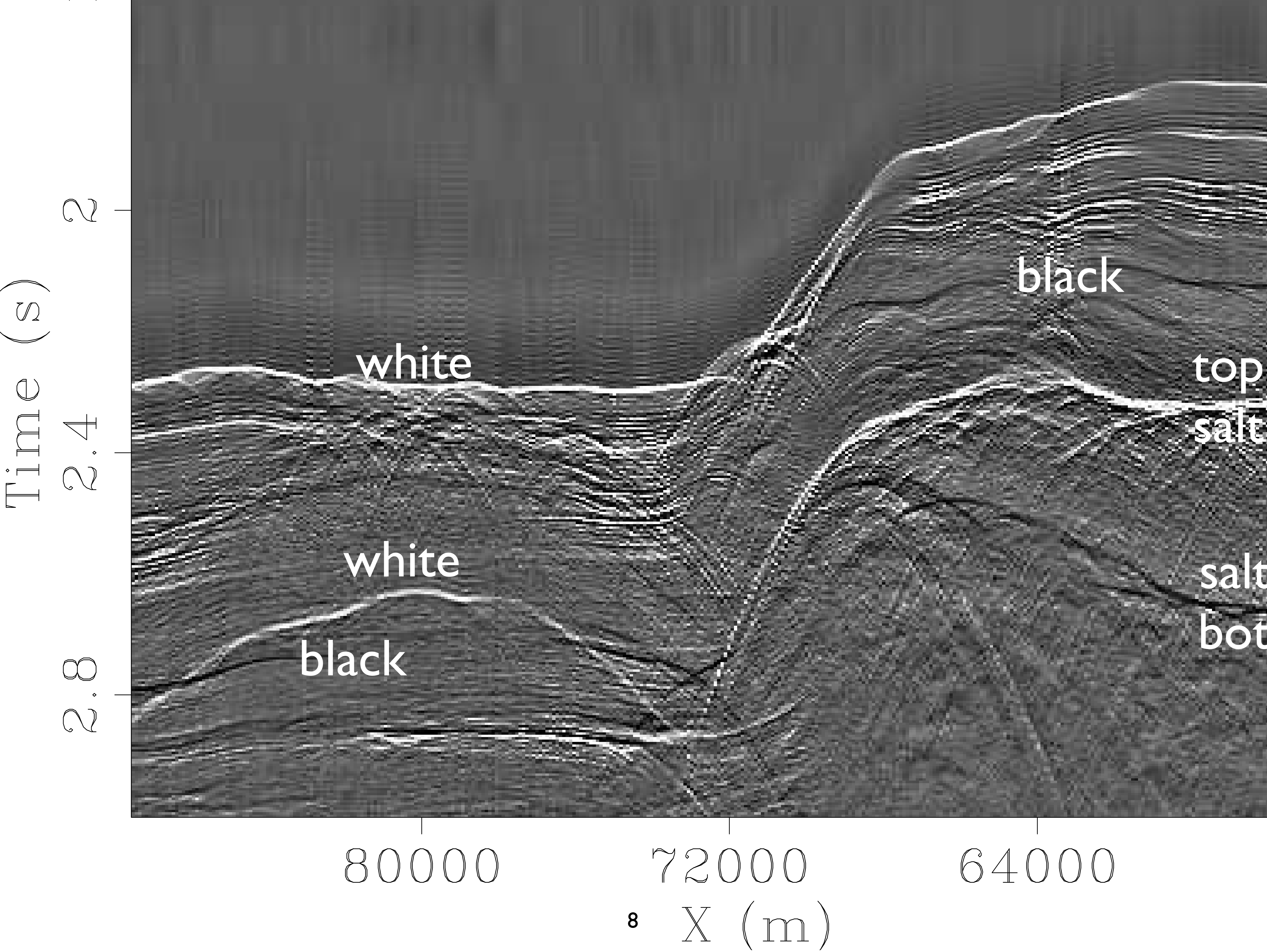

Ricker wavelet
0
-0.1
-0.2
voltage
0
10
20
30
40
50
60
70
80
90
100
time,ms

Ricker wavelet ray paths

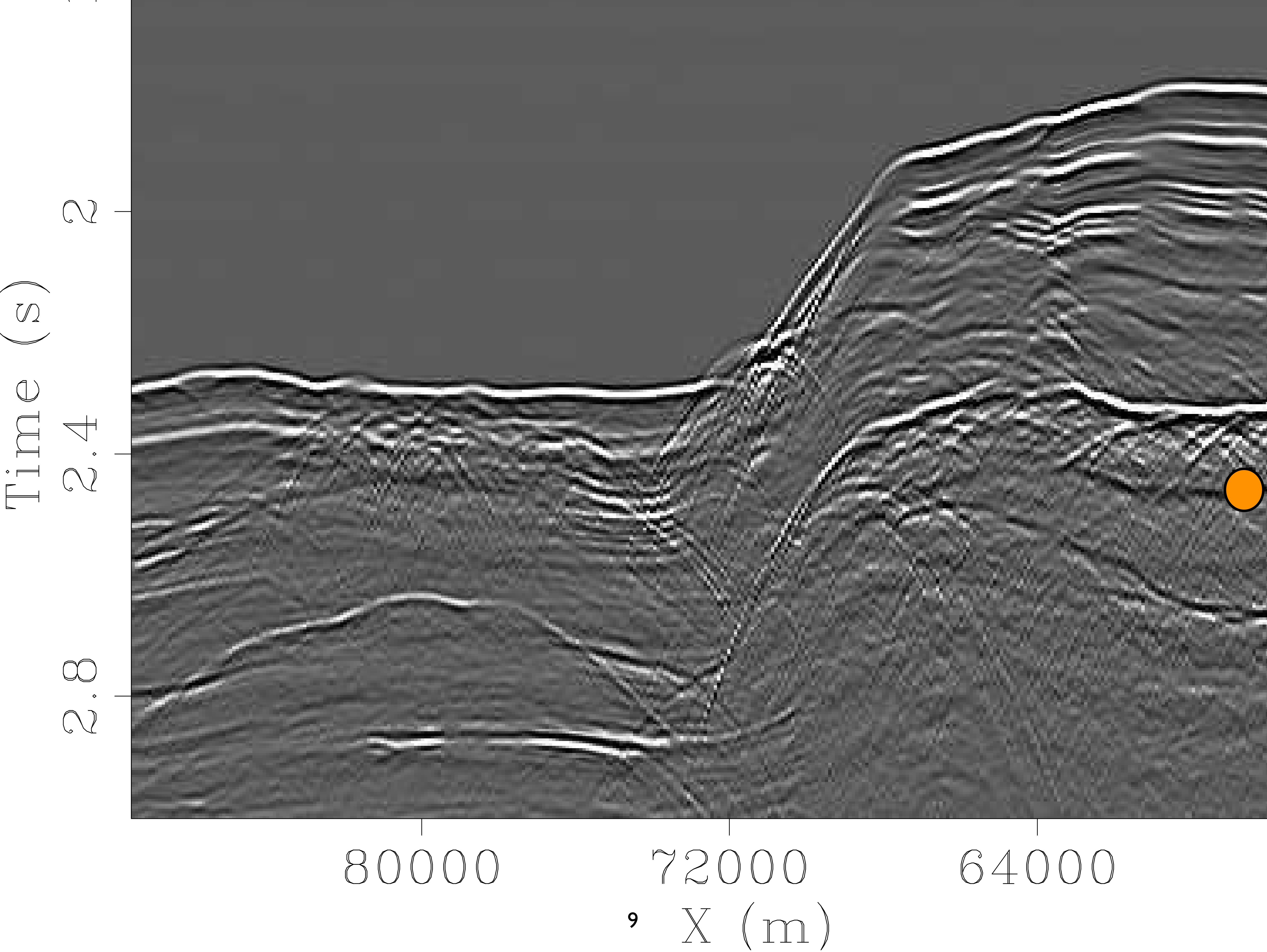


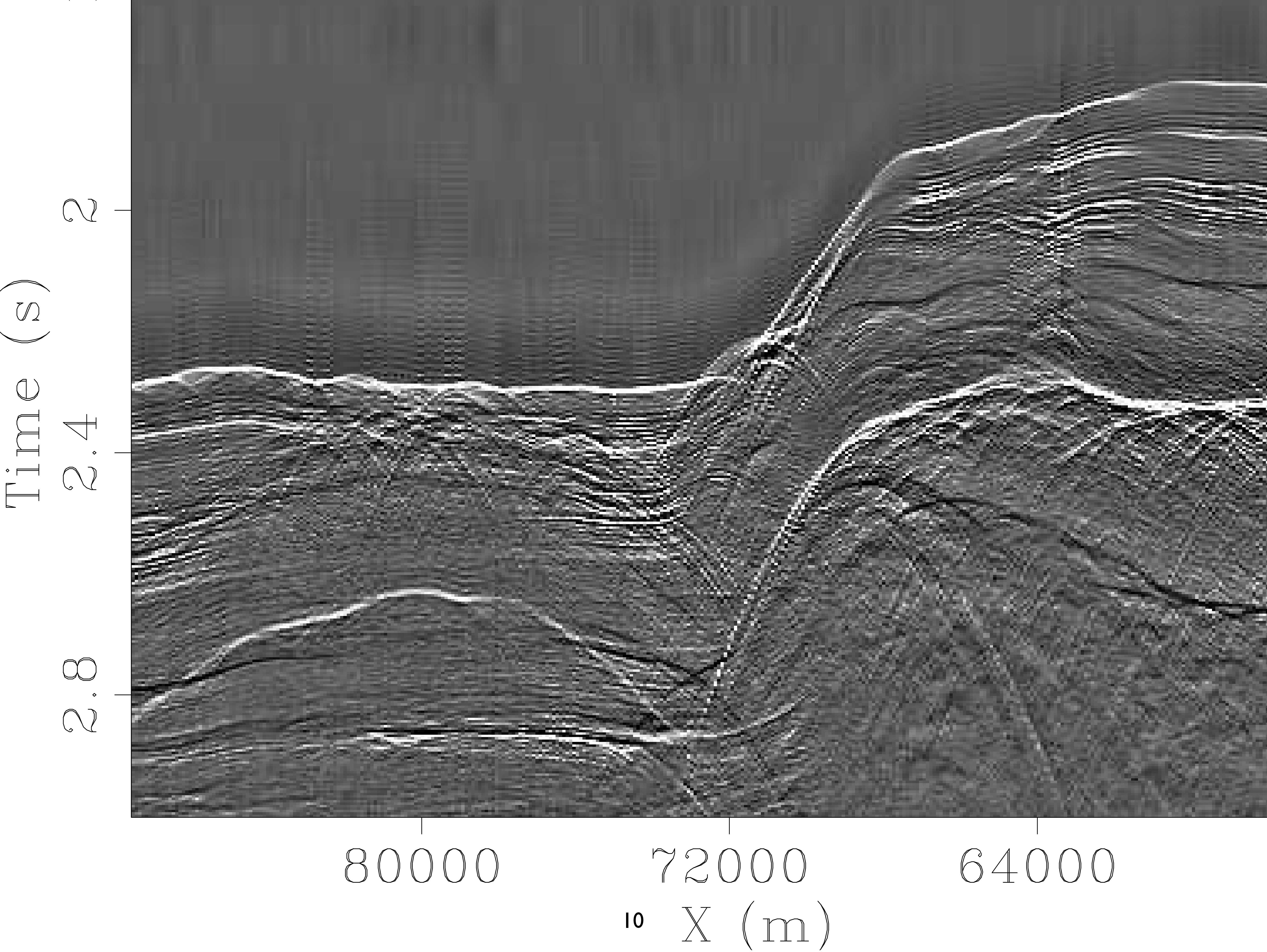

Ricker wavelet
voltage
0
−0.1
−0.2
0
10
20
30
40
50
60
70
80
90
100
time,ms
Causal decon spikes here.
We spike here.

