Ricker-compliant and pseudo-unitary decon

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EAGE London meeting

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ABSTRACT

Seismogram polarity becomes more apparent when deconvolution removes the correct source wavelet.

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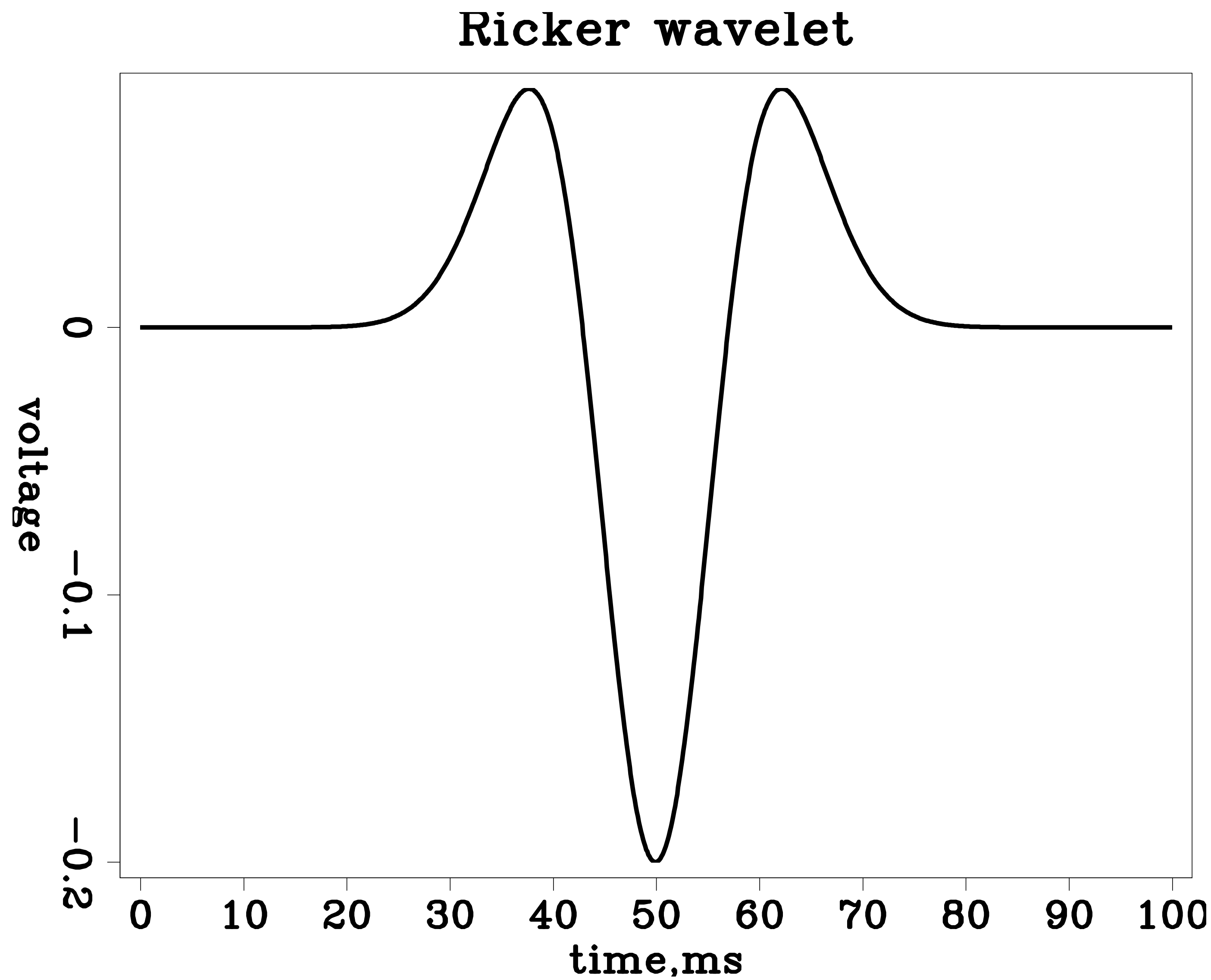
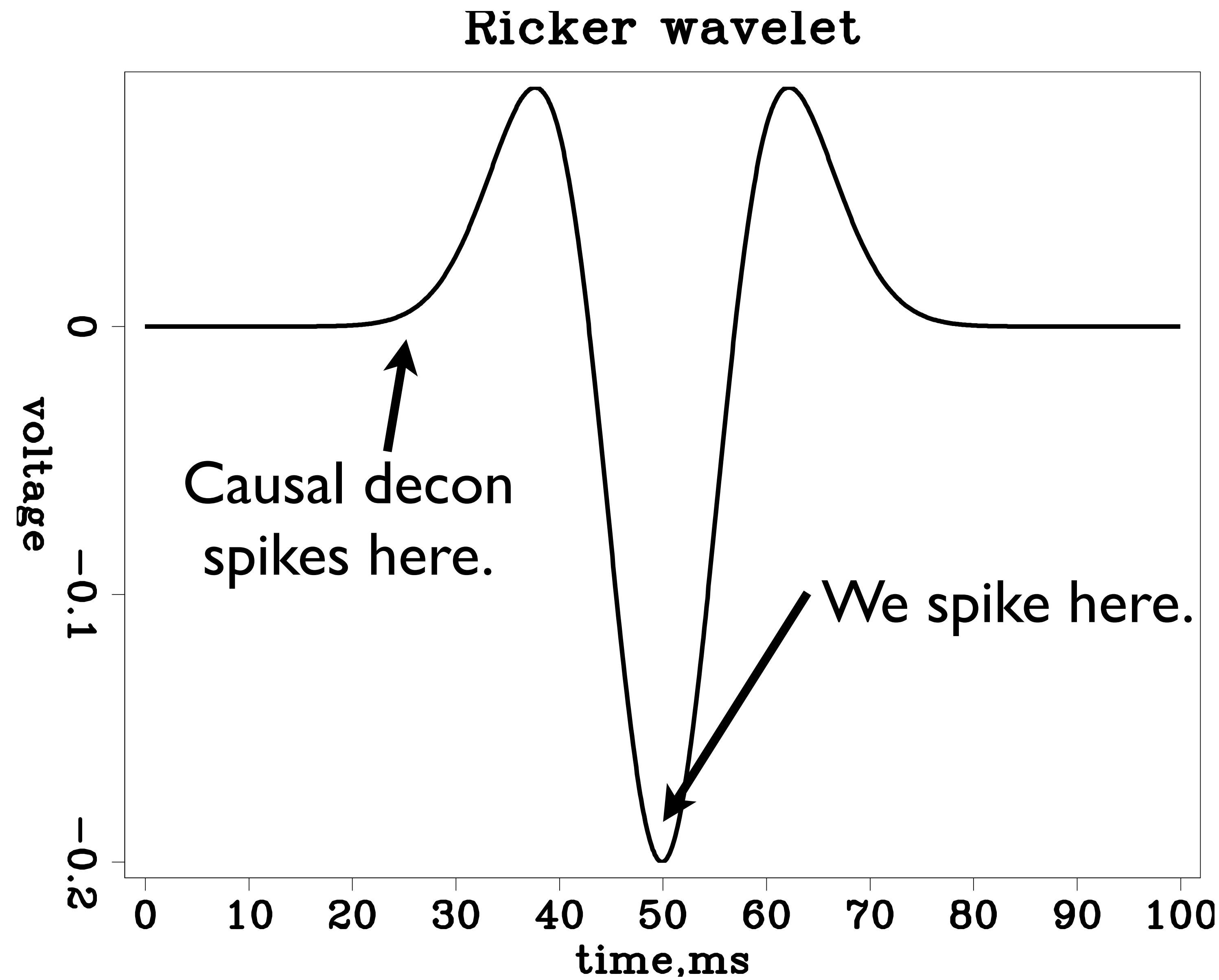
..but the essential feature is a memorable trick that I can squeeze into a 20 minute talk.

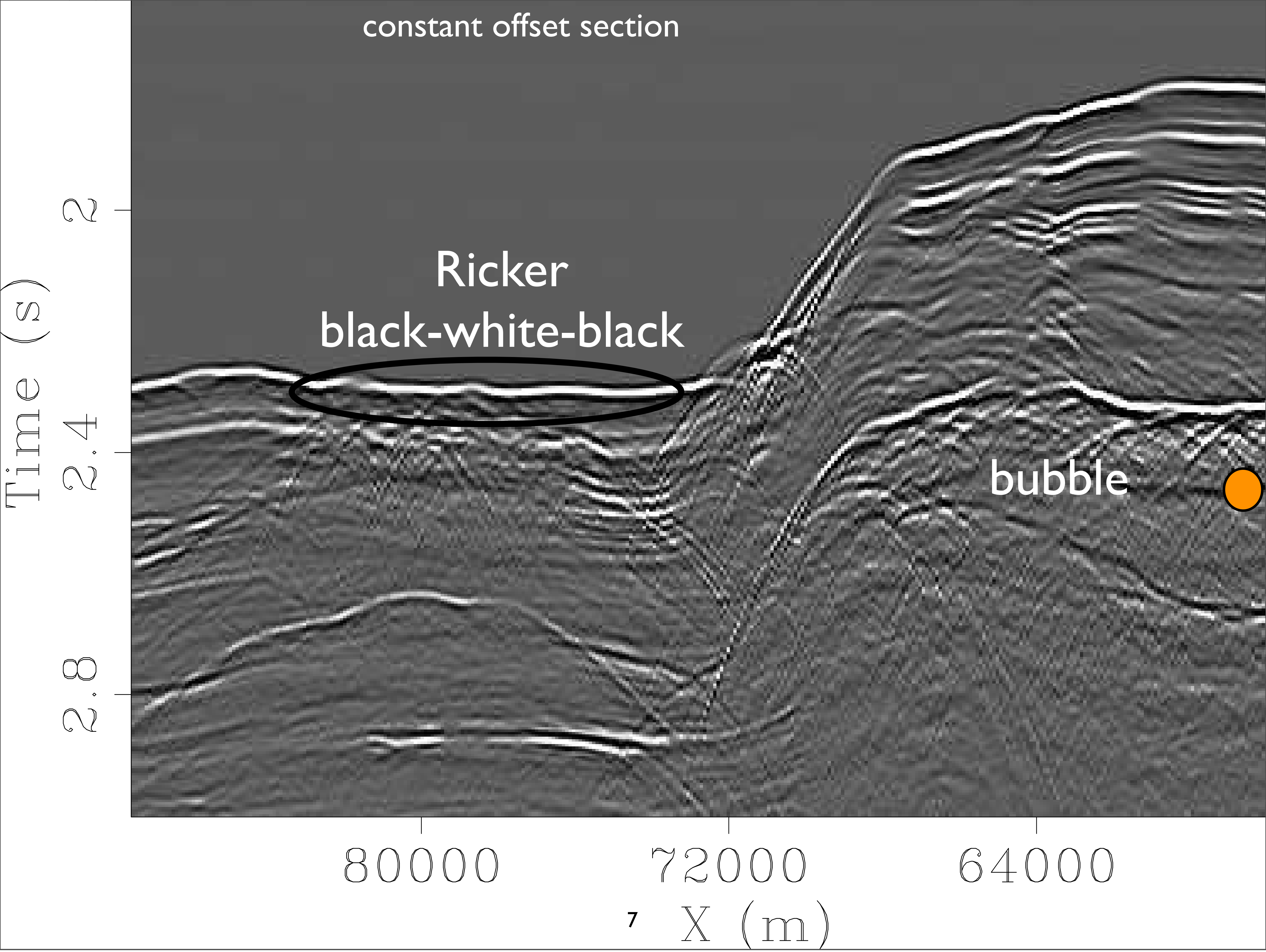


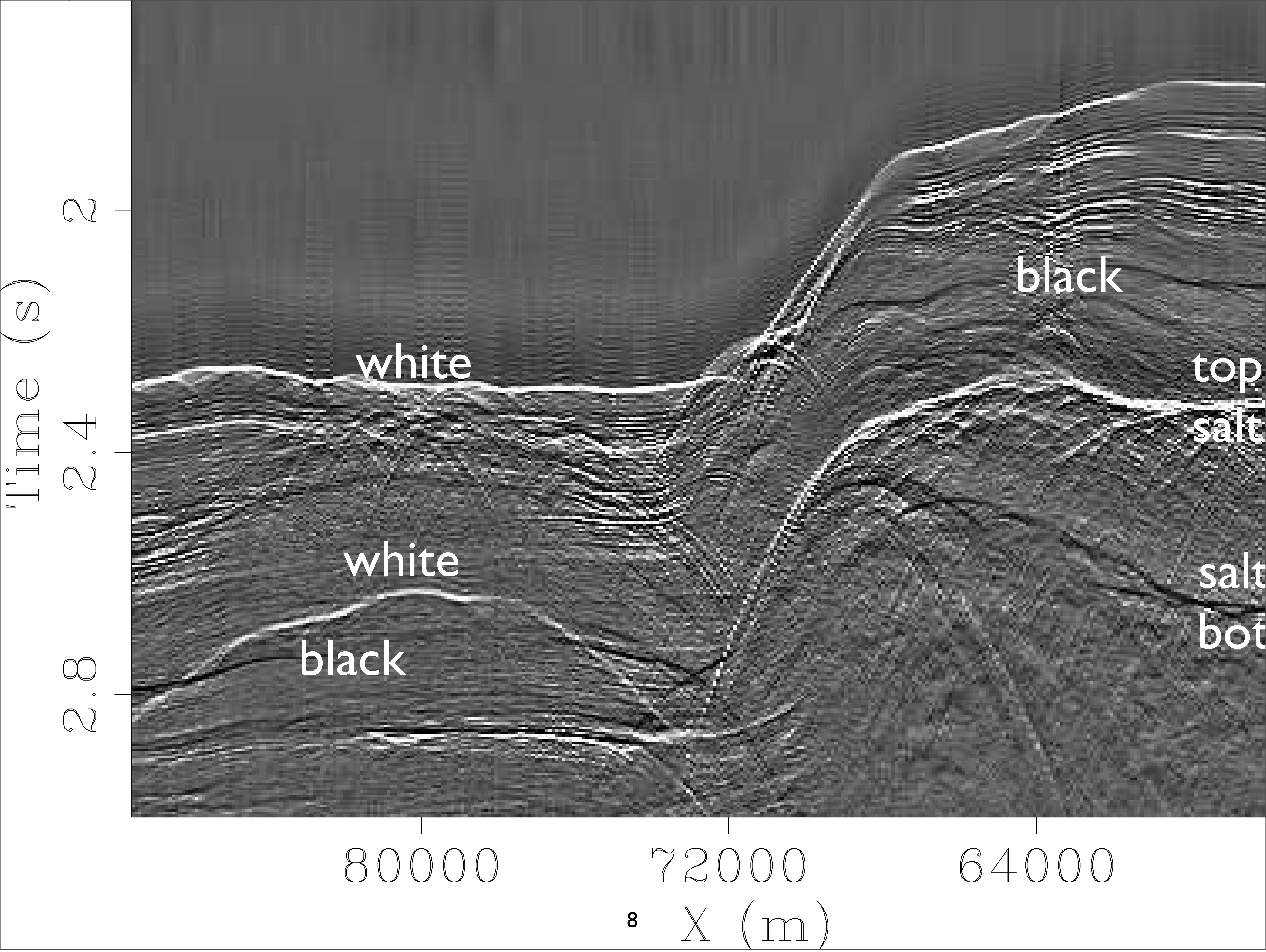
The universal marine wavelet is the Ricker wavelet.
Why? Marine gun and hydrophone are beneath the surface.
Both have a nearby surface reflection of opposite polarity.