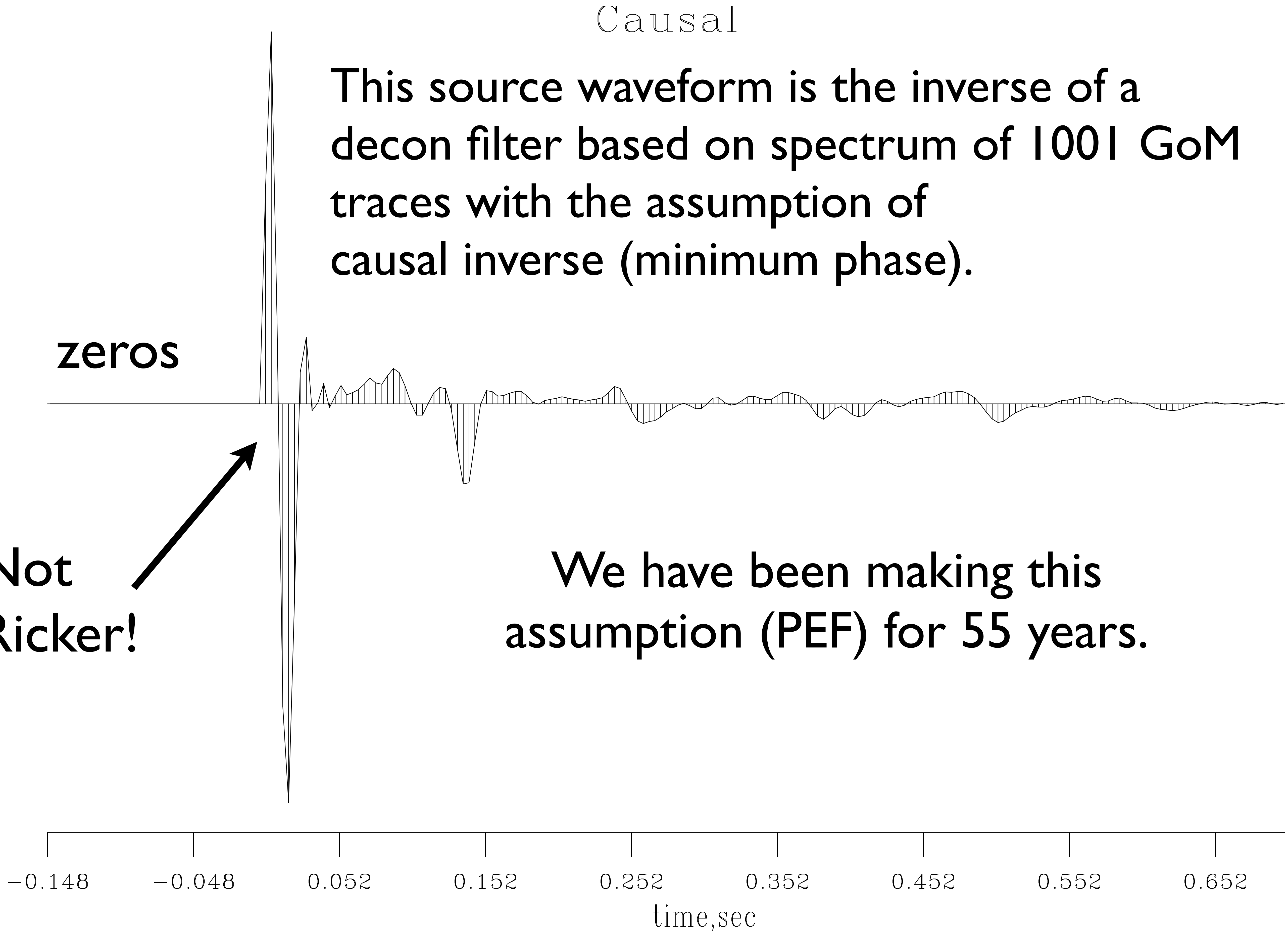

Ricker
black-white-black
bubble
Time (s)
2
2.4
2.8
80000
72000
64000
X (m)



Time (s)
2
2.4
2.8
black
white
top
salt
white
salt
bot
black
80000
72000
64000
X (m)

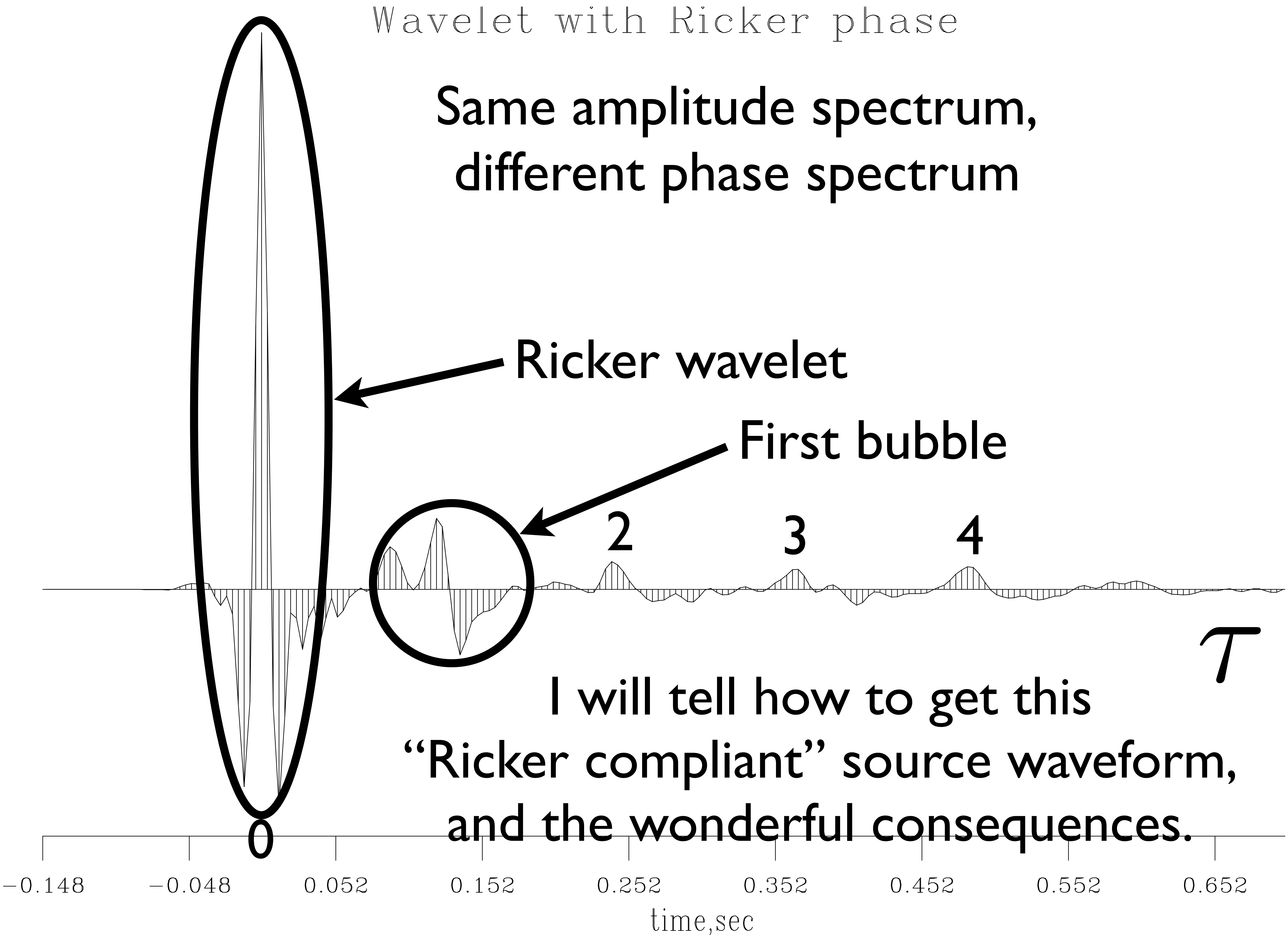

Time (s)
2
2.4
2.8
80000
72000
64000
X (m)


Time (s)
2
2.4
2.8
80000
72000
64000
X (m)

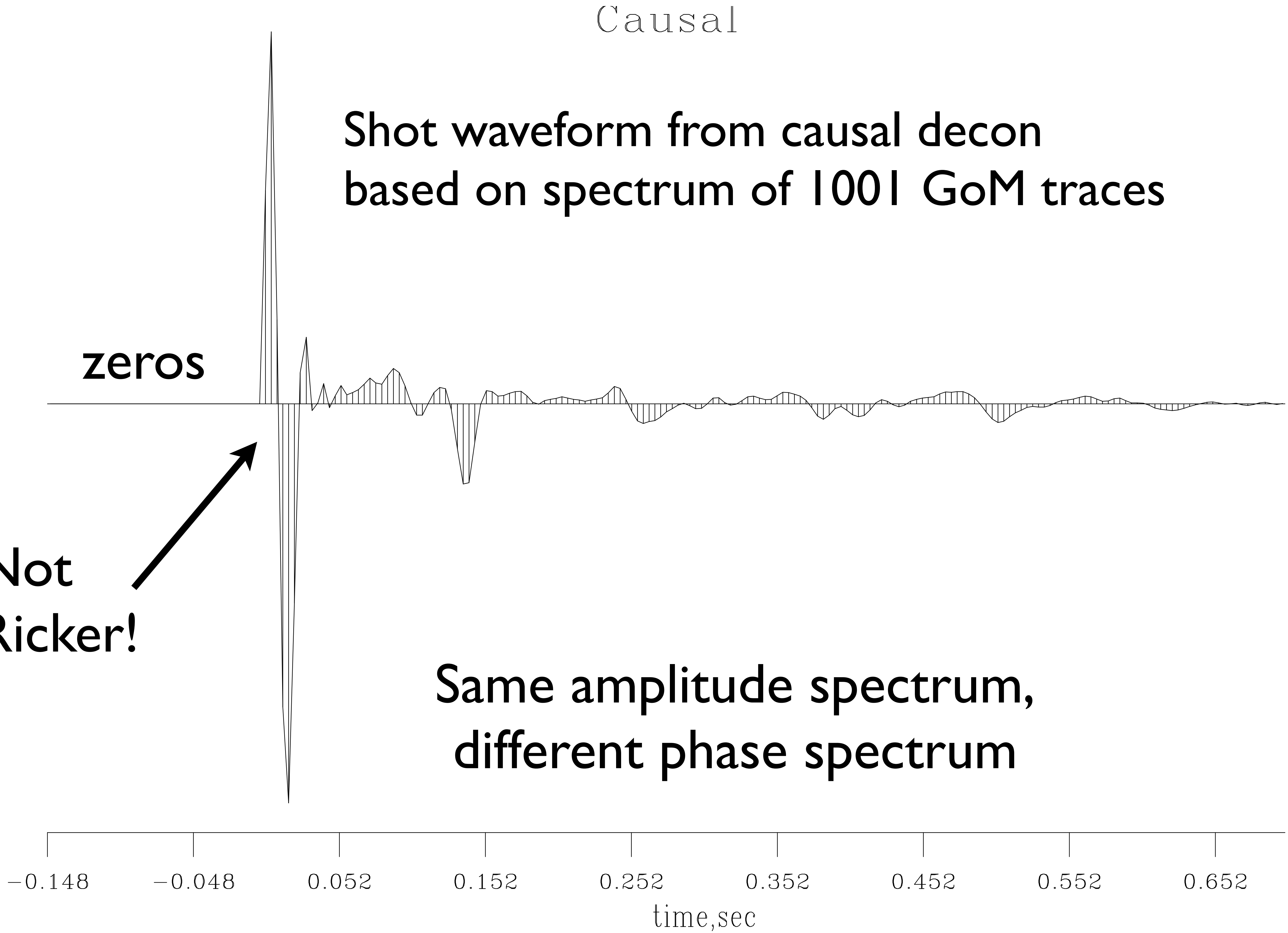


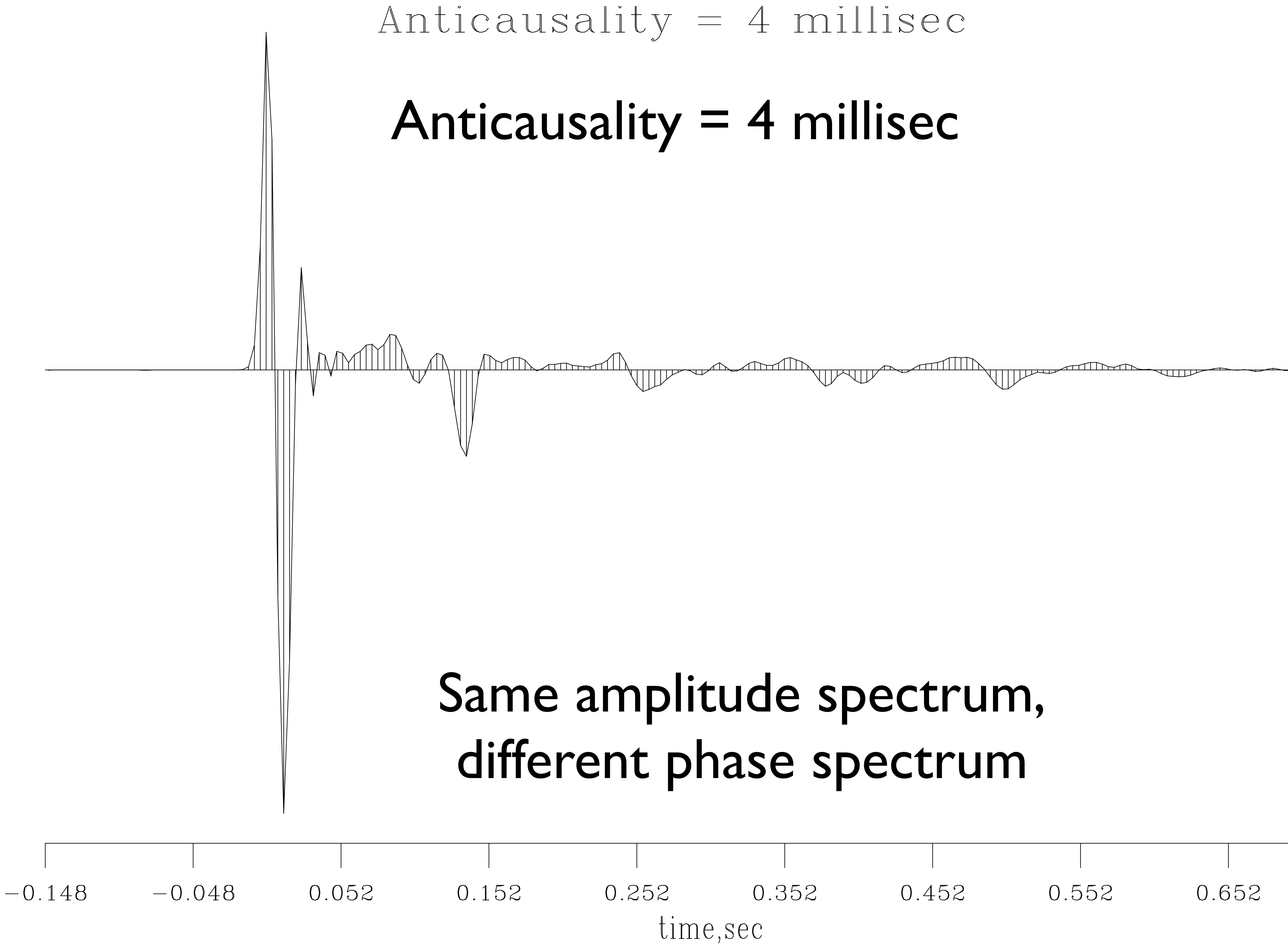
This source waveform is the inverse of a decon filter based on spectrum of 1001 GoM traces with the assumption of causal inverse (minimum phase).

We have been making this assumption (PEF) for 55 years.



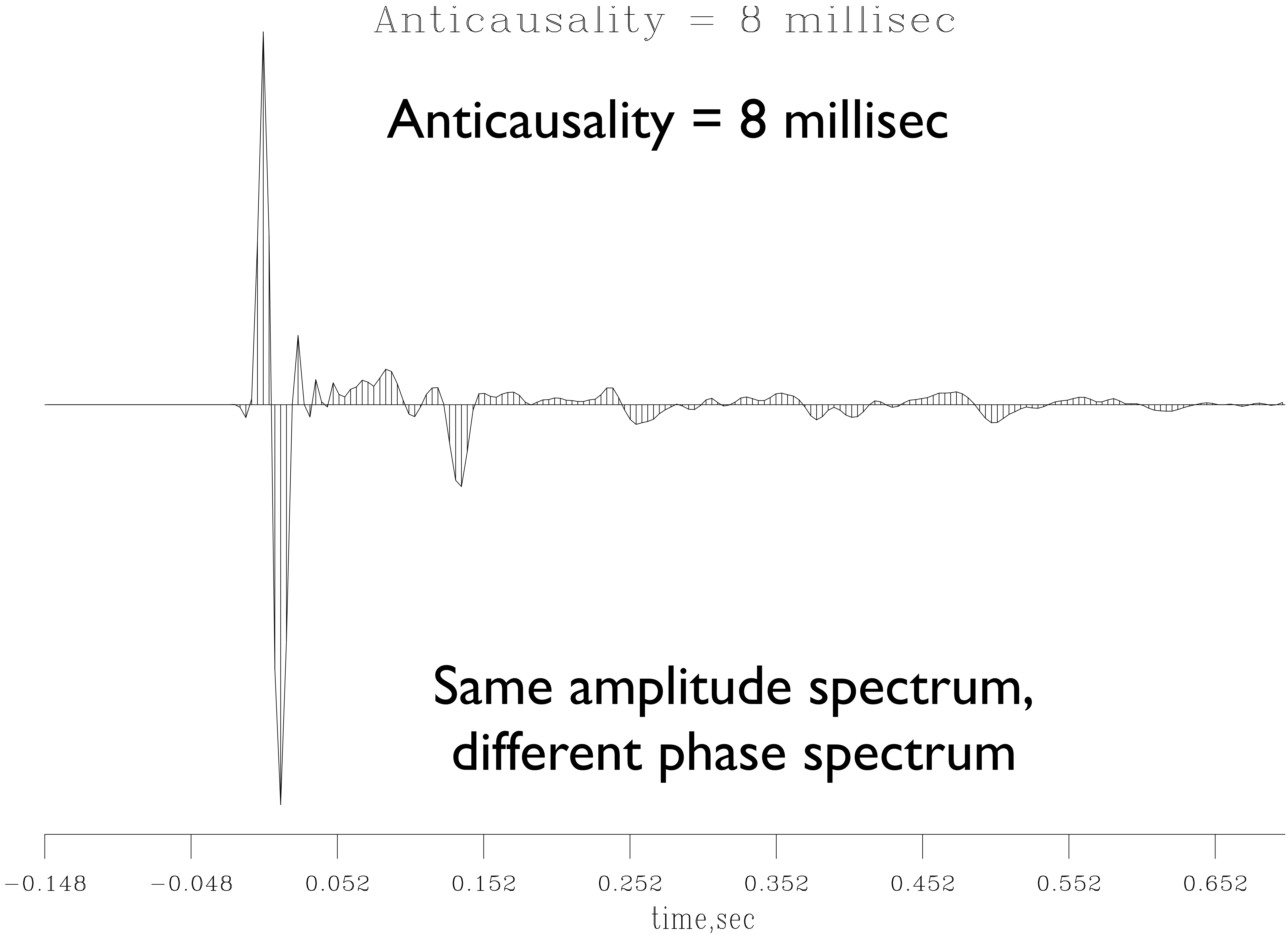
Wavelet with Ricker phase
Same amplitude spectrum,
different phase spectrum
Ricker wavelet
First bubble
2
3
4
τ
I will tell how to get this
"Ricker compliant" source waveform,
and the wonderful consequences.
0
−0.148
−0.048
0.052
0.152
0.252
0.352
0.452
0.552
0.652
time,sec


Causal
Shot waveform from causal decon
based on spectrum of 1001 GoM traces
zeros
Not
Ricker!
Same amplitude spectrum,
different phase spectrum
−0.148
−0.048
0.052
0.152
0.252
0.352
0.452
0.552
0.652
time,sec