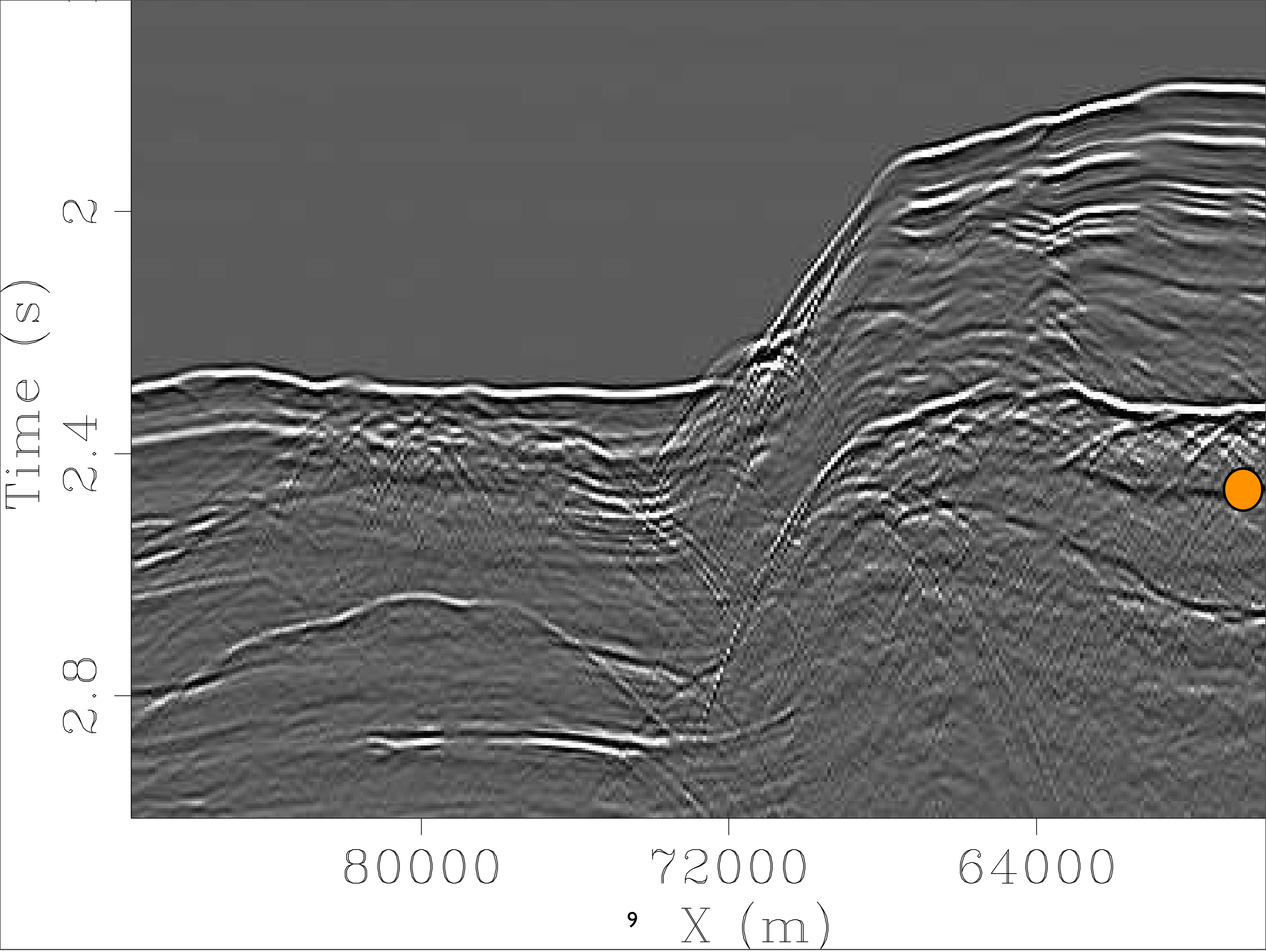


Traditional: Least squares

This talk: Analytic


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


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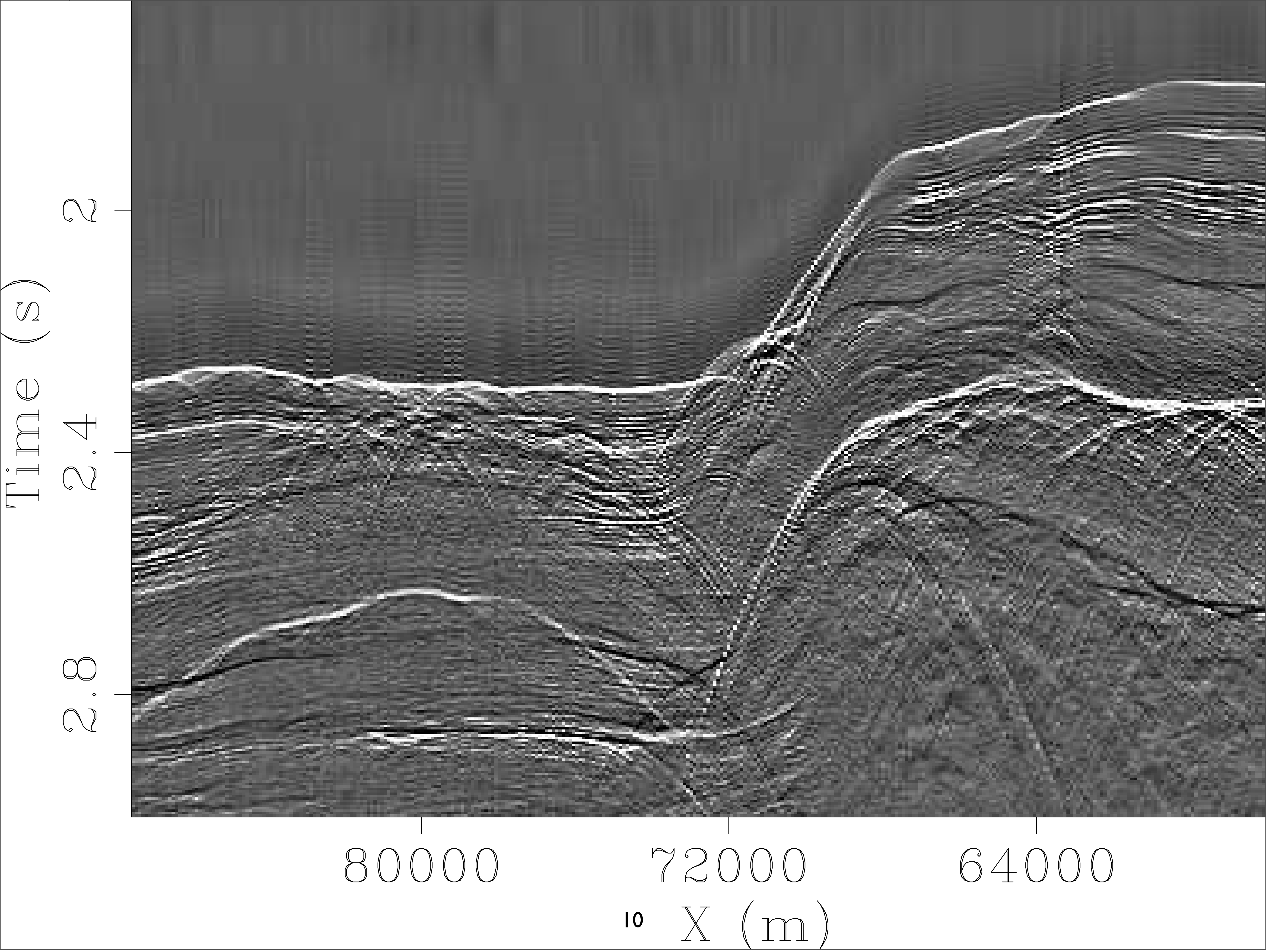
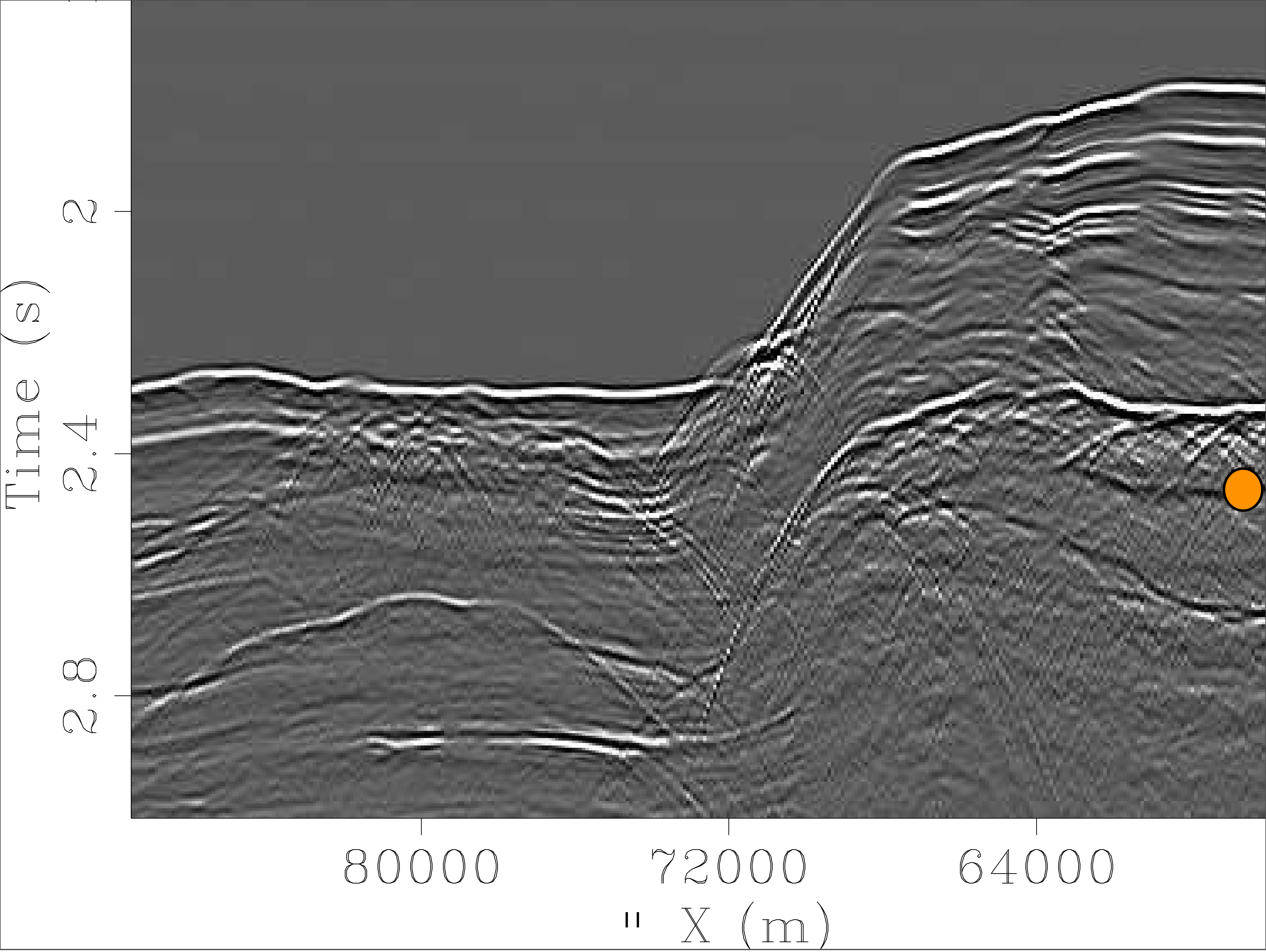
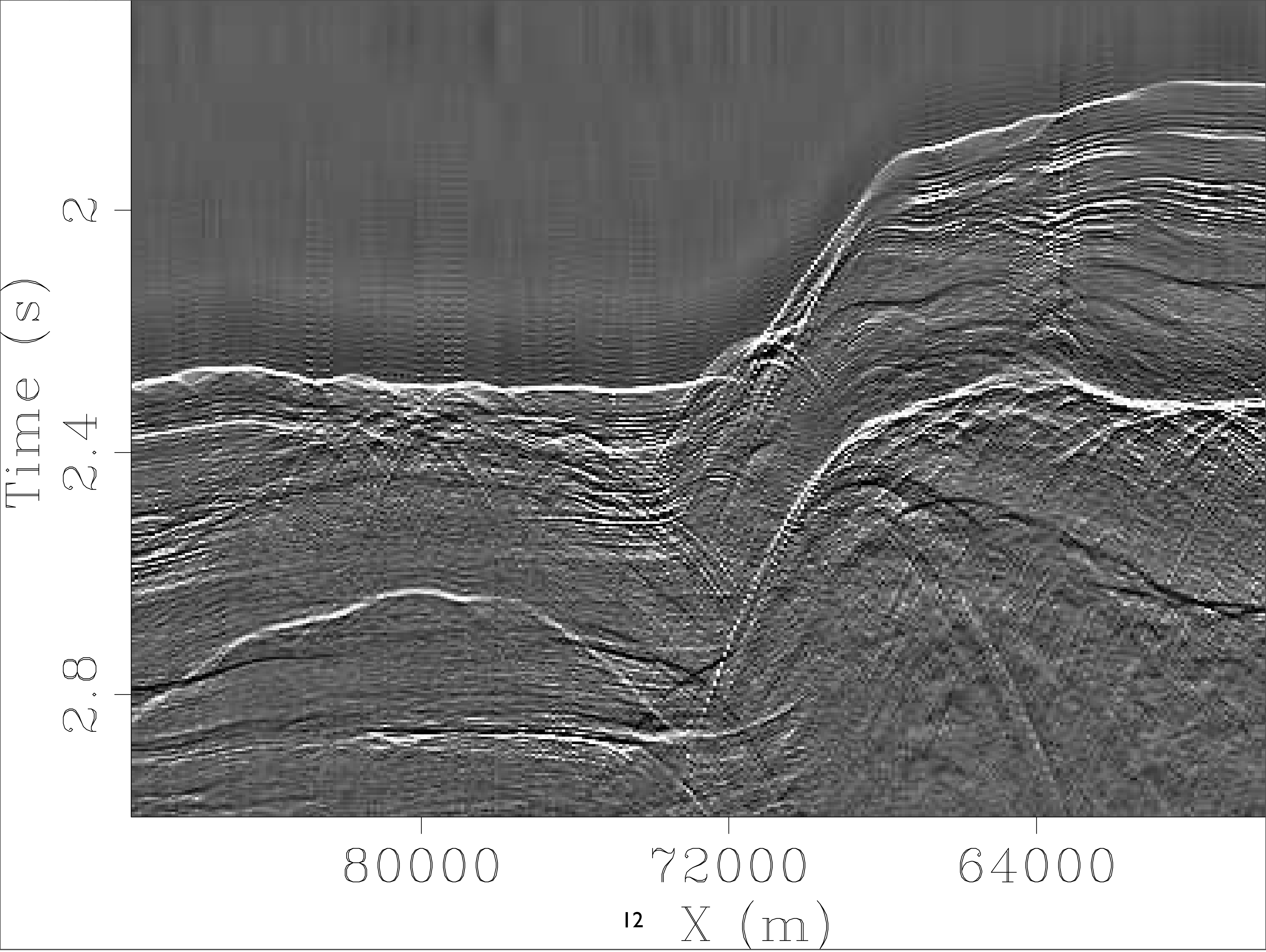
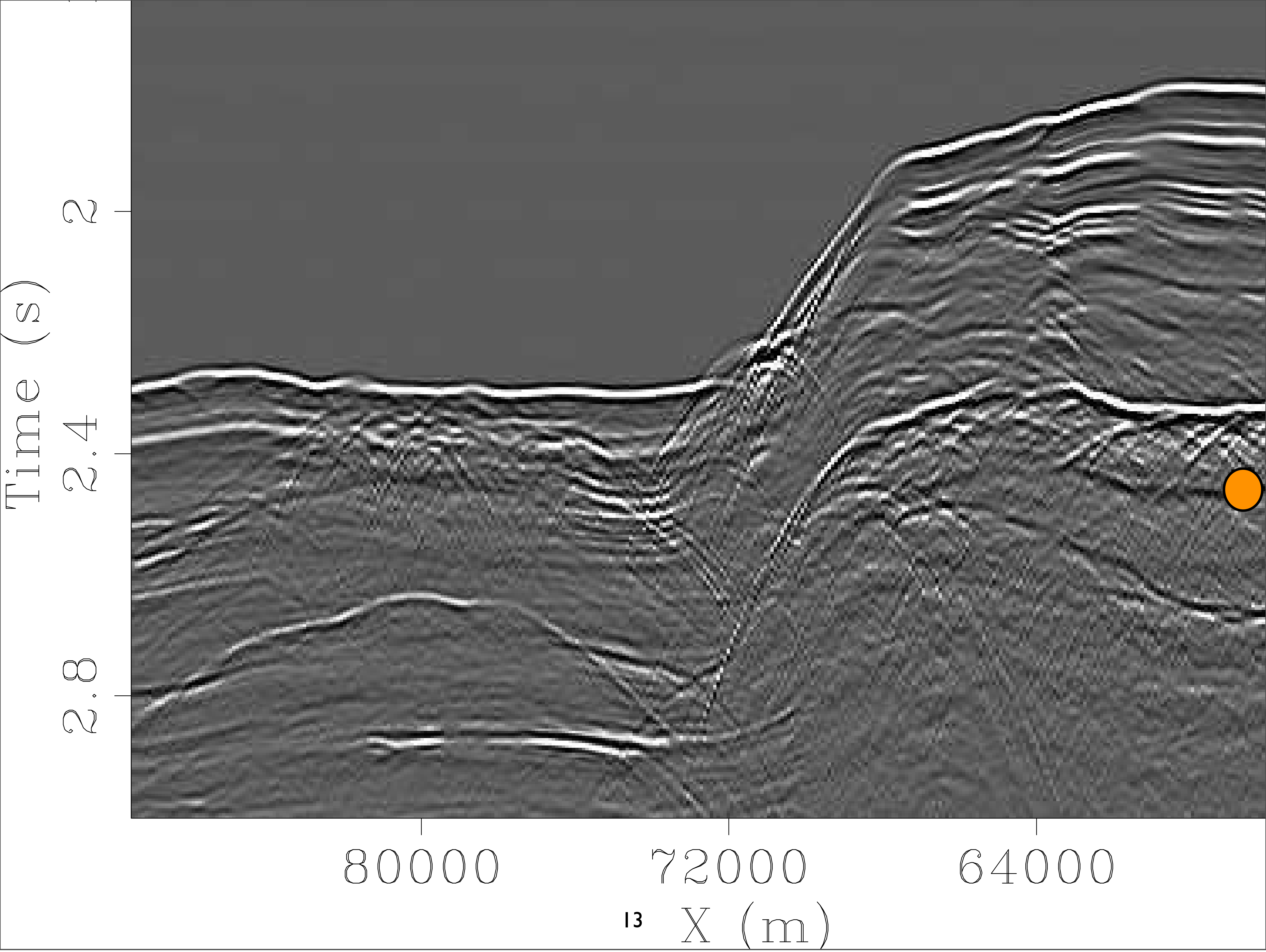
2.4
2.8
80000
72000
64000
X (m)