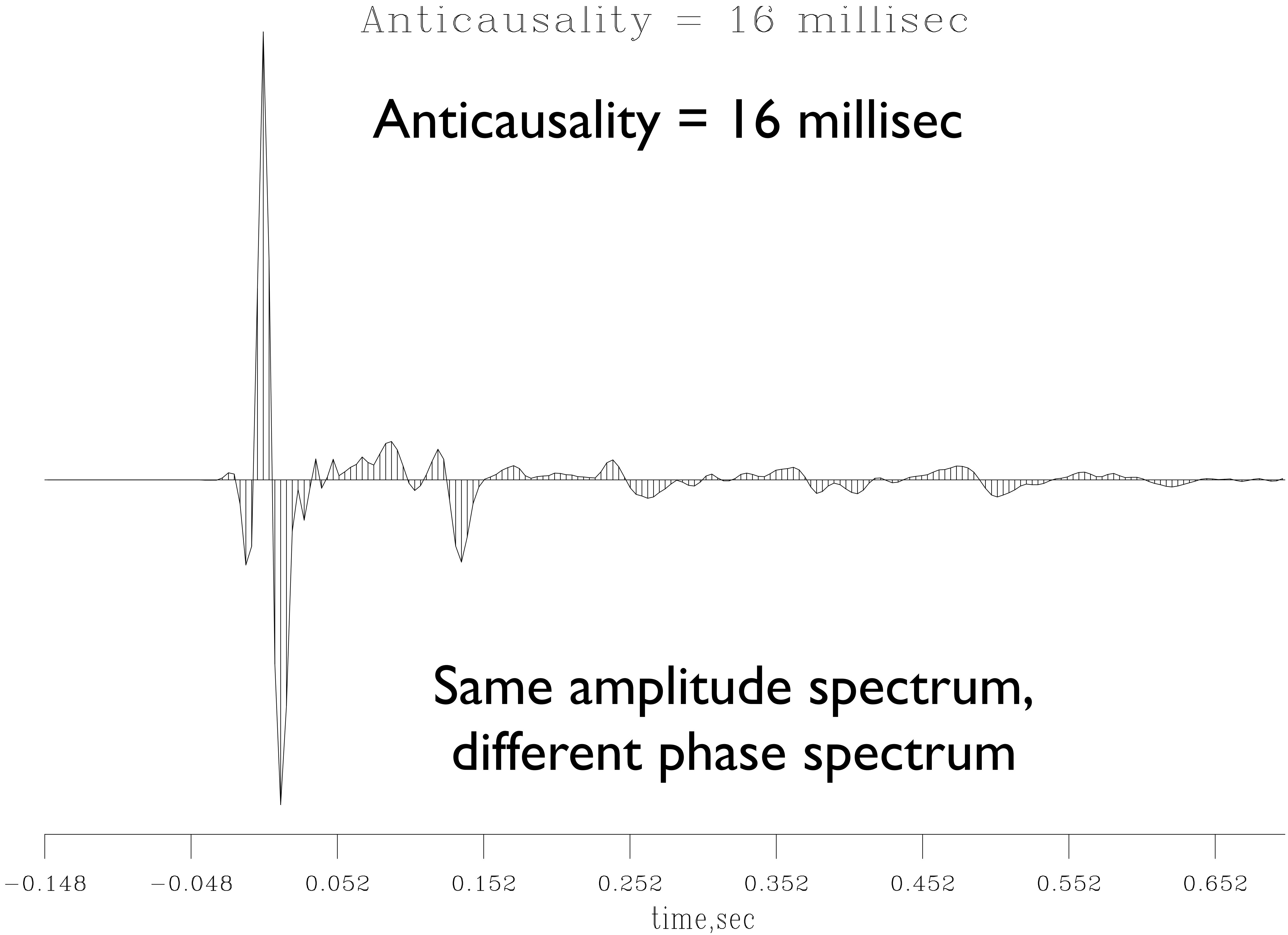
Anticausality = 4 millisec

Same amplitude spectrum, different phase spectrum



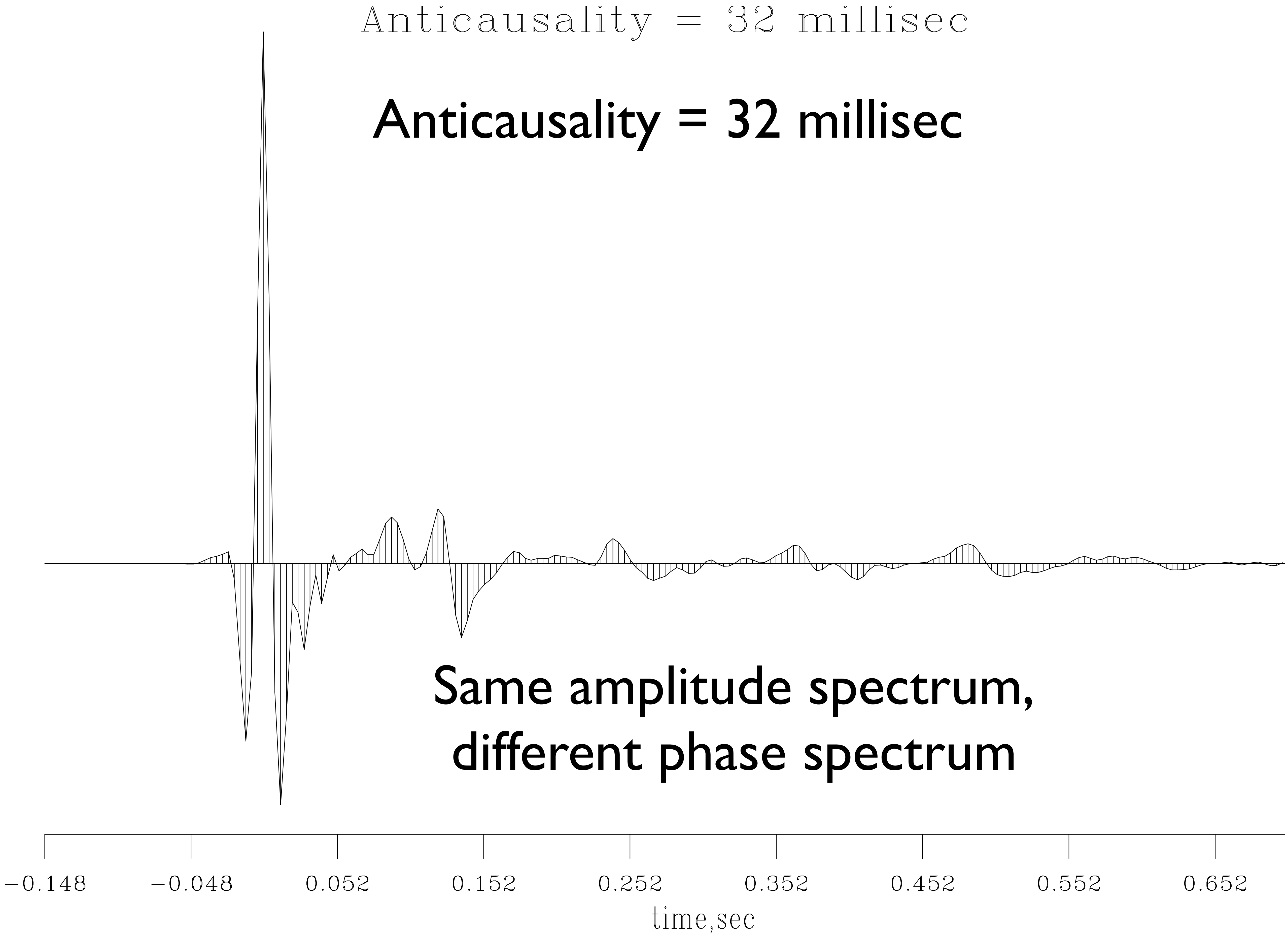
Anticausality = 8 millisec

Same amplitude spectrum, different phase spectrum



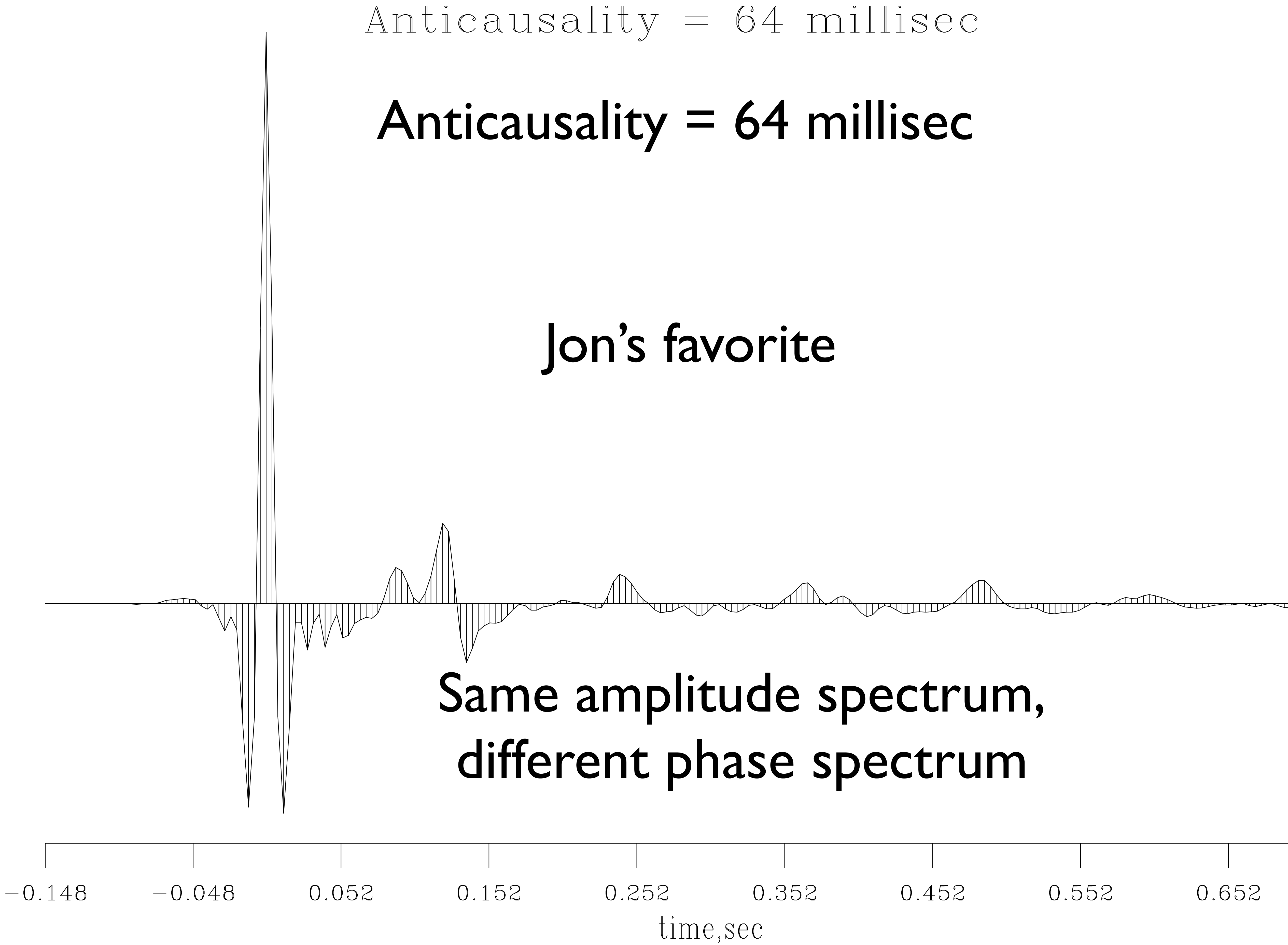
Anticausality = 16 millisec

Same amplitude spectrum,
different phase spectrum



Anticausality = 32 millisec

Same amplitude spectrum,
different phase spectrum

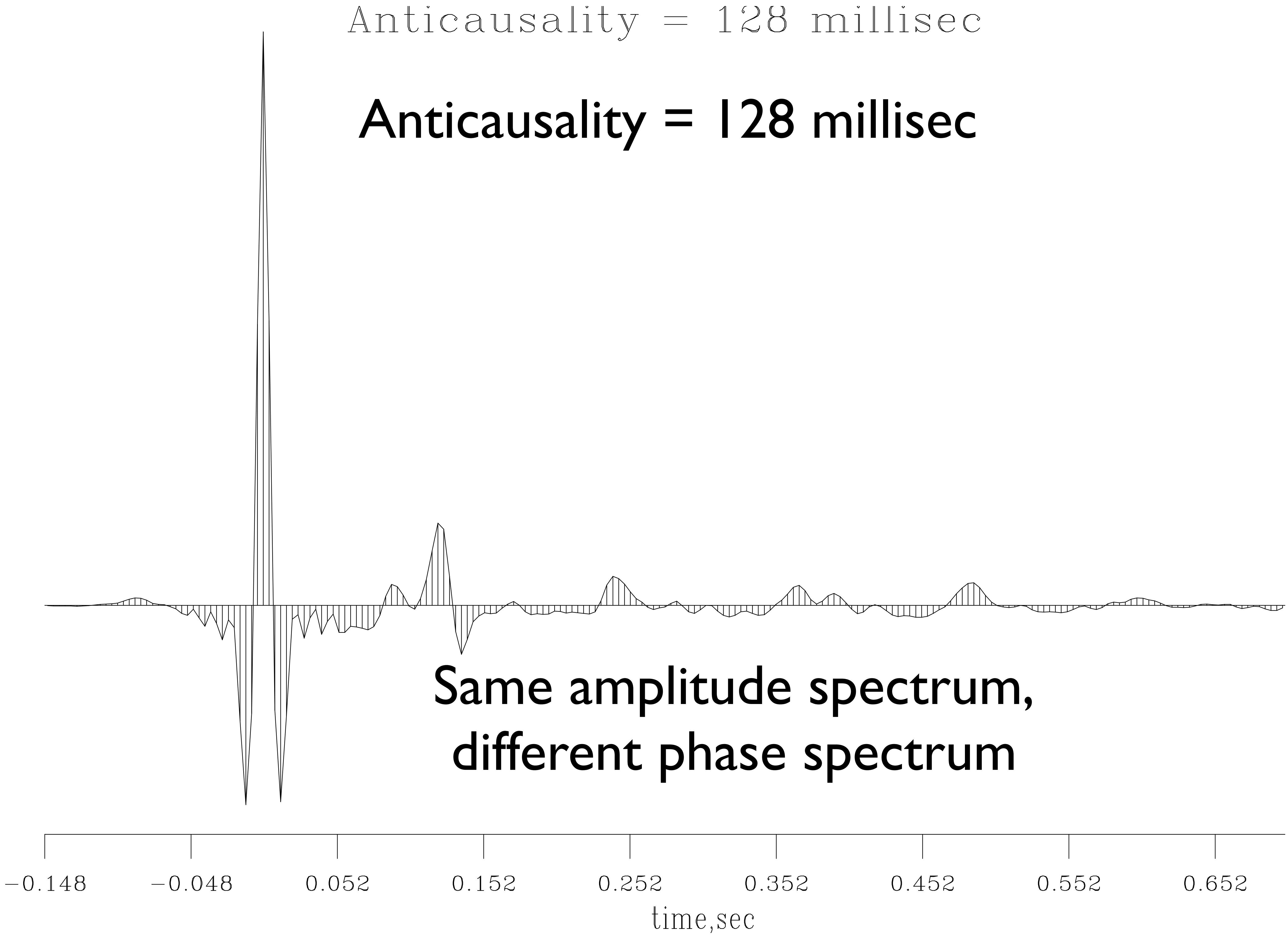


Anticausality = 64 millisec

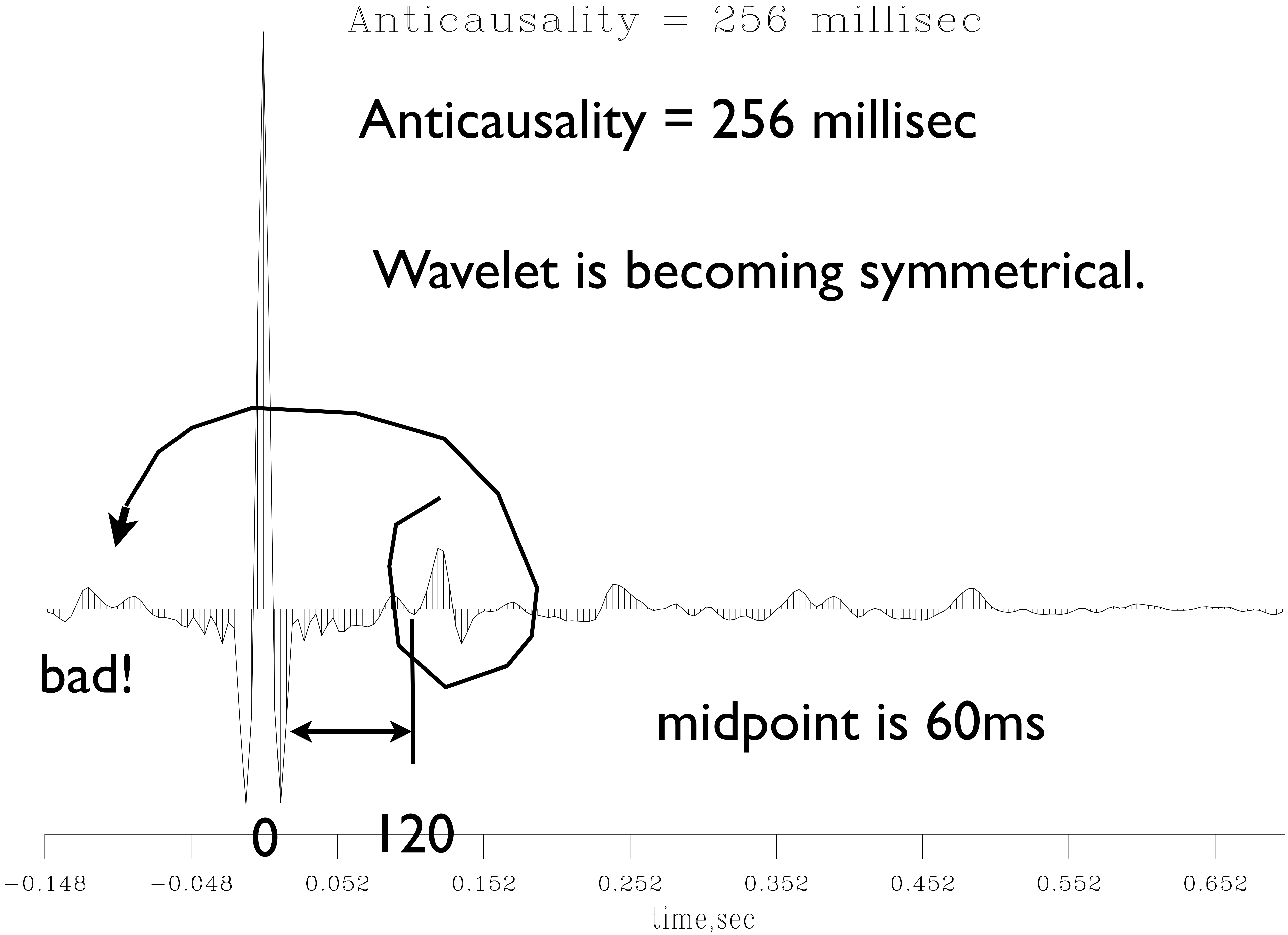
Jon's favorite

Same amplitude spectrum,
different phase spectrum

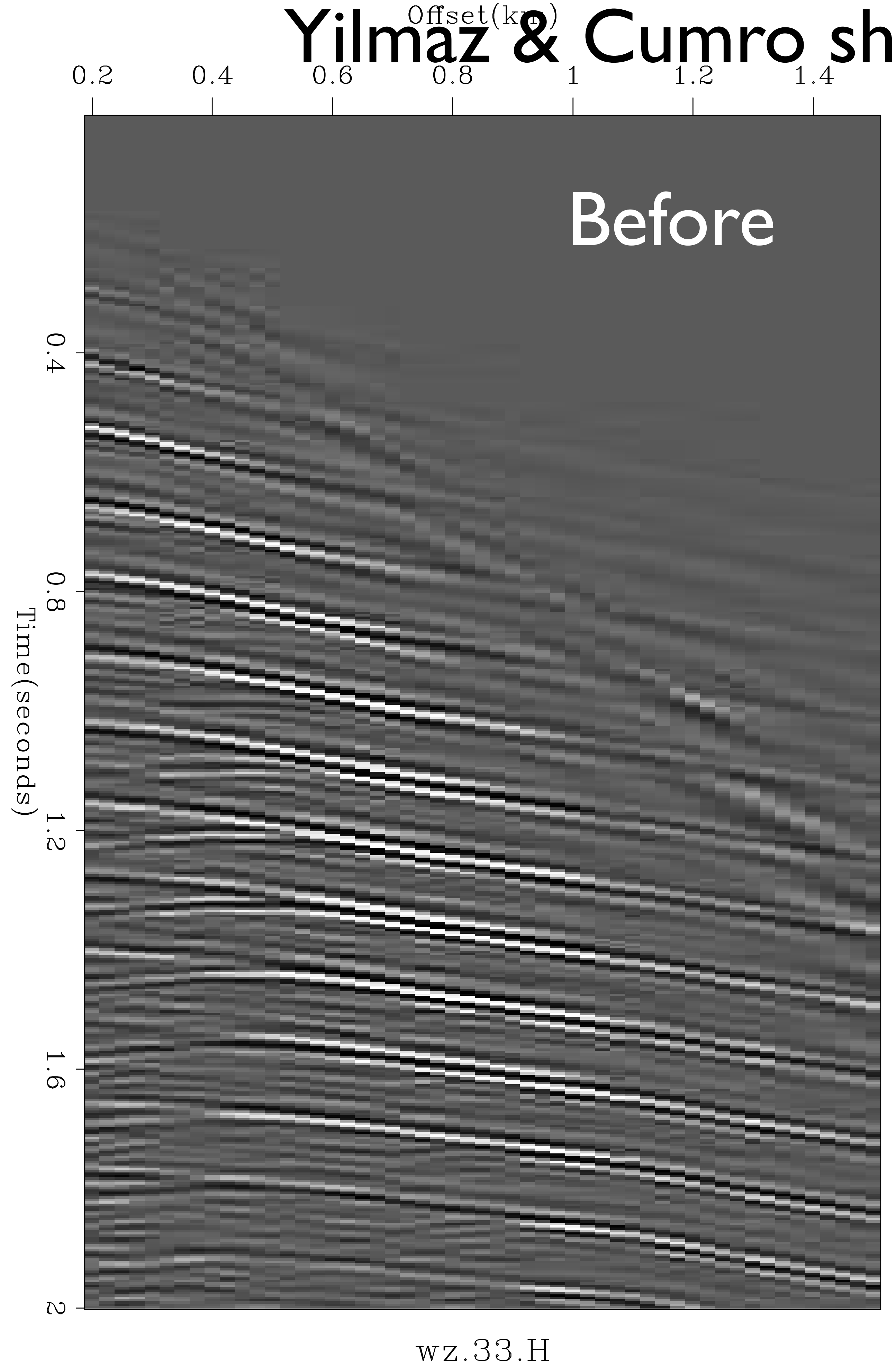
Anticausality = 128 millisec

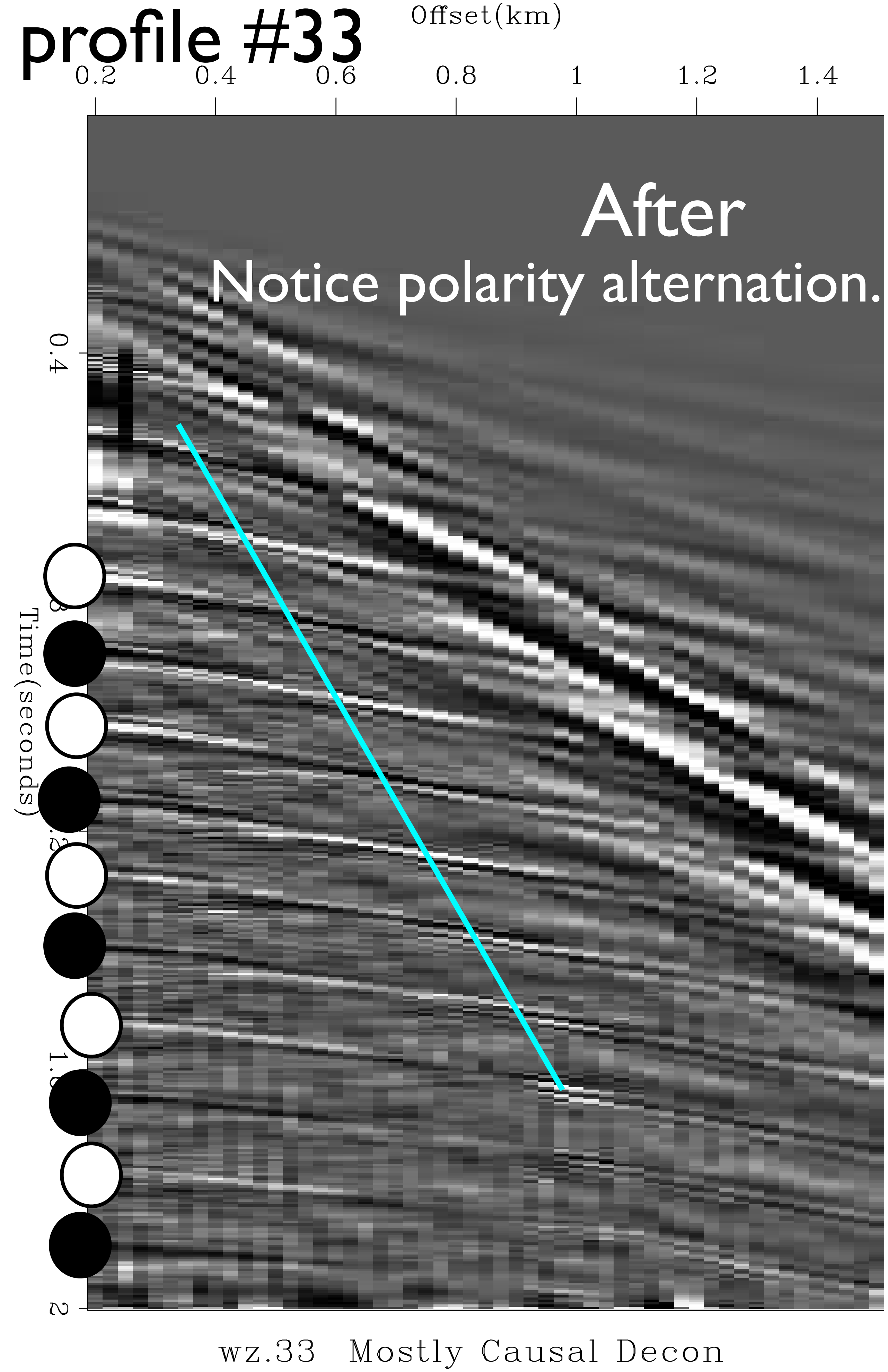


Same amplitude spectrum,
different phase spectrum

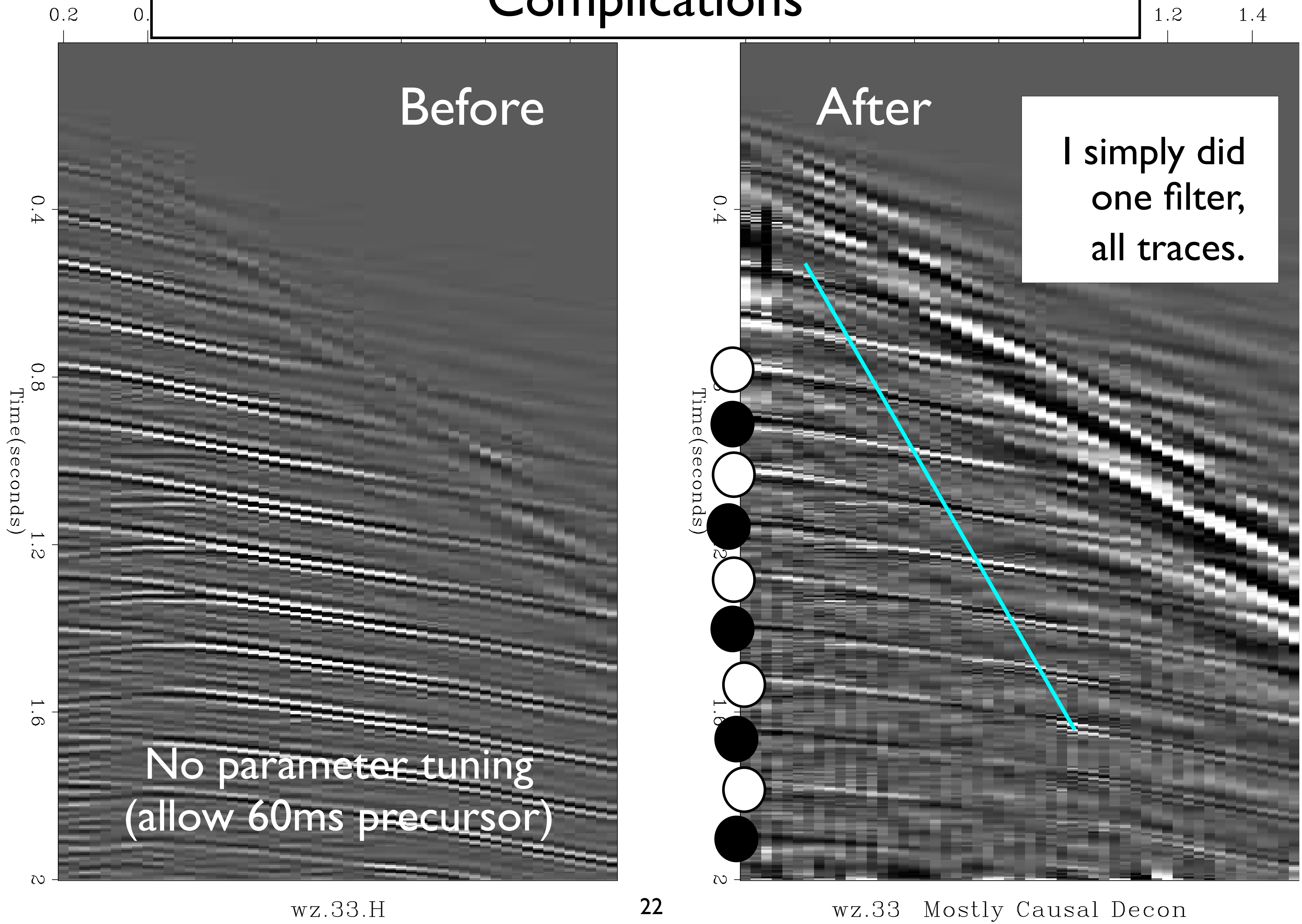

Anticausality = 256 millisec
Anticausality = 256 millisec
Wavelet is becoming symmetrical.
bad!
midpoint is 60ms
0
120
−0.148
−0.048
0.052
0.152
0.252
0.352
0.452
0.552
0.652
time,sec

Yilmaz & Cumro shot profile #33





Complications



Why is polarity revealed?

Deconvolve with the right wavelet, then seismogram polarity is revealed.

Generally equivalent terms and concepts

Blind decon
Predictive decon
Causal decon
Autoregression, Yule&Walker 1927
Minimum-phase decon, MIT GAG 1954
Wiener-Levinson, Toeplitz
Burg, Robinson, and Treitel

$t, \ N^2$ ↕

Kolmogoroff decon (1939)
(in my textbook FGDP 1974)
(the code is in my book PVI 1992)

$\omega, \ N \log N$ ↕

Generally equivalent terms and concepts

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Kolmogoroff decon (1939)
(in my textbook FGDP 1974)
(the code is in my book PVI 1992)

$t,\ N^2$ ↕ (Autoregression … Burg, Robinson, and Treitel)

$\omega,\ N \log N$ ↕ (Kolmogoroff decon …)

Here we adapt Kolmogoroff to "Ricker compliant," and then the others too.

Two ways to parameterize a filter's logarithm

$$|r|e^{i\phi} \;=\; e^{\ln|r|+i\phi} \;=\; e^{\,\pm\sum_\tau u_\tau Z^\tau}$$

$$r = r(\omega) \qquad \phi = \phi(\omega) \qquad Z^\tau = e^{i\omega\tau}$$

How to force Ricker-like wavelets

$$|r|e^{i\phi} \;=\; e^{\ln|r|+i\phi} \;=\; e^{\,\pm\sum_\tau u_\tau Z^\tau}$$

$\ln\lvert r\rvert$	$e_\tau = (u_\tau + u_{-\tau})/2$	even
$i\phi$	$o_\tau = (u_\tau - u_{-\tau})/2$	odd

Fixed spectrum says fixed e_τ.

Kolmogoroff: Causality says $u_\tau = 0$ for $\tau < 0$,
. so $u_\tau = e_\tau + o_\tau = 0$ for $\tau < 0$.

Ricker says to weaken the odd part o_τ at small lags.

To make any decon filter reveal polarity by respecting Ricker:

To make any decon filter reveal polarity by respecting Ricker:

"Grab its phase spectrum.
Bring it into the time domain.
Near zero lag, dampen it down."

(only 16 words)

Now that polarity means something,
shall we agree that,

White means hard,
and
black means soft?