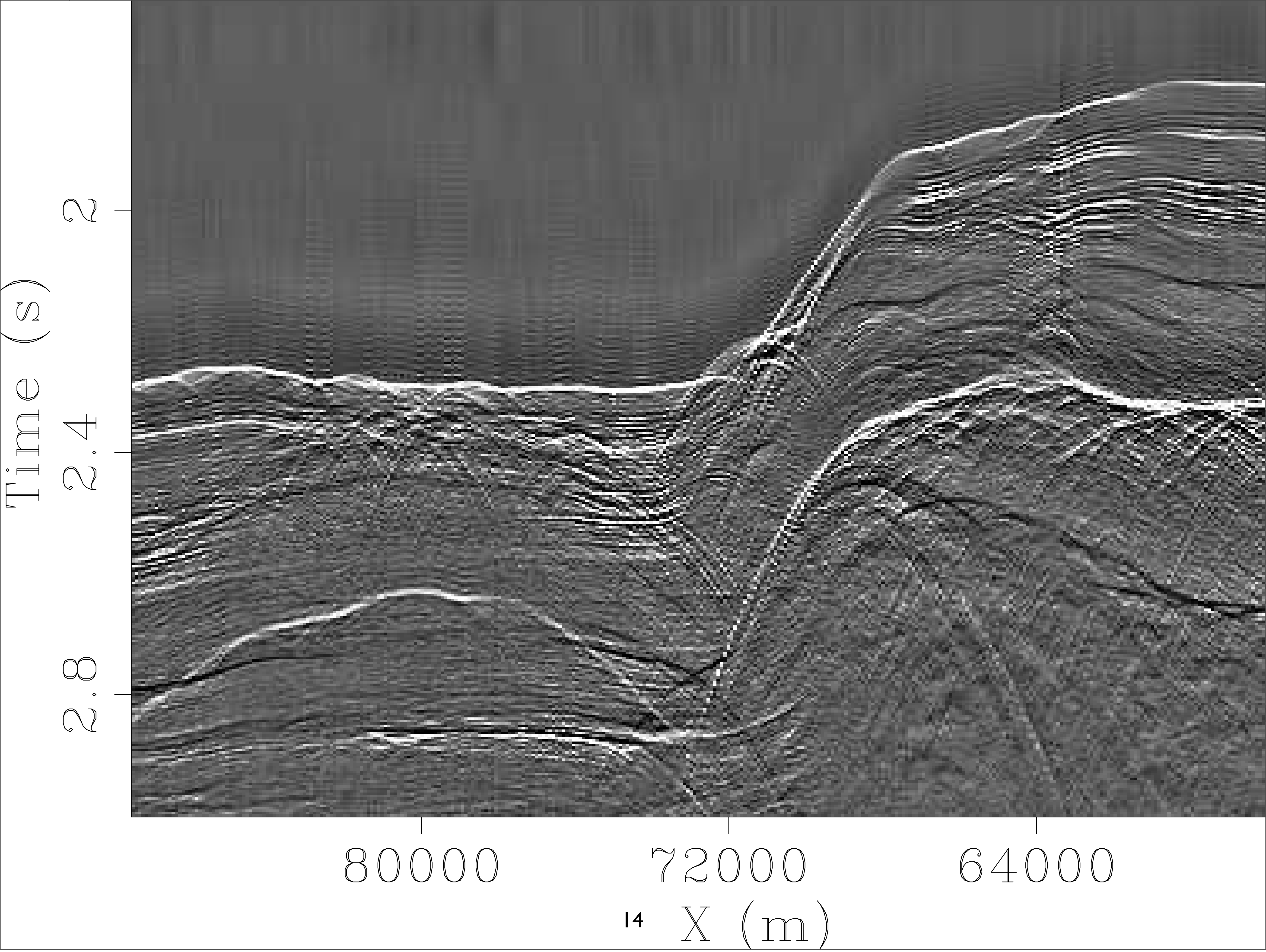

Time (s)
2
2.4
2.8
80000
72000
64000
X (m)


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

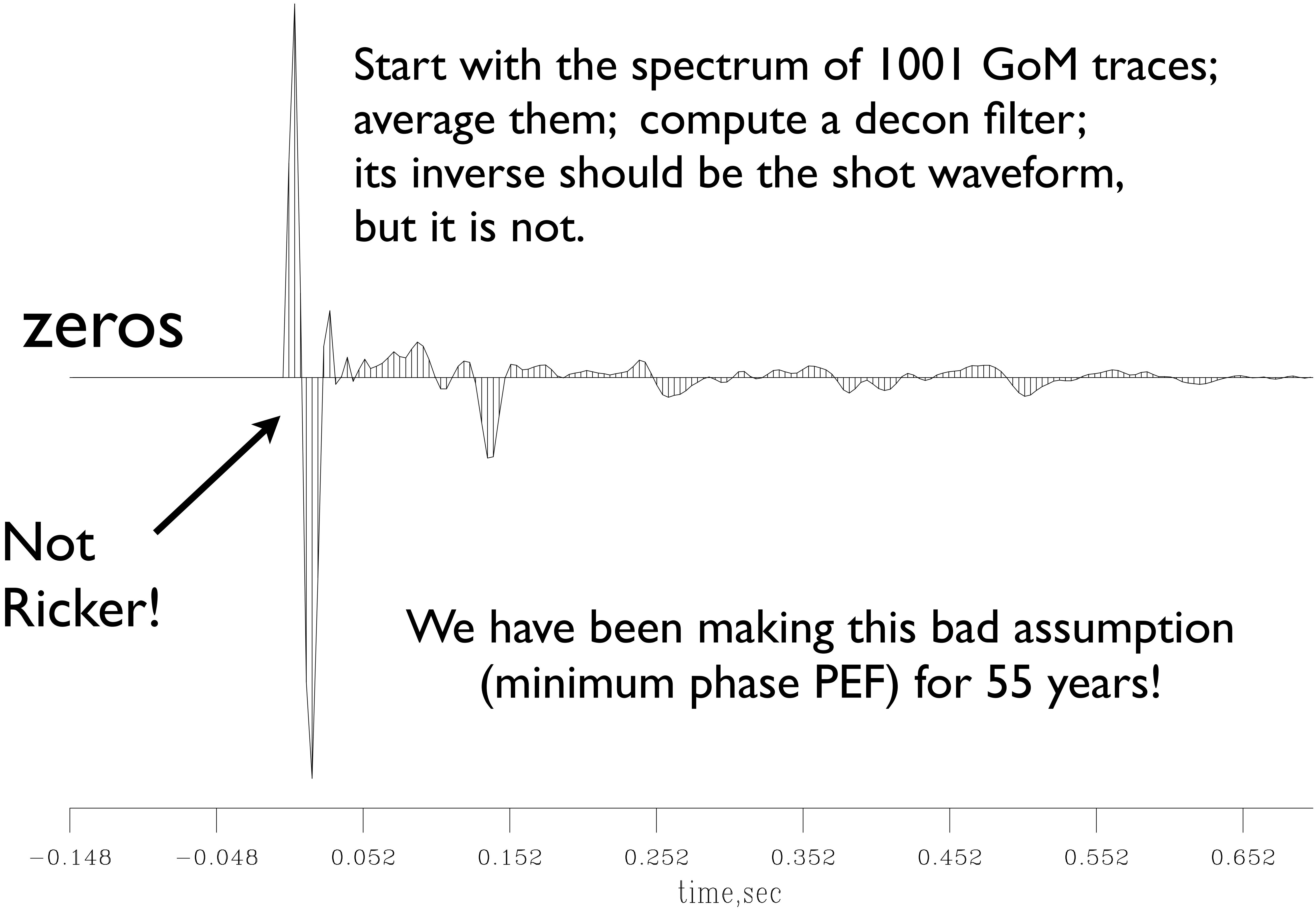


Time (s)
2
2.4
2.8
80000
72000
64000
X (m)


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

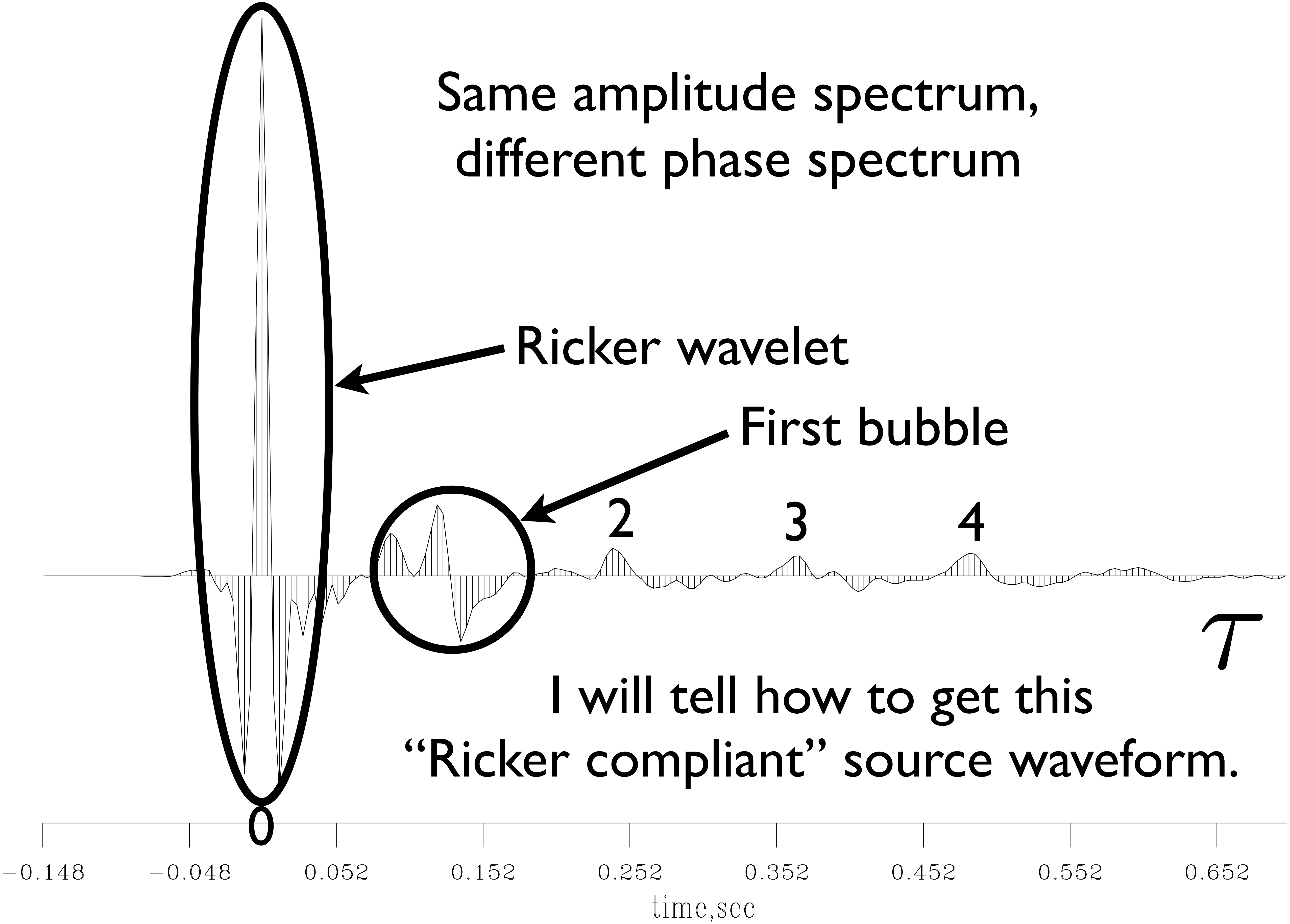

Time (s)
2
2.4
2.8
80000
72000
64000
X (m)

Start with the spectrum of 1001 GoM traces; average them; compute a decon filter; its inverse should be the shot waveform, but it is not.

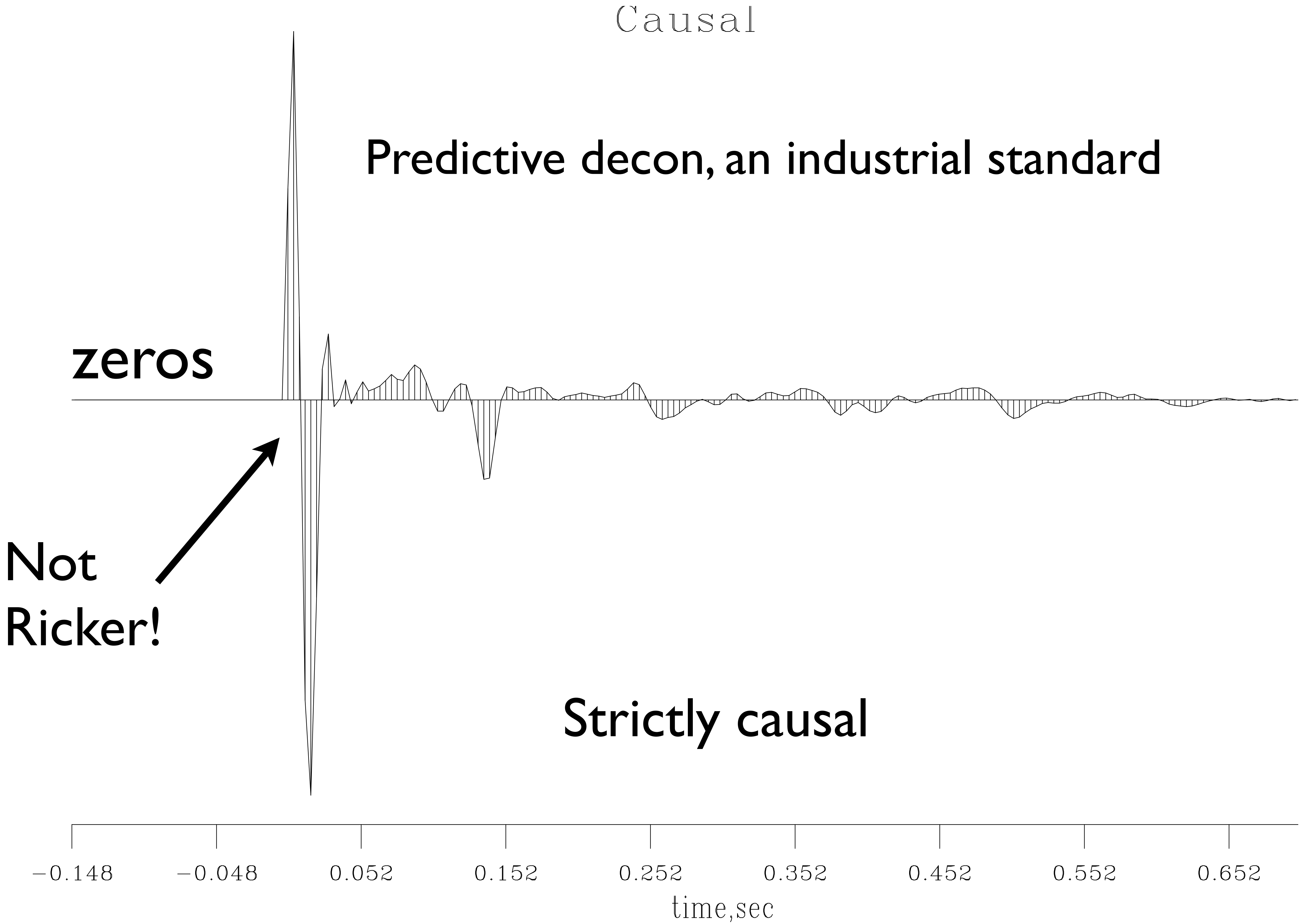


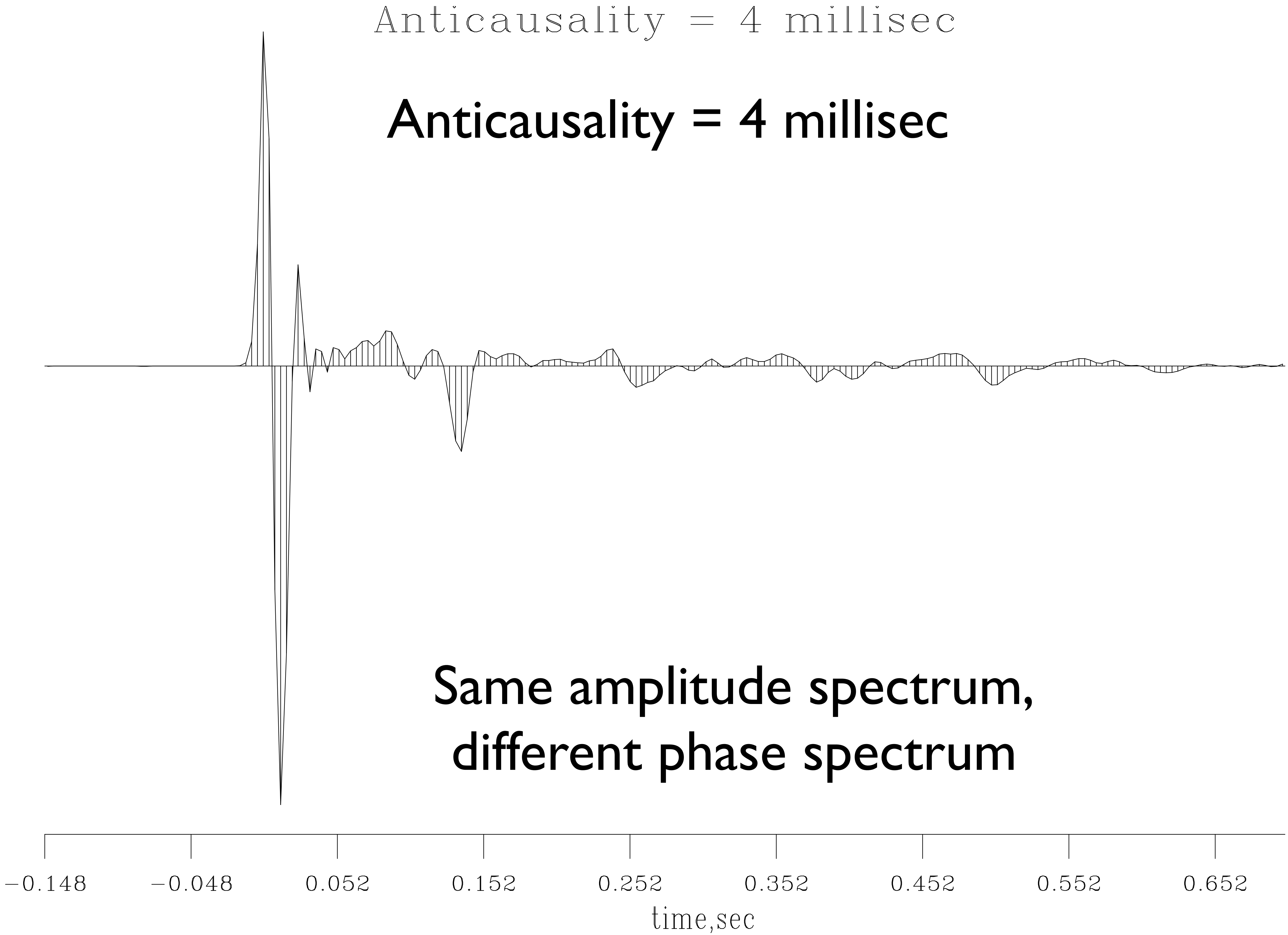
We have been making this bad assumption (minimum phase PEF) for 55 years!