Why did we not figure this out 40 years ago?

Why did we not figure this out 40 years ago?

Because everyone got interested in migration.

Two uses for this "Ricker trick"

(1) Use "as is" to modify conventional decon

(2) Use as regularization for "fancy decons"

$$0 \approx u_\tau - u_{-\tau}, \text{ for small values of } \tau$$

(Ricker trick was missing in our SEG abstract
so there was a uniqueness problem.)

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Sparsity decon in the log domain with variable gain

Sparsity decon in the log domain with variable gain

We seek sparse deconvolutions
by imposing a hyperbolic penalty function.

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Use the u(t) lag-log (quefrency) parameterization.

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Use the u(t) lag-log (quefrency) parameterization.

Gain(t) and mute(t,x) should be
done after decon, not before.

Sparsity decon in the log domain with variable gain

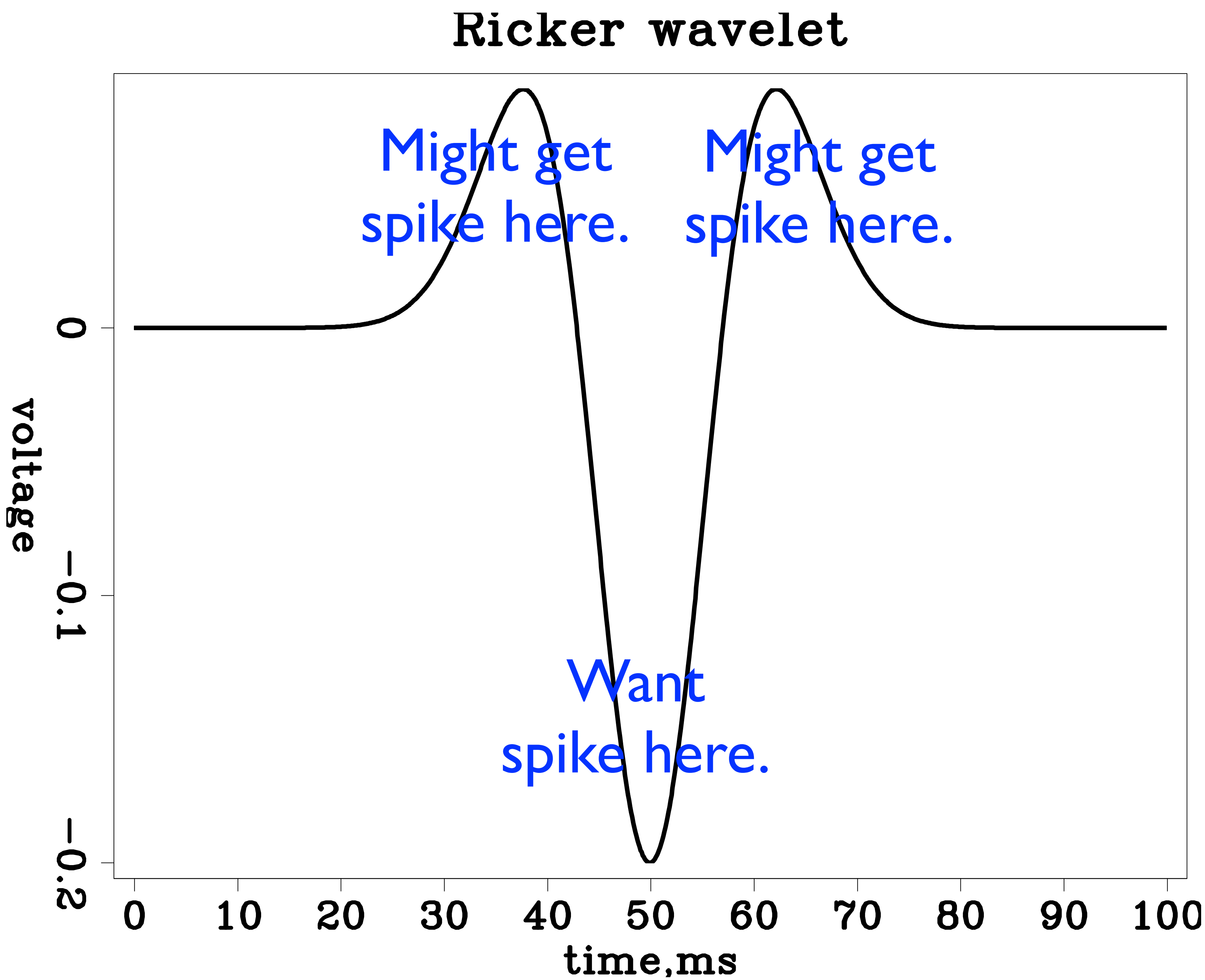
We seek sparse deconvolutions
by imposing a hyperbolic penalty function.

Use the u(t) lag-log (quefrency) parameterization.

Gain(t) and mute(t,x) should be
done after decon, not before.

Results will show that "gain after decon" benefits
(1) low frequencies, (2) noise

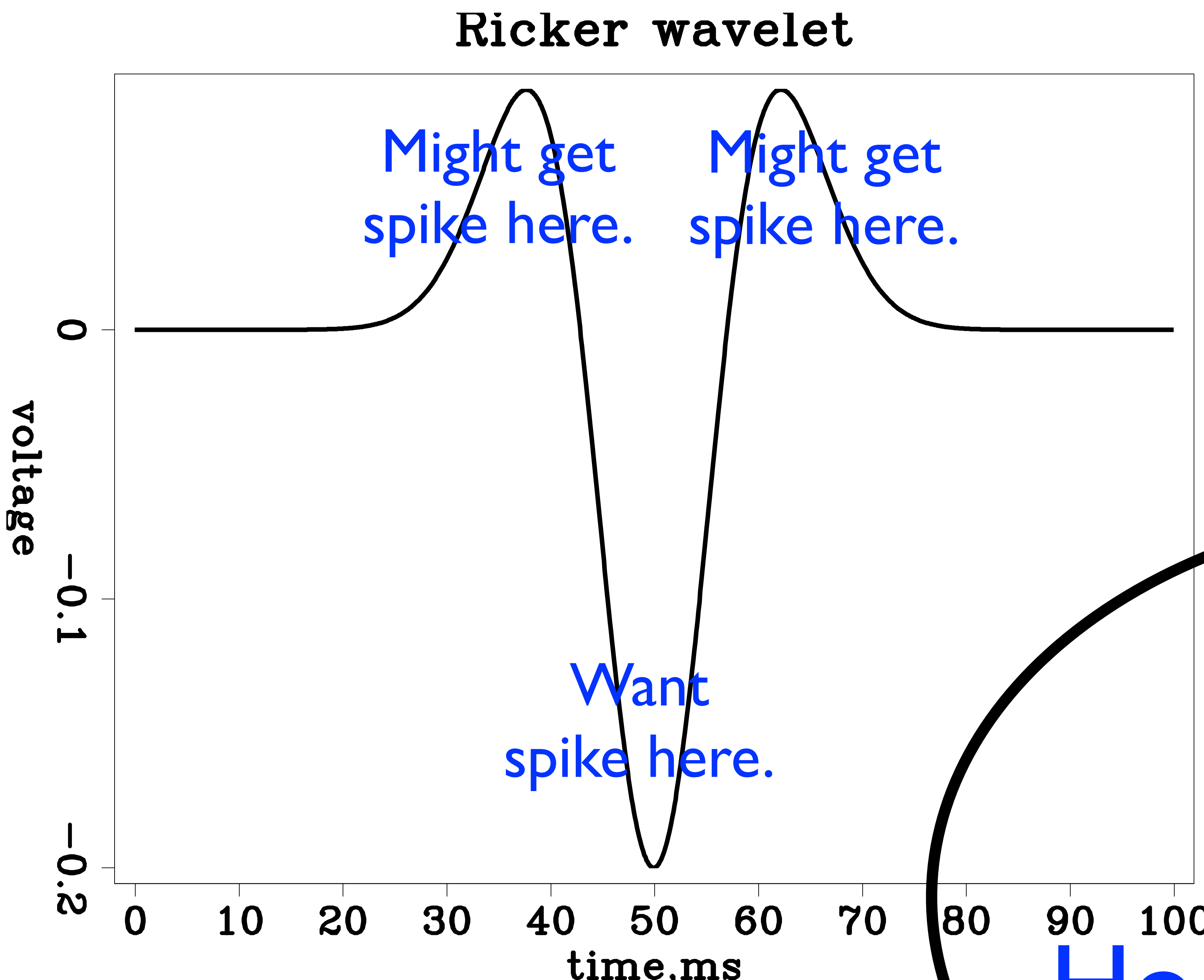
Two years of frustration,
always great results, but.......



Polarity clear,
but random!
and
unexpected
time shifts.

3 students quit!

Two years of frustration,
always great results, but........



Polarity clear,
but random!
and
unexpected
time shifts.

3 students quit!

All is resolved by
Ricker regularization.

Hooray!

Logarithmic parameterization

$$r_t \;=\; \mathrm{FT}^{-1}\; D(\omega)\; \exp\left(\sum_{\tau \neq 0} u_\tau Z^\tau\right)$$

$D(\omega)$ is the FT of the data.

r_t is reflectivity (and residual).

u_τ are the free parameters.

$u_0 = 0$ is mean log spectrum.

u_τ is the quefrency or lag-log space.

Gain and sparsity

$$q_t = g_t \; r_t$$

where:

r_t is the physical output of the filter

g_t is the given gain function, often t^2

q_t is the gained output, also called the "statistical signal" to be sparsified.

$$q_t = g_t \, r_t$$

$$H(q_t) = \sqrt{q_t^2 + 1} - 1$$

softly clipped residual

$$\frac{dH}{dq} = H'(q) = \frac{q}{\sqrt{q^2+1}} = \text{softclip}(q)$$

r_t is the physical output of the filter
g_t is the given gain function
q_t is the gained output,
$H(q)$ is the hyperbolic penalty function.
Choose g_t so that $q_t \approx 1$.
"Sparsity" is $1 \, / \, \sum_t H(q_t)$

$$r_t = \mathrm{FT}^{-1}\ D(Z)\ e^{\cdots + u_2 Z^2 + u_3 Z^3 + u_4 Z^4 + \cdots}$$

$$\frac{dr_t}{du_\tau} = \mathrm{FT}^{-1}\ D(Z)\ Z^\tau e^{\cdots + u_2 Z^2 + u_3 Z^3 + u_4 Z^4 + \cdots}$$

$$\frac{dr_t}{du_\tau} = r_{t+\tau}$$

$$r_t = \mathrm{FT}^{-1}\ D(Z)\ e^{\cdots + u_2 Z^2 + u_3 Z^3 + u_4 Z^4 + \cdots}$$

$$\frac{dr_t}{du_\tau} = \mathrm{FT}^{-1}\ D(Z)\ Z^\tau e^{\cdots + u_2 Z^2 + u_3 Z^3 + u_4 Z^4 + \cdots}$$

$$\frac{dr_t}{du_\tau} = r_{t+\tau}$$

Physical output gradient
w.r.t. lag-log variable

$$q_t = r_t\ g_t$$

$$\frac{dq_t}{du_\tau} = \frac{dr_t}{du_\tau}\ g_t = r_{t+\tau}\ g_t$$

Statistical gradient

amazing result coming

the step

$$\Delta u_\tau = \sum_t \frac{dH(q_t)}{du_\tau} \qquad \tau \neq 0$$

$$= \sum_t \frac{dq_t}{du_\tau} \frac{dH(q_t)}{dq_t}$$

$$\Delta u_\tau = \sum_t (r_{t+\tau}) \quad (g_t H'(q_t)) \qquad \tau \neq 0$$

A crosscorrelation: Compute it in the Fourier domain;

Jon's favorite theory slide.

the step

$$\Delta u_\tau = \sum_t \frac{dH(q_t)}{du_\tau} \qquad \tau \neq 0$$

$$= \sum_t \frac{dq_t}{du_\tau} \frac{dH(q_t)}{dq_t}$$

$$\Delta u_\tau = \sum_t (r_{t+\tau}) \quad (g_t H'(q_t)) \qquad \tau \neq 0$$

A crosscorrelation: Compute it in the Fourier domain;
it's the gradient, vanishes at convergence;
it's a delta function.