Same amplitude spectrum, different phase spectrum



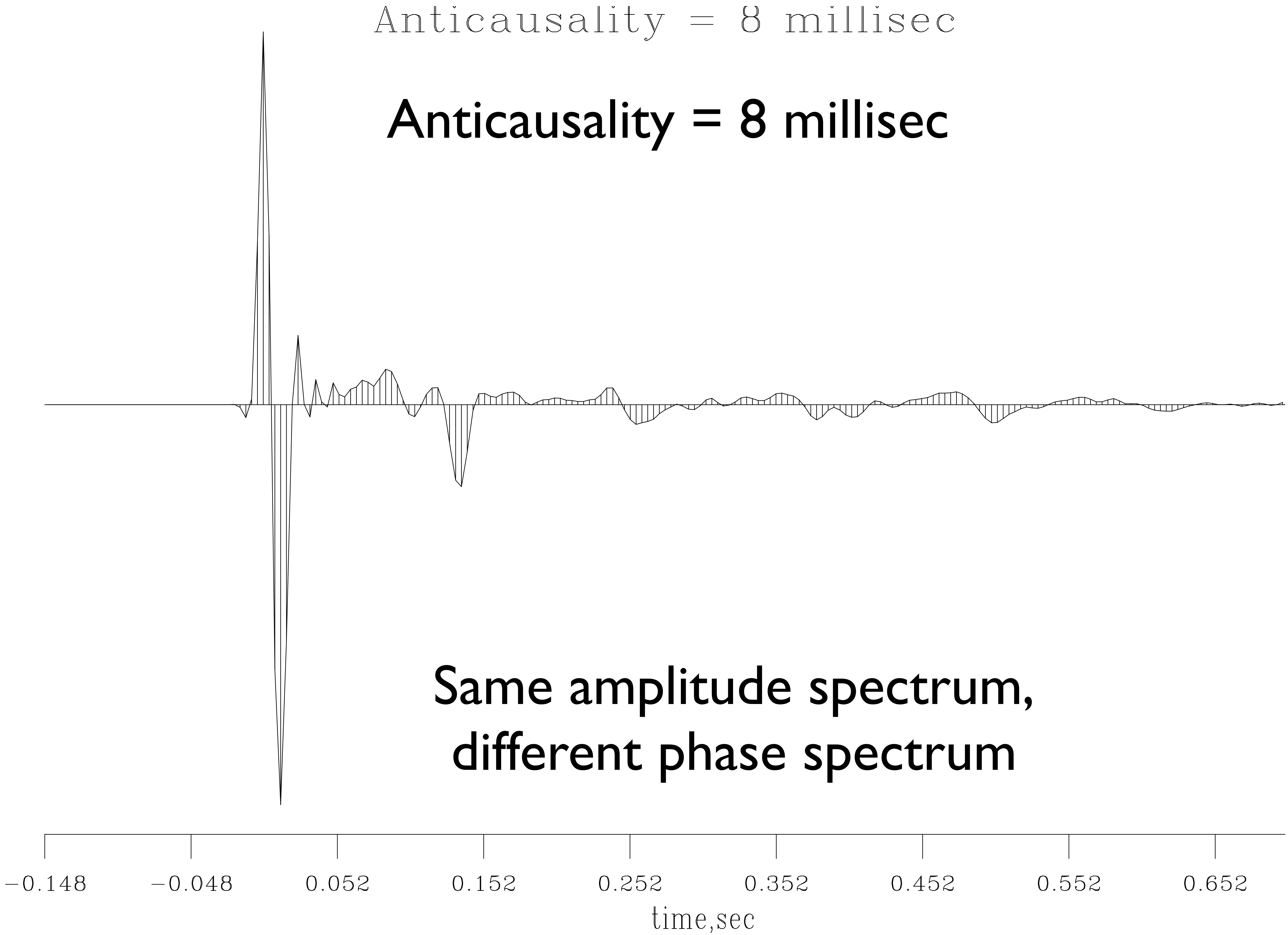
I will tell how to get this “Ricker compliant” source waveform.


Causal
Predictive decon, an industrial standard
zeros
Not
Ricker!
Strictly causal
−0.148
−0.048
0.052
0.152
0.252
0.352
0.452
0.552
0.652
time,sec



Anticausality = 4 millisec

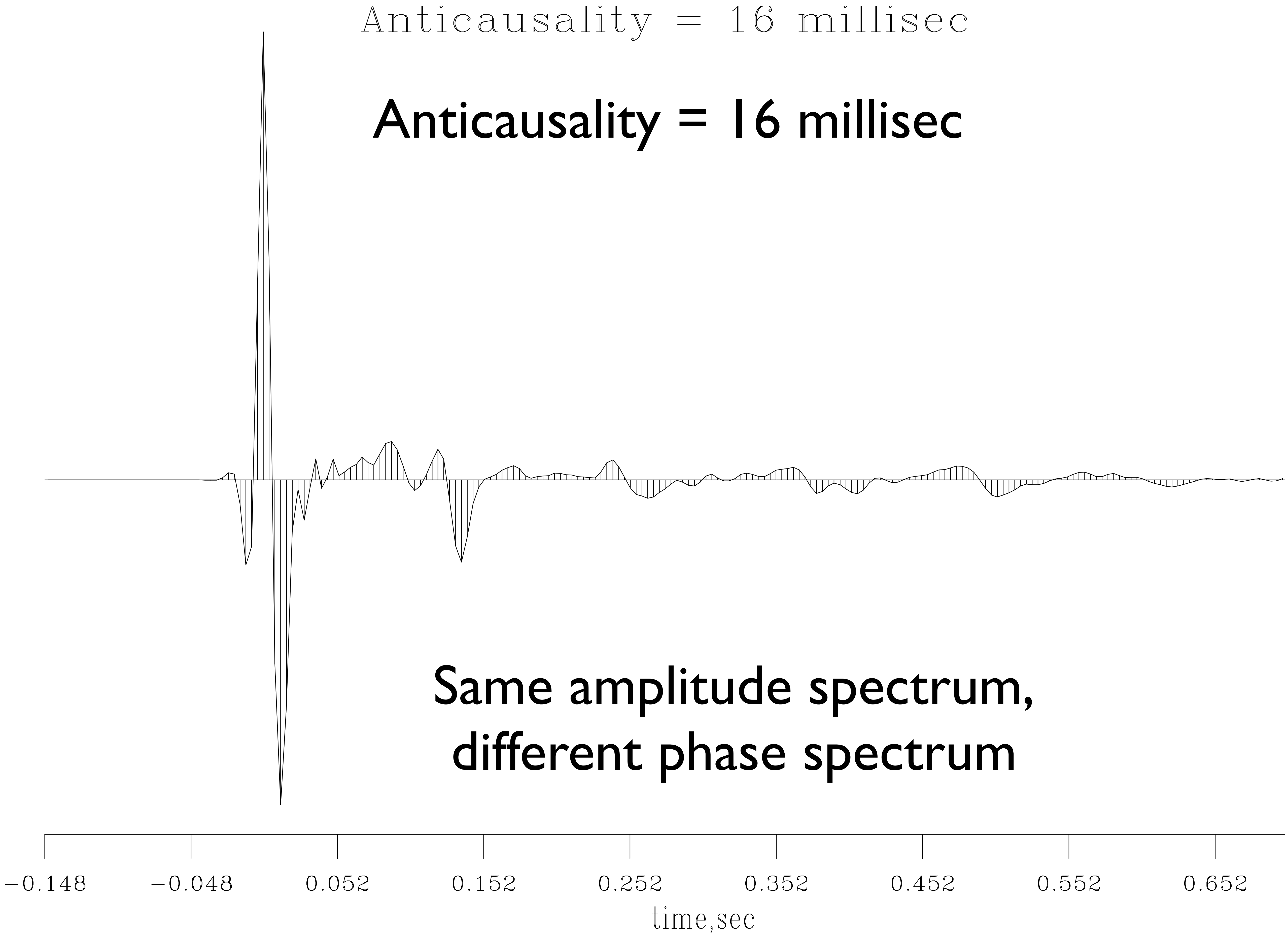
Same amplitude spectrum,
different phase spectrum



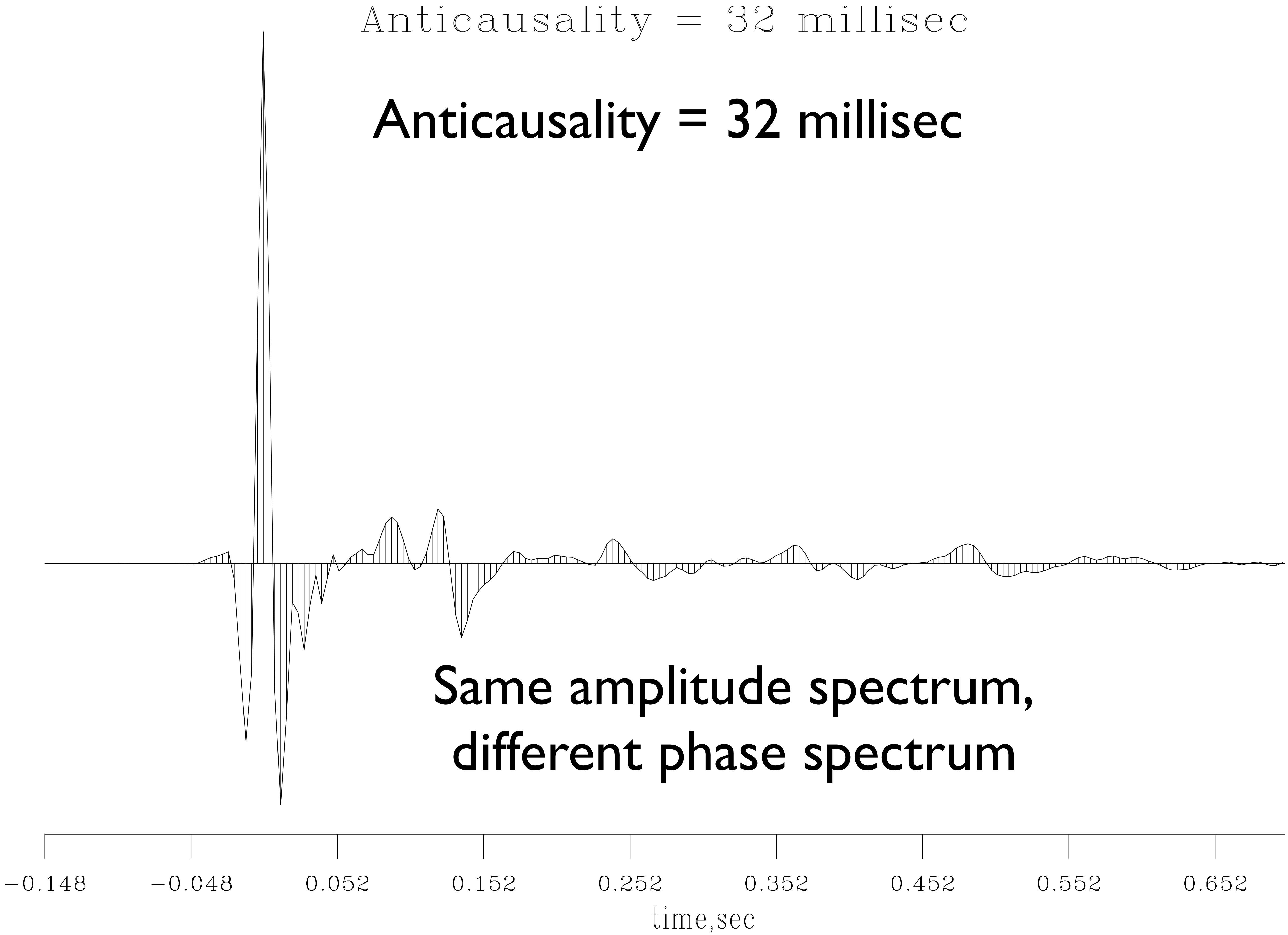
Anticausality = 8 millisec

Same amplitude spectrum,
different phase spectrum

Anticausality = 16 millisec



Same amplitude spectrum,
different phase spectrum

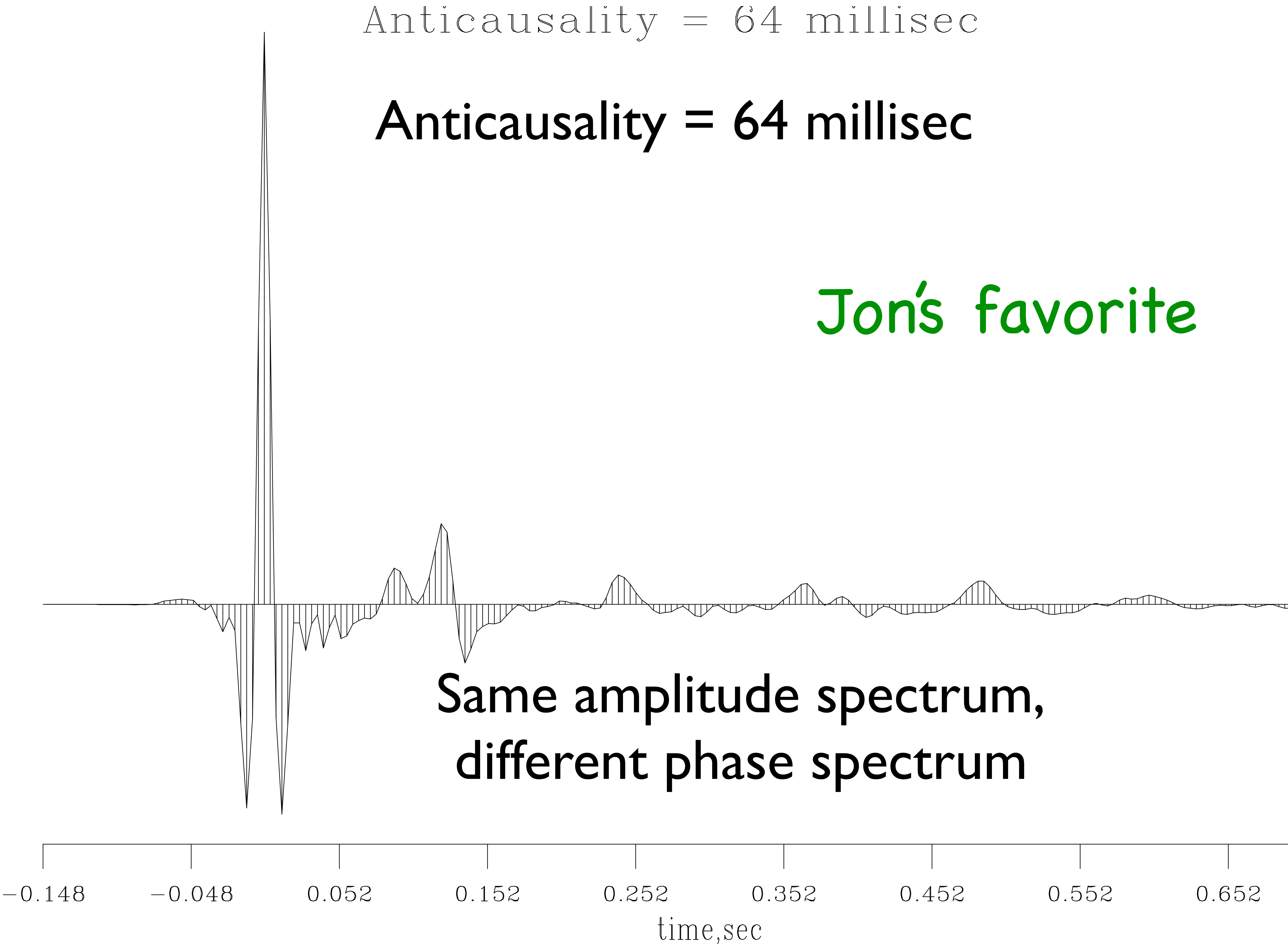


Anticausality = 32 millisec

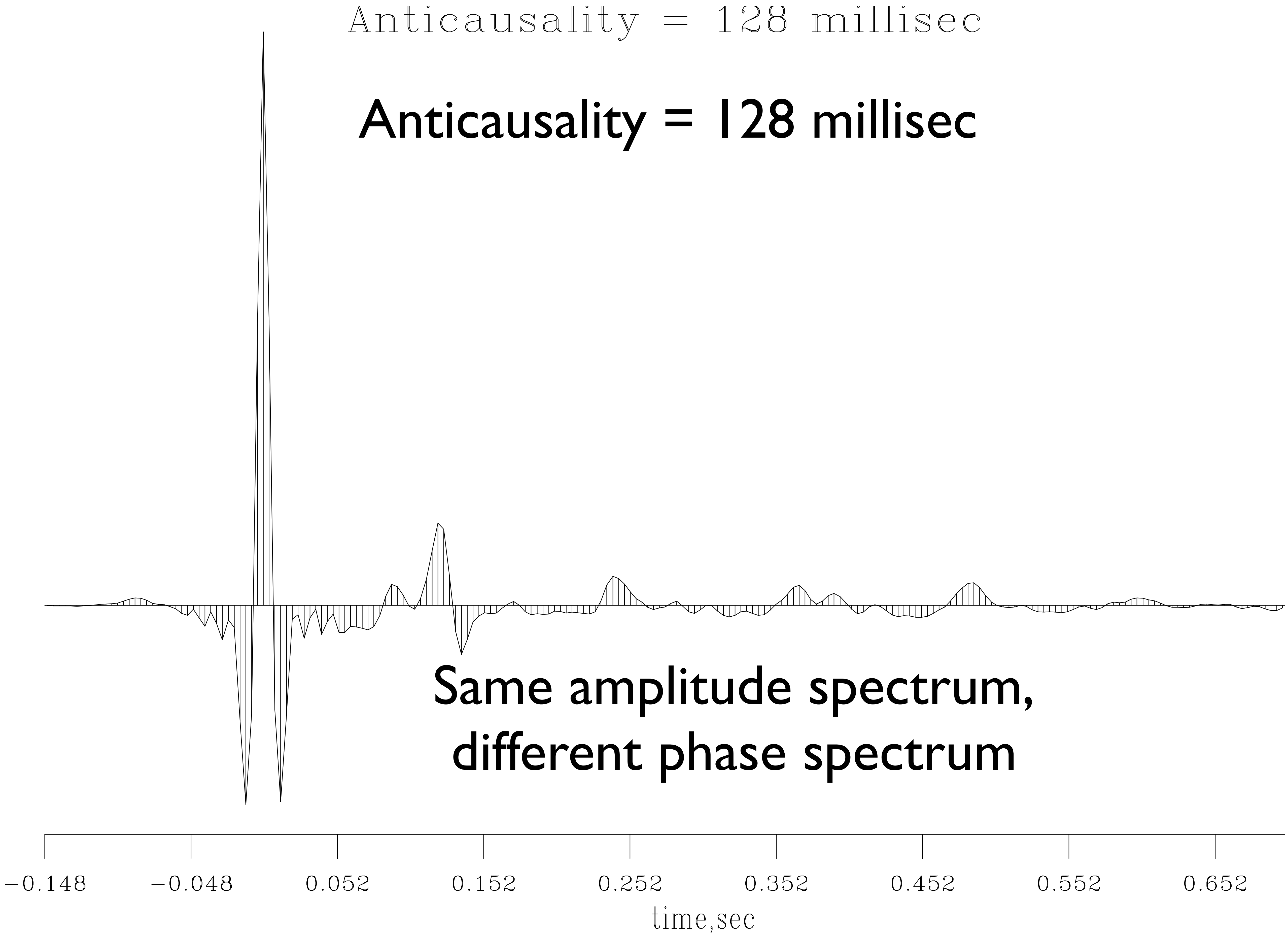
Same amplitude spectrum,
different phase spectrum

Anticausality = 64 millisec

Jon's favorite



Same amplitude spectrum,
different phase spectrum

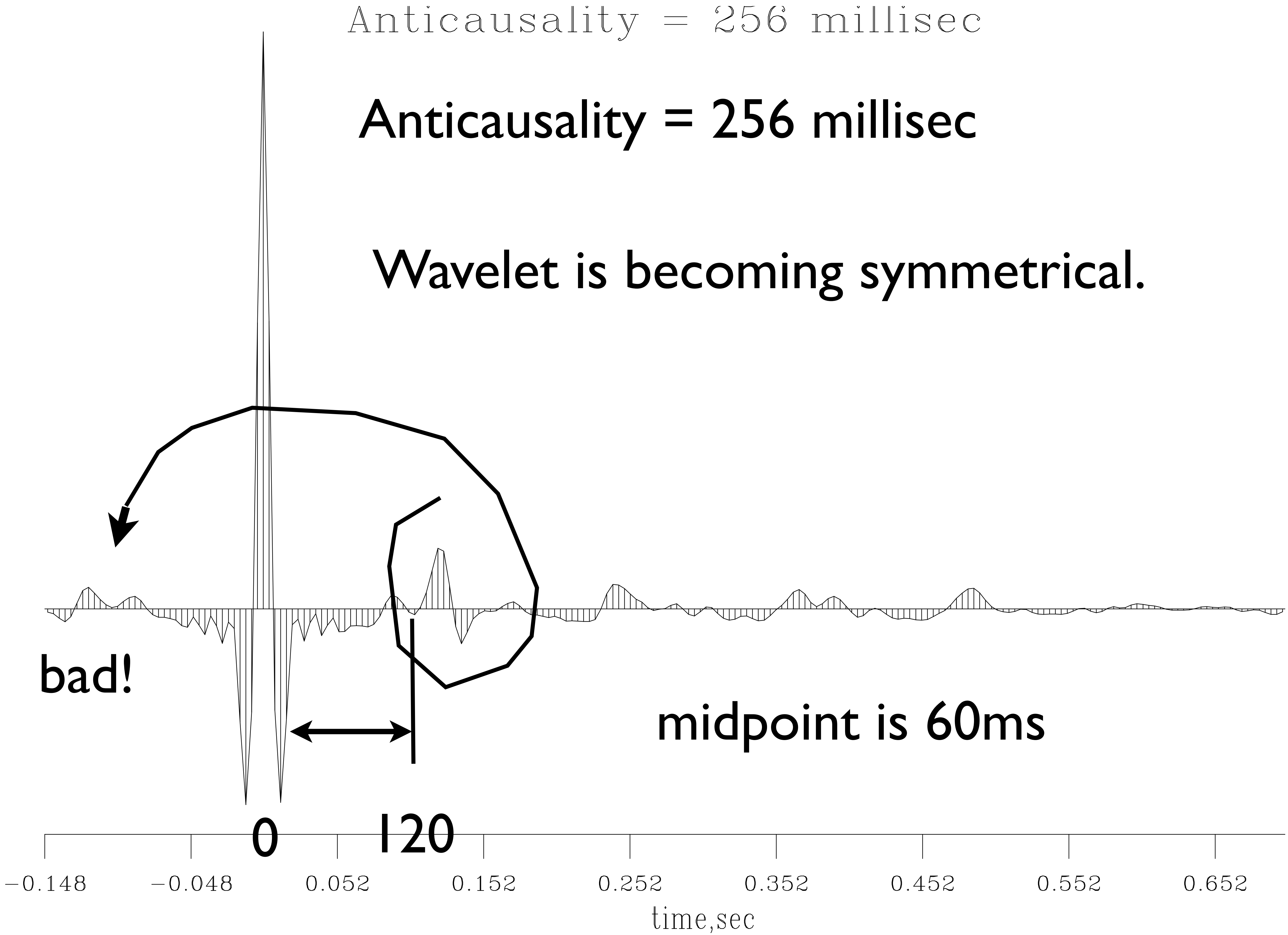


Anticausality = 128 millisec

Same amplitude spectrum, different phase spectrum

Anticausality = 256 millisec

Wavelet is becoming symmetrical.



Now I'll tell you how I did it.

Generally equivalent terms and concepts

Blind decon
Predictive decon
Causal decon
Autoregression, Yule&Walker 1927
Minimum-phase decon, MIT GAG 1954
$t,\ N^2$ Wiener-Levinson, Toeplitz
Burg, Robinson, and Treitel
Kolmogoroff decon (1939)
$\omega,\ N \log N$ (in my textbook FGDP 1974)
(the code is in my book PVI 1992)

20th century mathematics !

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$\omega,\ N \log N$

Here we adapt Kolmogoroff to "Ricker compliant"

AGENDA

Kolmogoroff theorem statement
Kolmogororff proof (in the abstract)
Kolmogoroff method
Ricker modification of Kolmogoroff

Norbert Wiener
versus
Andrey Kolmogoroff

Kolmogoroff theorem statement

$$c(t) = 0 \quad \text{for } t < 0$$

$$c(t) \quad \text{is causal}$$

FT

$$A(\omega) \quad = \quad e^{C(\omega)}$$

IFT

$$a(t) \quad \text{is causal}$$

"Exponential of a causal is a causal."

The parameterization C gives us both the shot and its decon filter.

Shot waveform $$A = e^{C}$$

Decon filter $$\frac{1}{A} = e^{-C}$$

They are both causal.

"Exponential of a causal is minimum phase."

Kolmogoroff construction

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

polynomial is Fourier sum

Start with the spectrum.

FT

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

time domain parameterization

want this causal

Kolmogoroff construction

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

$\ln\|r\|$	$e_\tau = (u_\tau + u_{-\tau})/2$	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 $\tau < 0$.

Kolmogoroff construction

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How to force Ricker-like wavelets

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So far, this is all textbook stuff.

How to force Ricker-like wavelets

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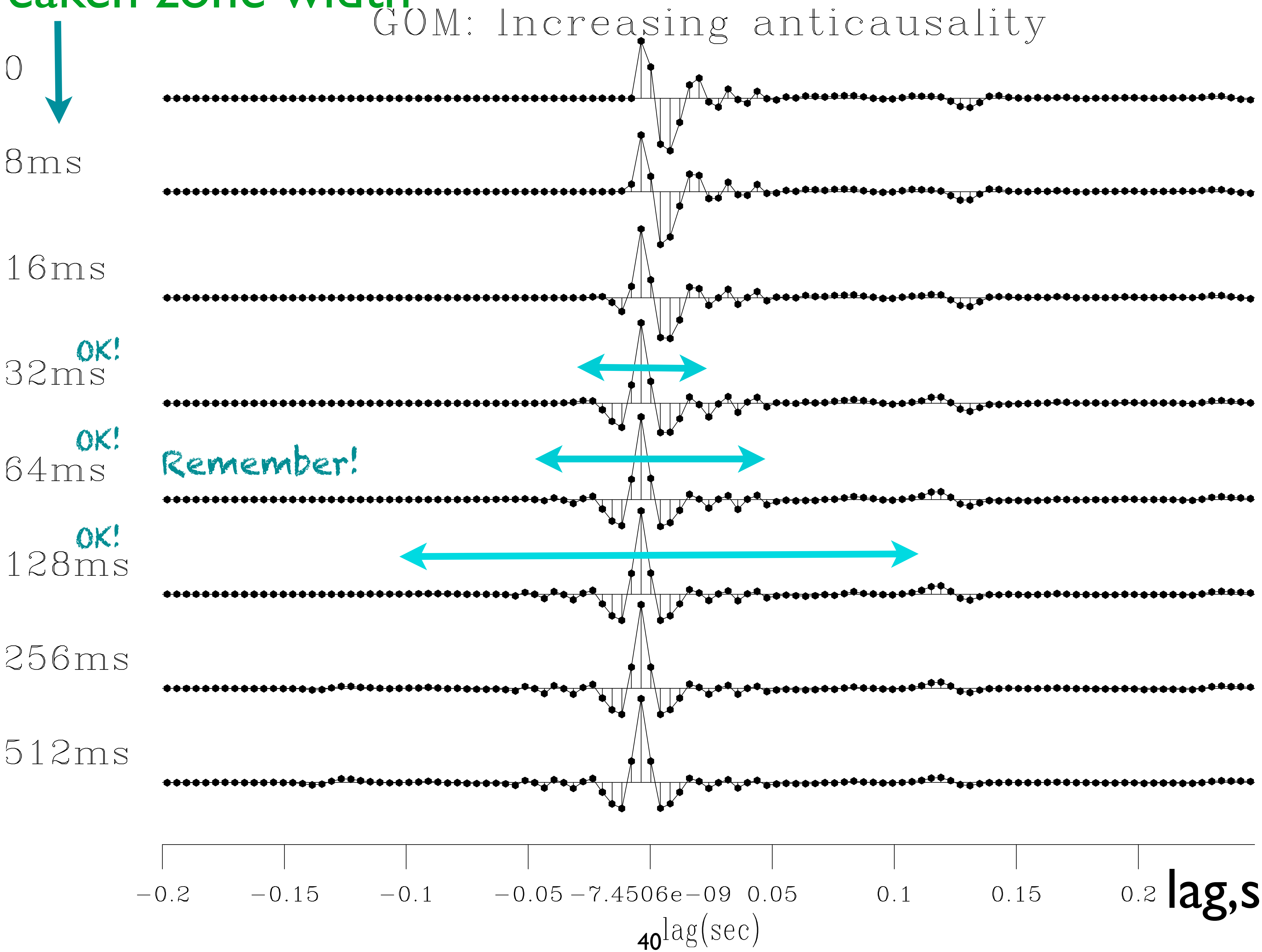
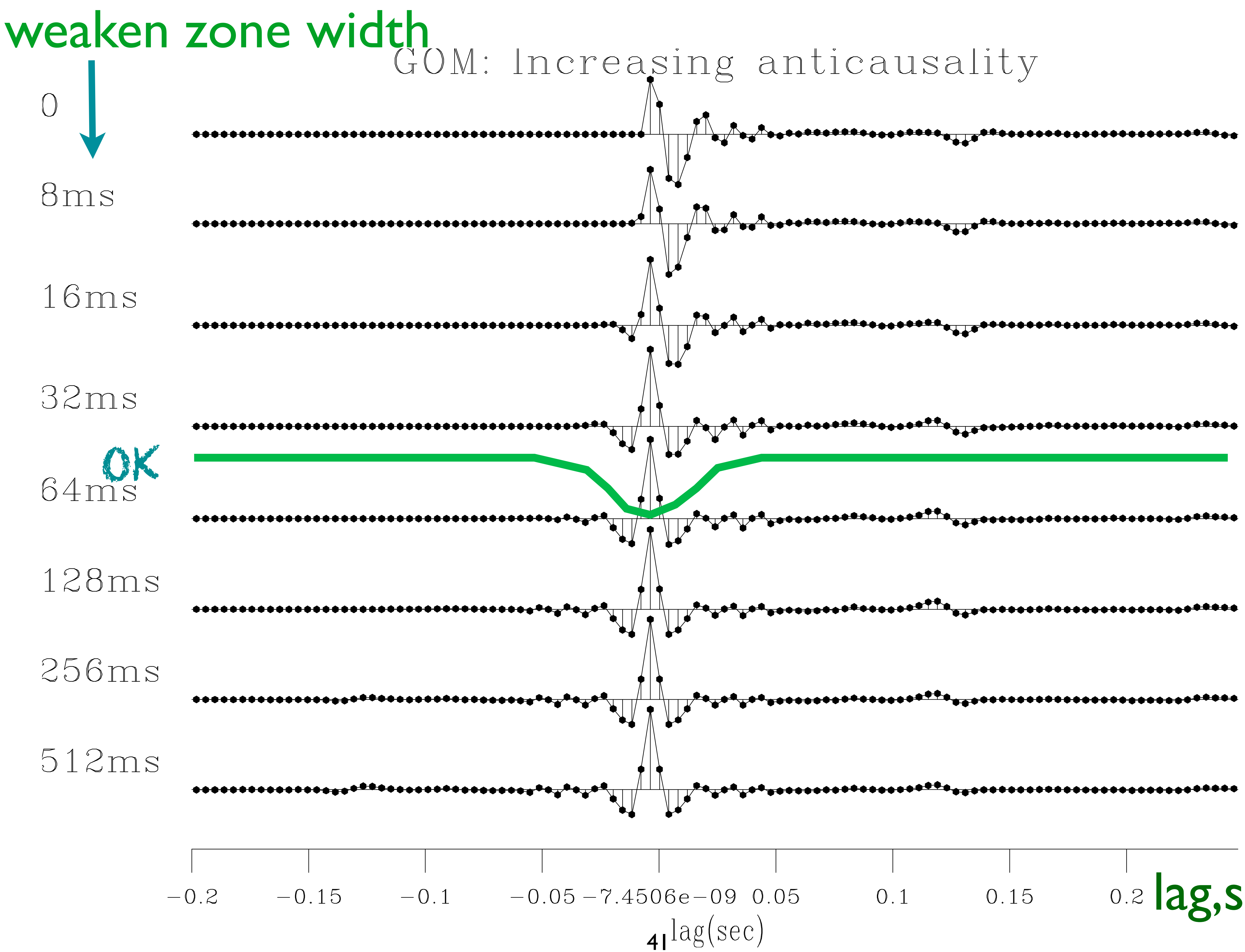
so $u_\tau = e_\tau + o_\tau = 0$ for $\tau < 0$.