Jon's favorite theory slide.

the step

$$\Delta u_\tau = \sum_t \frac{dH(q_t)}{du_\tau} \qquad \tau \neq 0$$

$$= \sum_t \frac{dq_t}{du_\tau} \frac{dH(q_t)}{dq_t}$$

$$\Delta u_\tau = \sum_t (r_{t+\tau}) \quad (g_t H'(q_t)) \qquad \tau \neq 0$$

A crosscorrelation: Compute it in the Fourier domain.

Special case: stationary L2 then r(t) is white.
Generalized three ways,
(1) non-causal, (2) gain, and (3) sparsity!

Jon's favorite theory slide.

RESULTS

Compare gain before with gain after.

OLD:

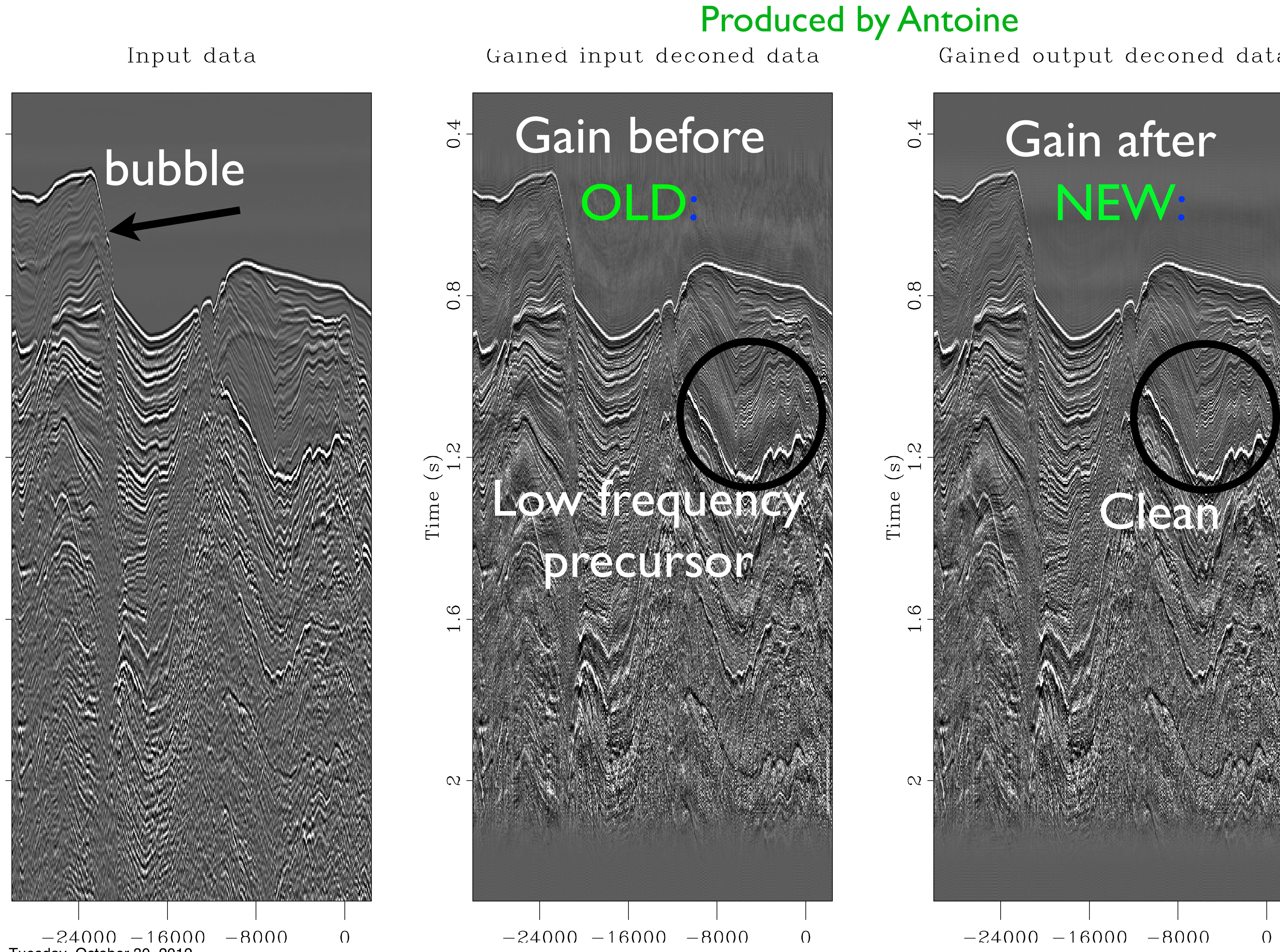
data $\longrightarrow$ t-squared gain $\longrightarrow$ decon

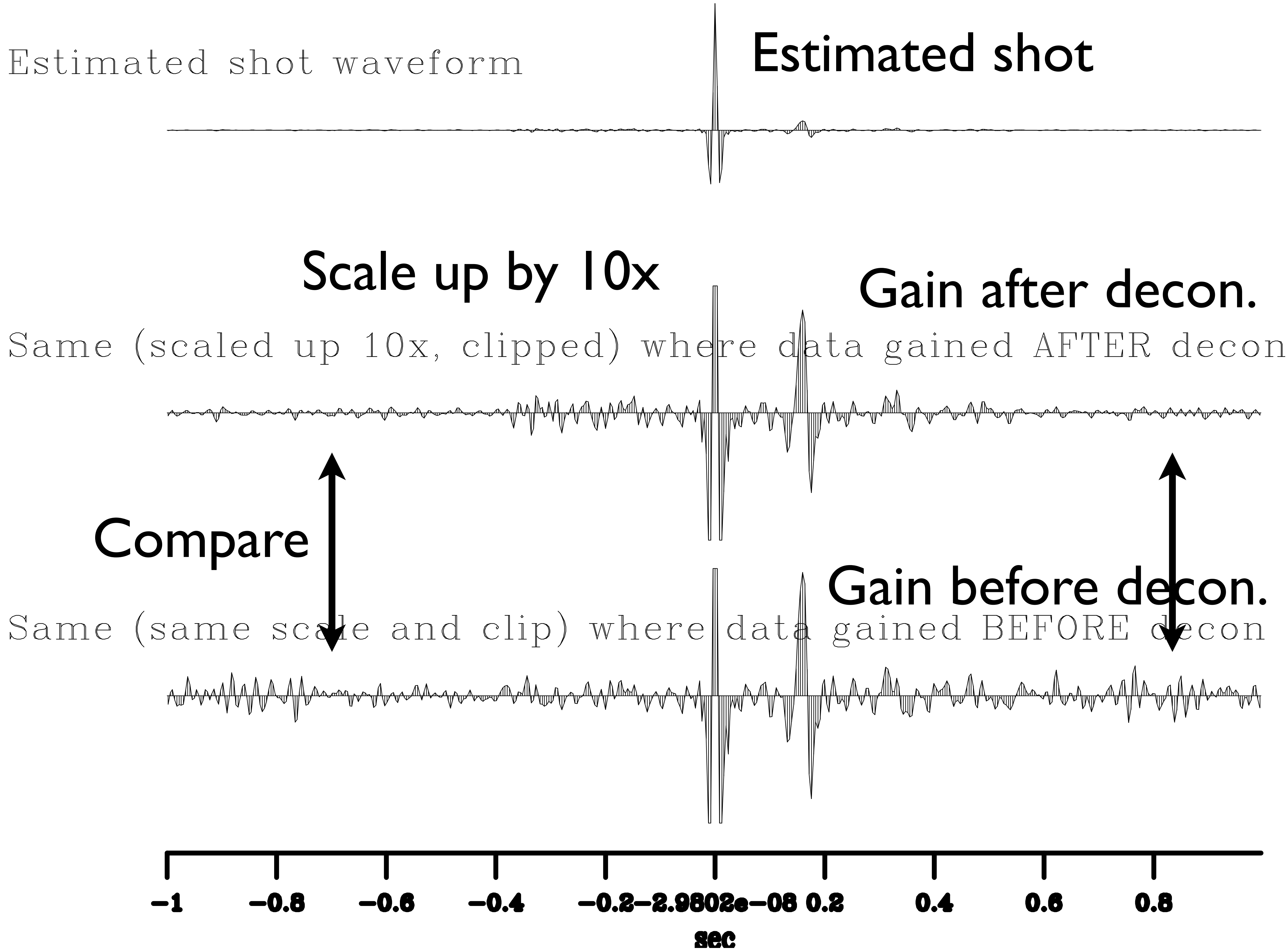
NEW:

data $\longrightarrow$ new decon $\longrightarrow$ t-squared gain

r_t q_t

Want to get the low frequencies correct.


Produced by Antoine
Input data
Gained input deconed data
Gained output deconed dat
bubble
Gain before
OLD:
Low frequency
precursor
Gain after
NEW:
Clean
Time (s)
0.4
0.8
1.2
1.6
2
−24000
−16000
−8000
0


Estimated shot waveform
Estimated shot
Scale up by 10x
Gain after decon.
Same (scaled up 10x, clipped) where data gained AFTER decon
Compare
Gain before decon.
Same (same scale and clip) where data gained BEFORE decon
−1
−0.8
−0.6
−0.4
−0.2−2.9802e−08 0.2
0.4
0.6
0.8
sec

CONCLUSIONS

Seismogram polarity is revealed
by Ricker compliant deconvolution
which is simple to code.

Gain does not commute with decon
and should be done after
(but not many examples yet).


I'd like to thank the team.
Fu
Yang
Antoine
Elita
Yi
STANFORD

ACKNOWLEDGEMENT

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Antoine Guitton thanks Repsol Sinopec Brasil SA and Geo Imaging Solucoes Tecnologicas em Geociencias Ltda.

We'd like to thank Yang Zhang for continued interest.

Thank you for your interest too.

Enjoy!