This is the innovation !

Ricker says to $\boxed{\text{weaken the odd part } o_\tau \text{ at small lags.}}$

weaken zone width





weaken zone width
GOM: Increasing anticausality
0
8ms
16ms
32ms
OK
64ms
128ms
256ms
512ms
−0.2
−0.15
−0.1
−0.05
−7.4506e−09
0.05
0.1
0.15
0.2
lag,s
lag(sec)

To make any decon filter reveal polarity by respecting Ricker:

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

(only 16 words)

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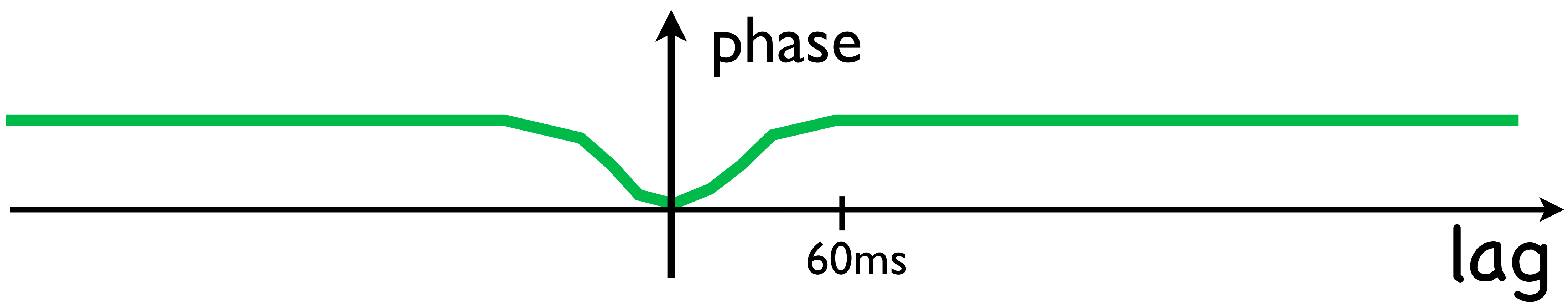


"Grab its phase spectrum.
Bring it into the time domain.
Near zero lag, dampen it down."

(only 16 words)

IT'S OBVIOUS BECAUSE

Take all the phase away, get a symmetric time function.

Here we take away phase for small lags only.

Ricker trick

Why did we not figure this out 40 years ago?

Ricker trick

Why did we not figure this out 40 years ago?

Because everyone got interested in migration.

Two uses for this "Ricker trick"

Jon: "Antoine, your sparseness code gives better polarities."

Antoine: "Jon, your Ricker code is much easier to choose parameters."

New!

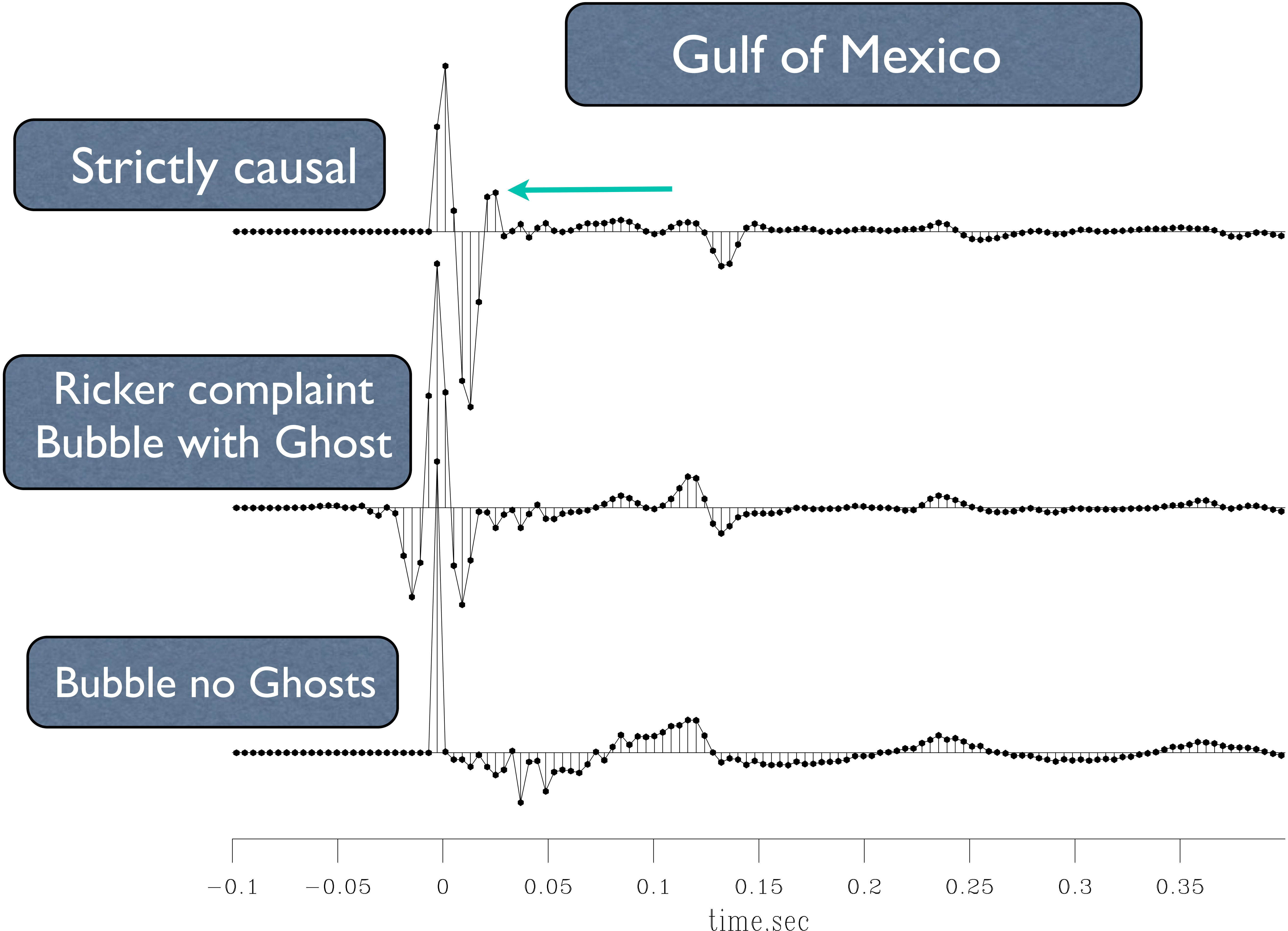
Parameters more intuitive in lag-log (quefrency)

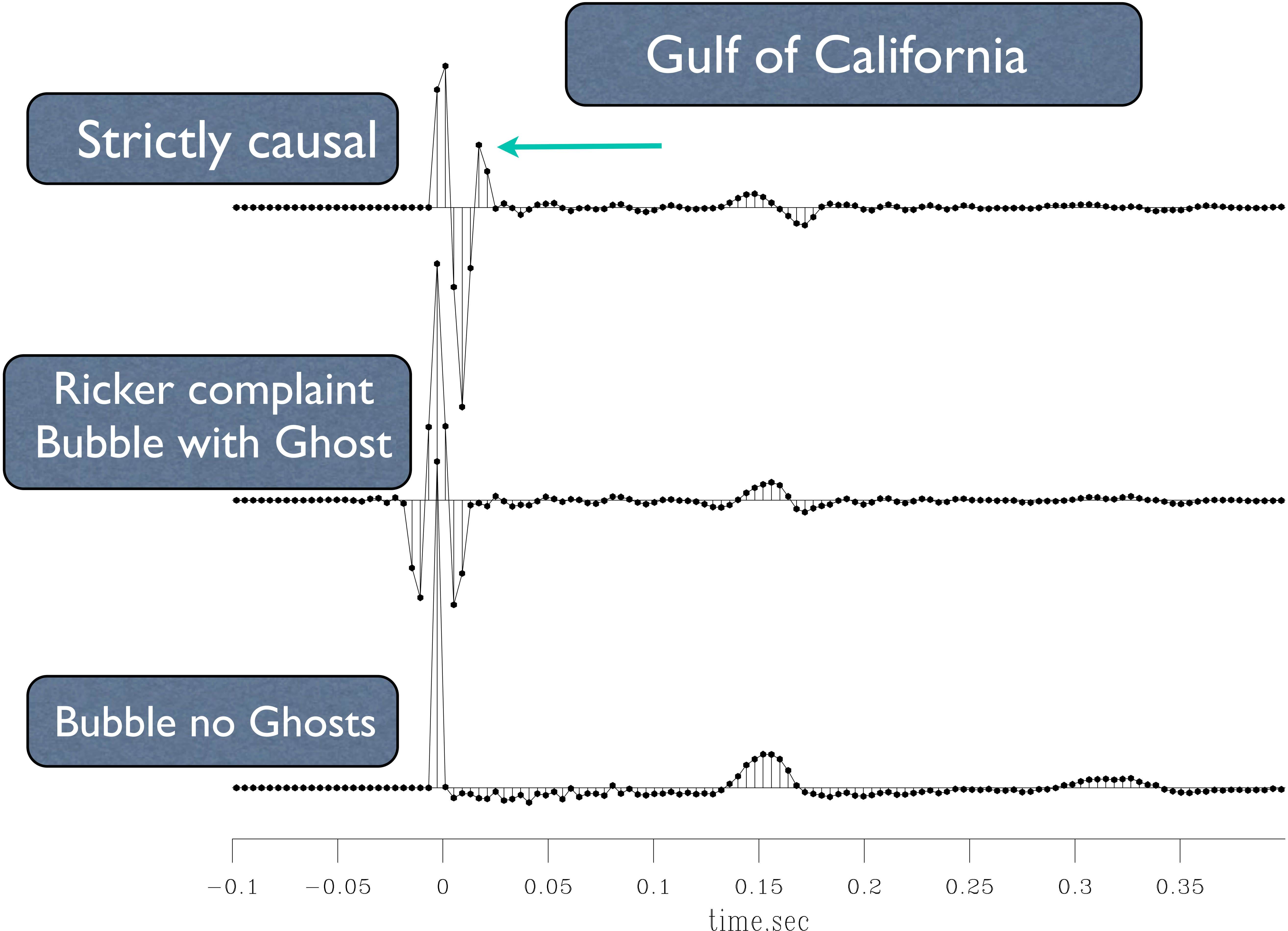
$$
\begin{aligned}
|r|e^{i\phi} &= e^{\ln|r|+i\phi} \\
&= e^{\sum_{\tau=0}^{2047} u_\tau Z^\tau} \\
&= e^{A+B+C} \quad = \quad e^A \; e^B \; e^C \\
&= \qquad e^{\sum_0^2} \qquad e^{\sum_3^{15}} \qquad e^{\sum_{16}^{2047}} \\
(\text{wavelet}) &= (\text{continuity})(\text{Ricker})(\text{bubble})
\end{aligned}
$$

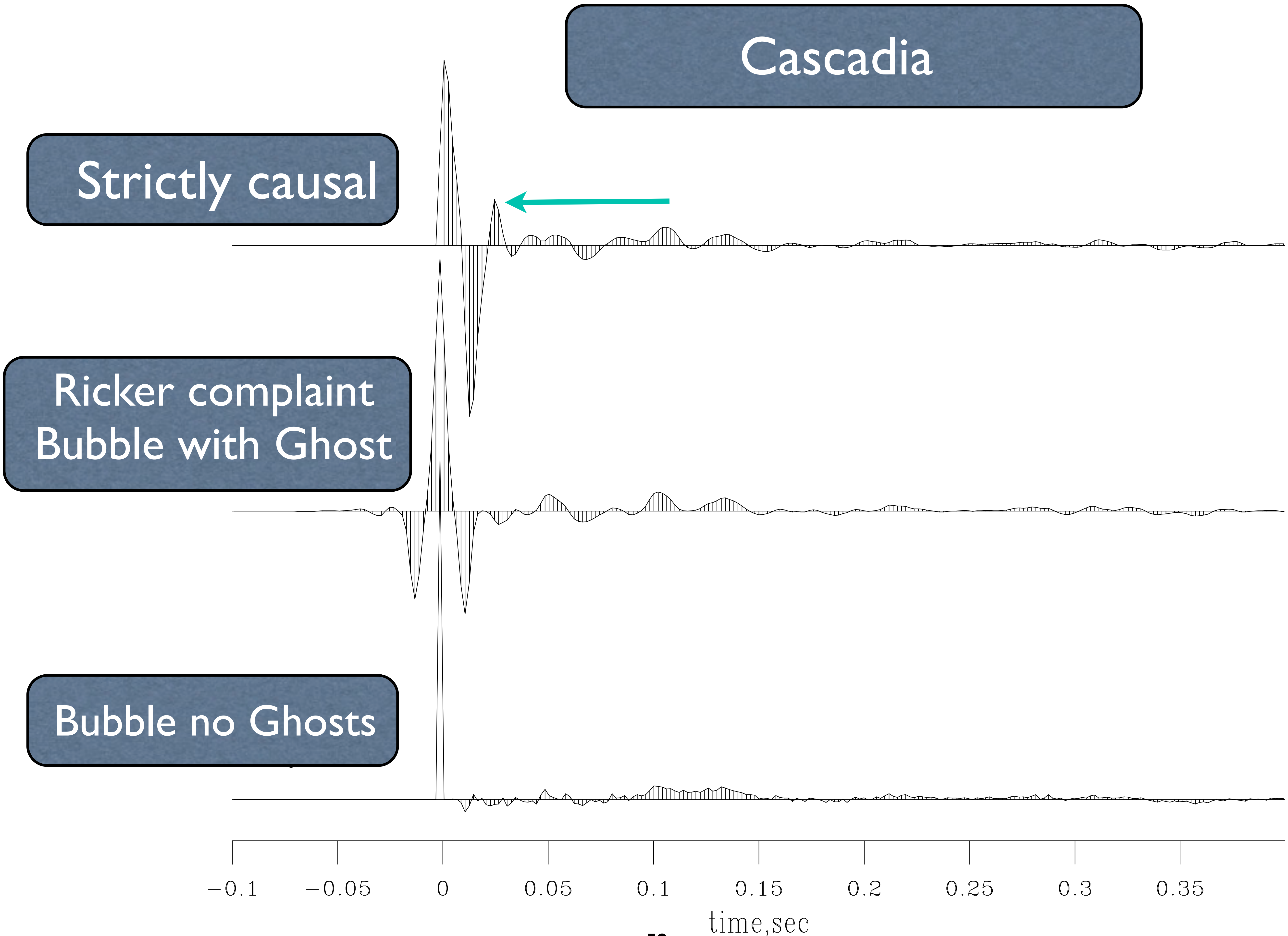
Kolmogoroff

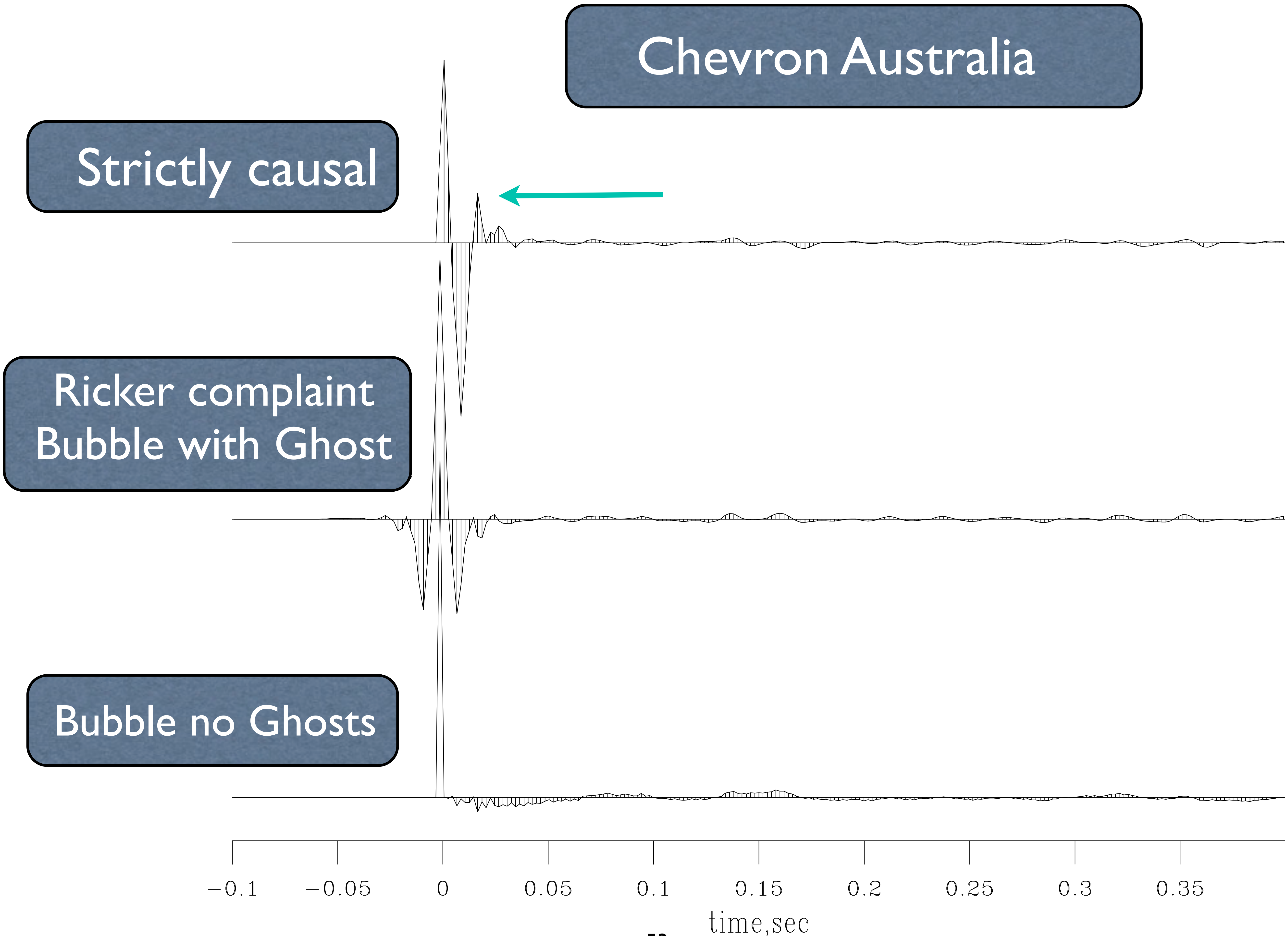
very high frequencies

4 ms data
15x4=60ms


Gulf of Mexico
Strictly causal
Ricker complaint
Bubble with Ghost
Bubble no Ghosts
−0.1
−0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
time,sec


Gulf of California
Strictly causal
Ricker complaint
Bubble with Ghost
Bubble no Ghosts
−0.1
−0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
time,sec


Cascadia
Strictly causal
Ricker complaint
Bubble with Ghost
Bubble no Ghosts
−0.1
−0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
time,sec



Chevron Australia
Strictly causal
Ricker complaint
Bubble with Ghost
Bubble no Ghosts
−0.1
−0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
time,sec

Reminder

$$
\begin{aligned}
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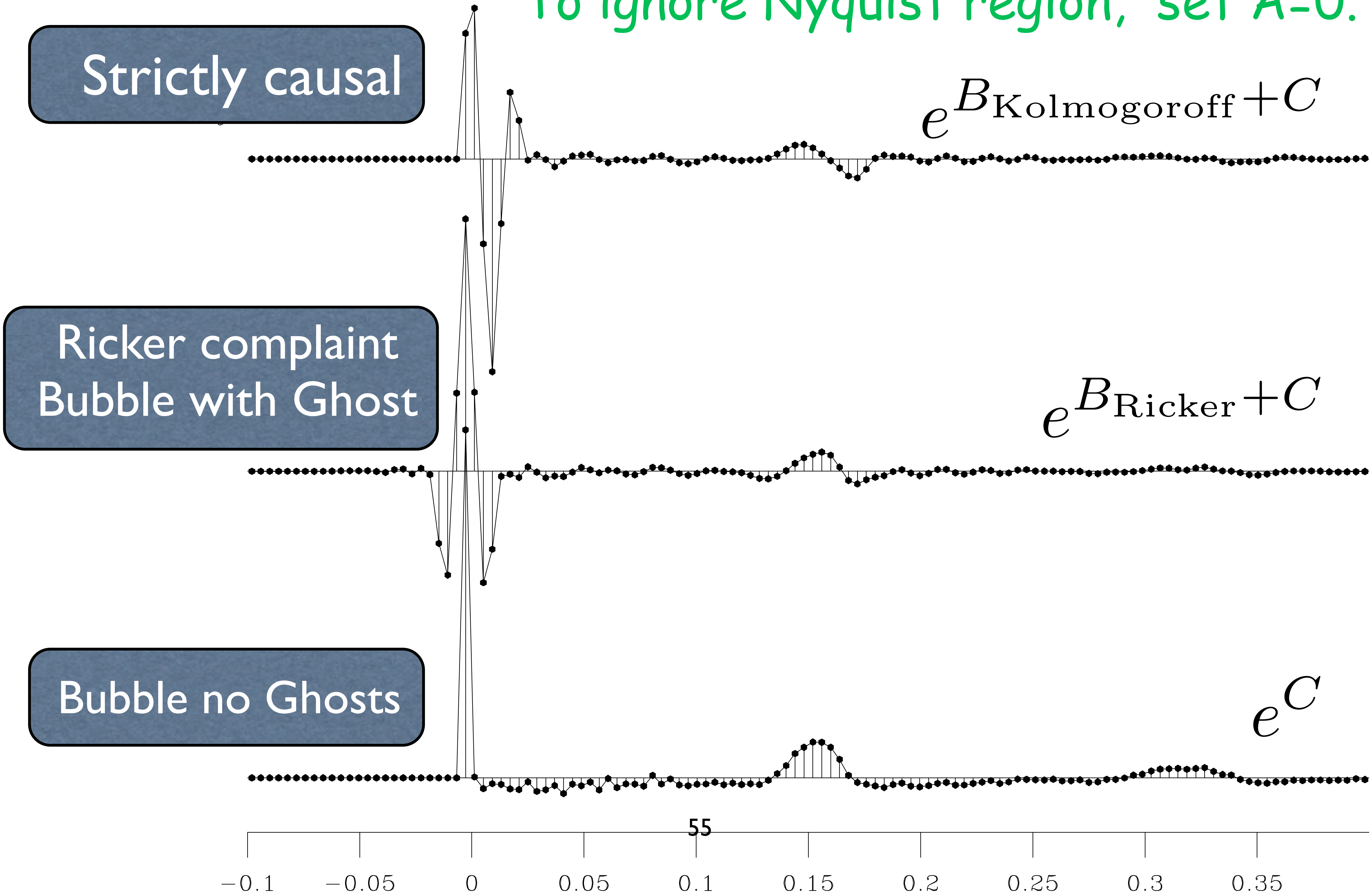
\end{aligned}
$$

Kolmogoroff

A B C

Divisor

To ignore Nyquist region, set A=0.



To ignore Nyquist, set A=0.

Why do I call this pseudo-unitary?

Setting A=0 or B=0 or C=0

means exp(0)=1, so

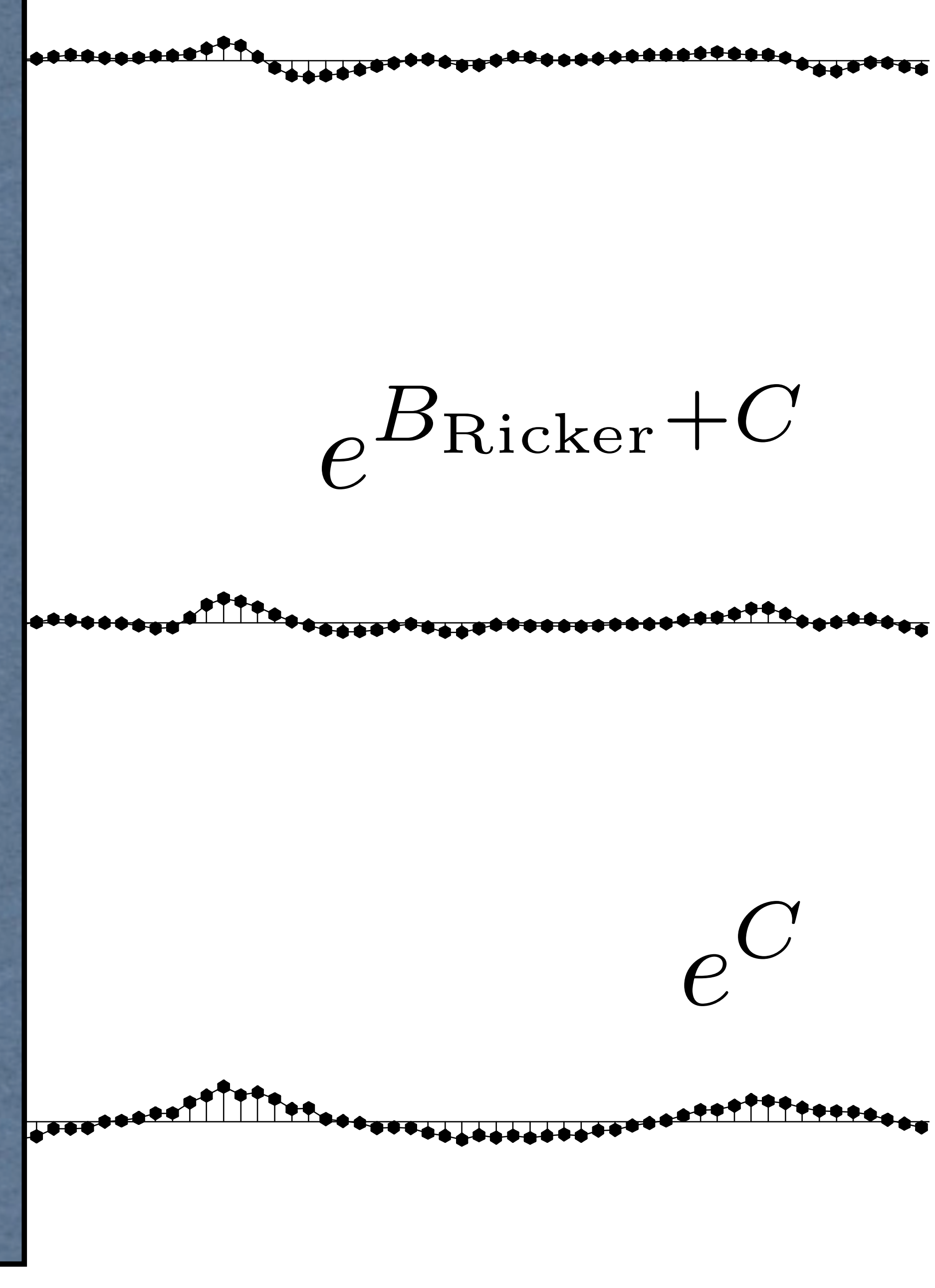
the filter has become unitary
for those lags.

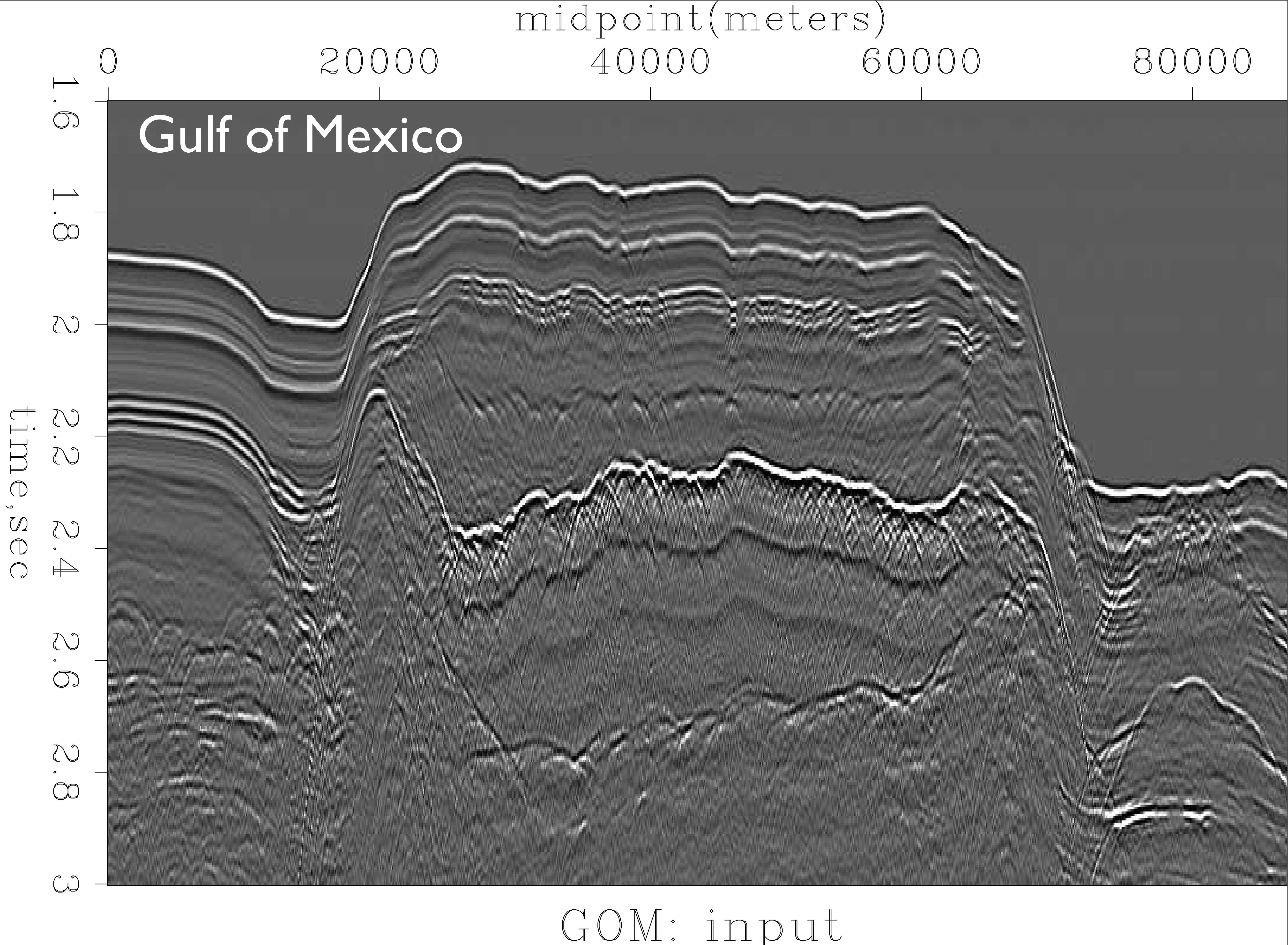
Divisor

$e^{B_{\mathrm{Kolmogoroff}}+C}$

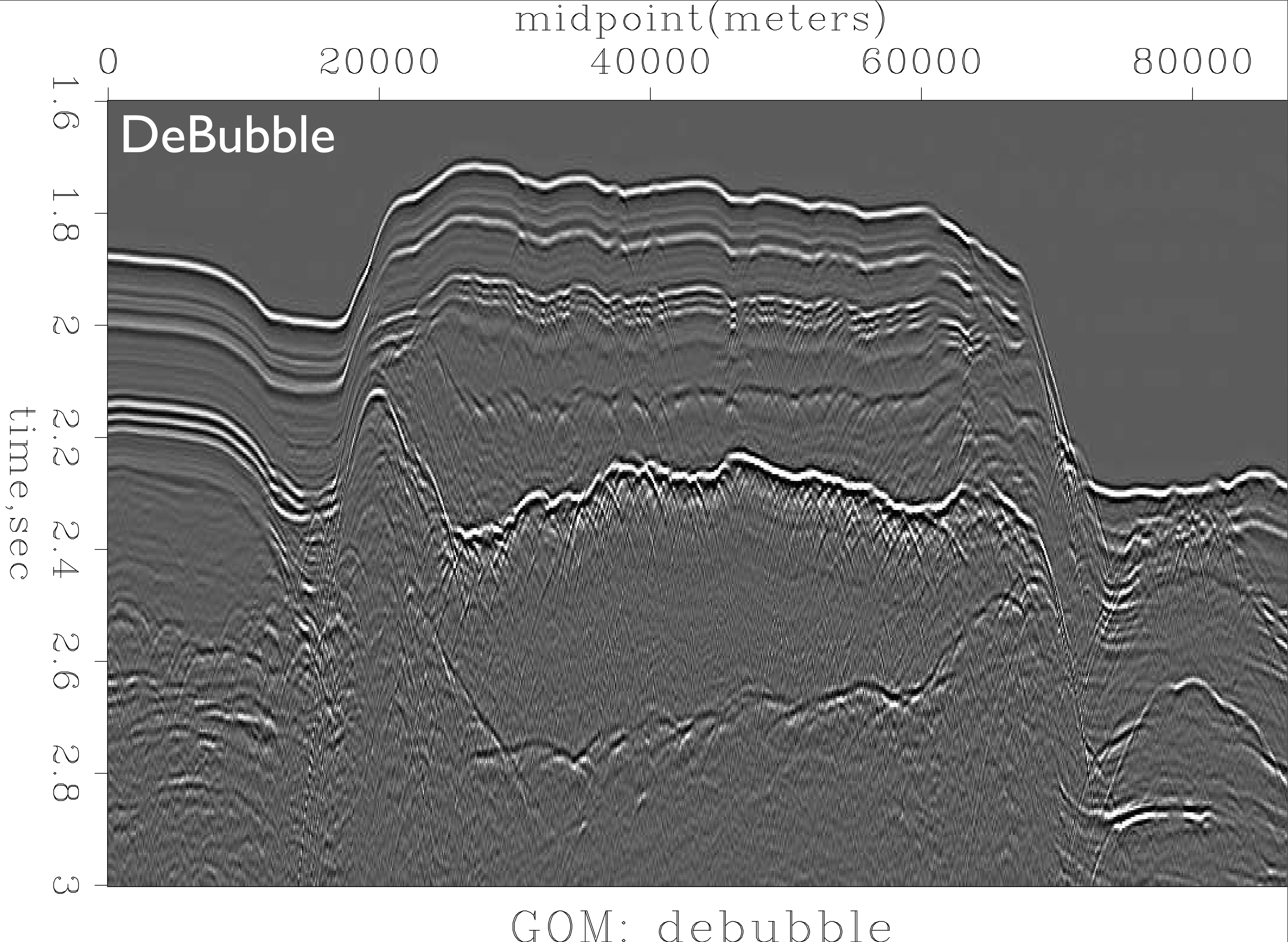
$e^{B_{\mathrm{Ricker}}+C}$

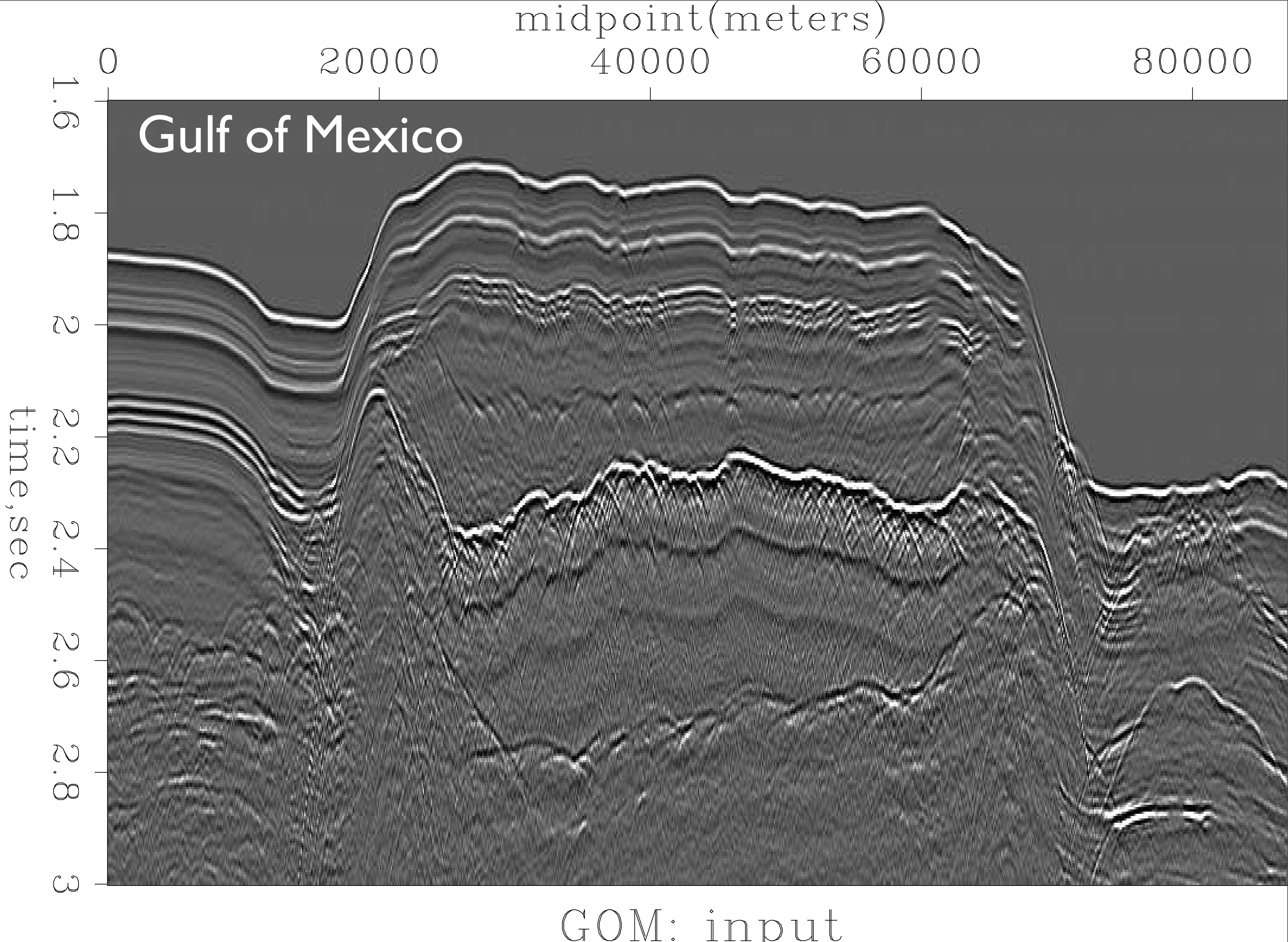
e^{C}

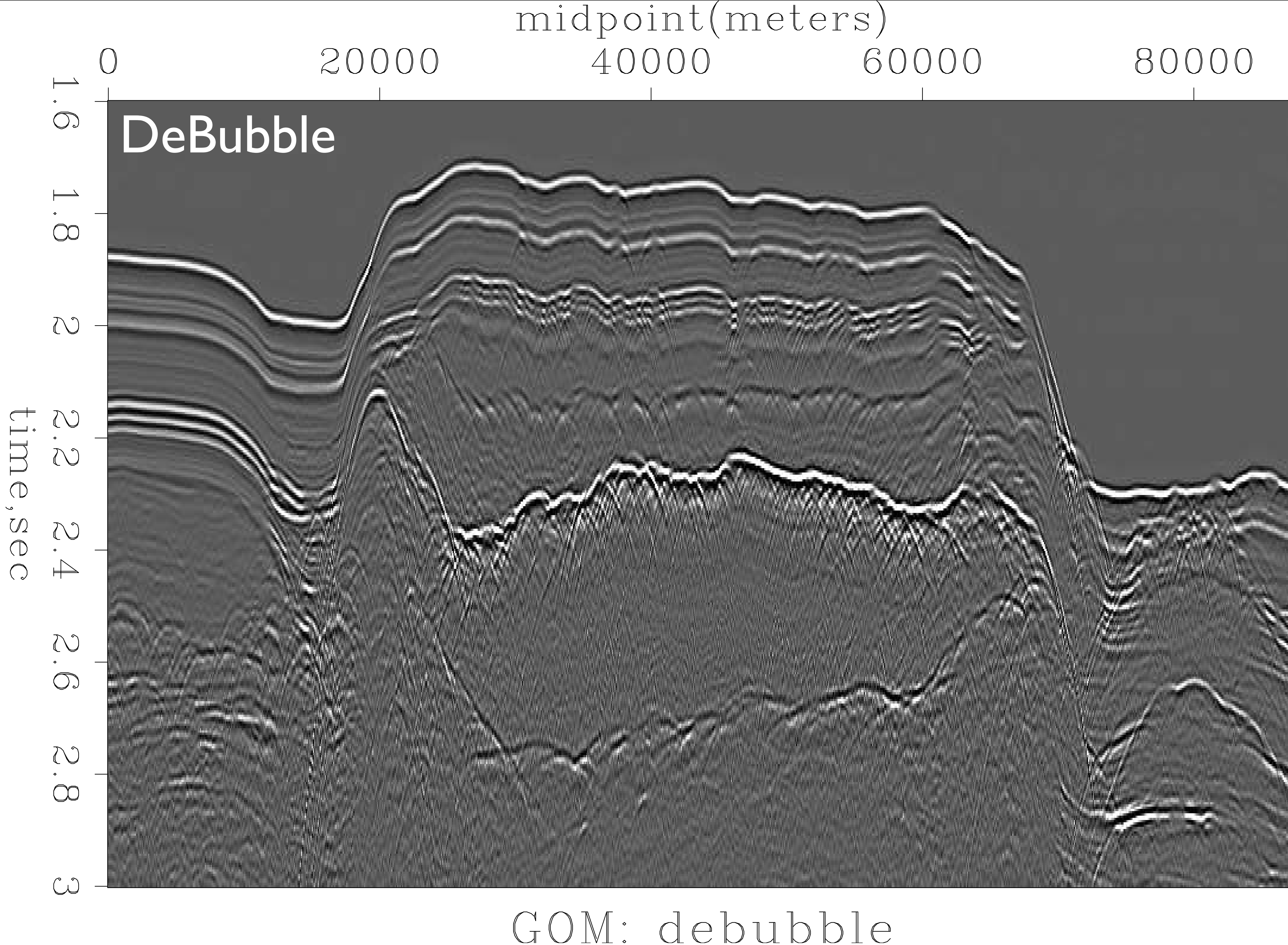




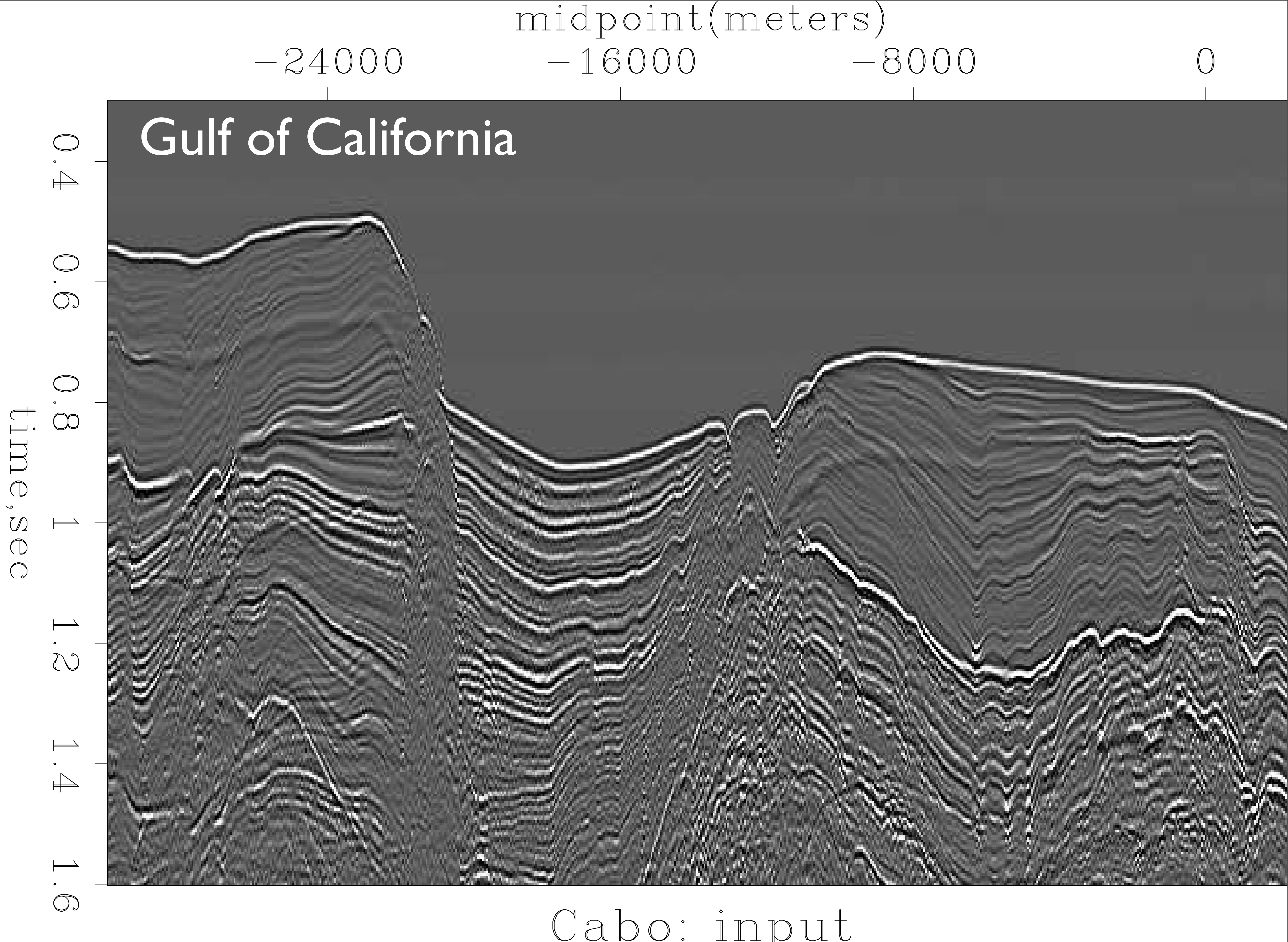
midpoint(meters)
0
20000
40000
60000
80000
Gulf of Mexico
time,sec
1.6
1.8
2
2.2
2.4
2.6
2.8
3
GOM: input

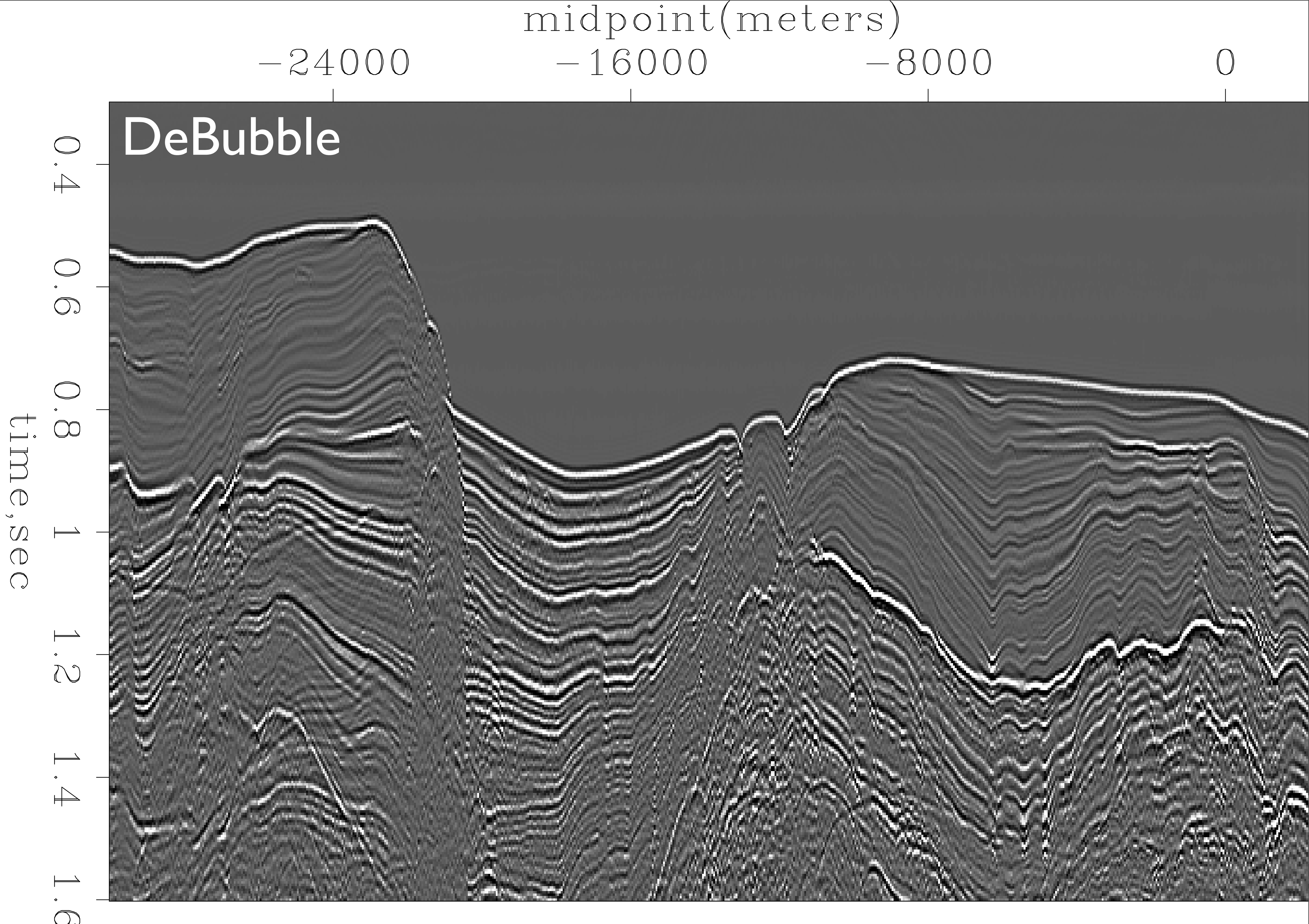

midpoint(meters)
0
20000
40000
60000
80000
DeBubble
time,sec
1.6
1.8
2
2.2
2.4
2.6
2.8
3
GOM: debubble


midpoint(meters)
0
20000
40000
60000
80000
time,sec
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Gulf of Mexico
GOM: input

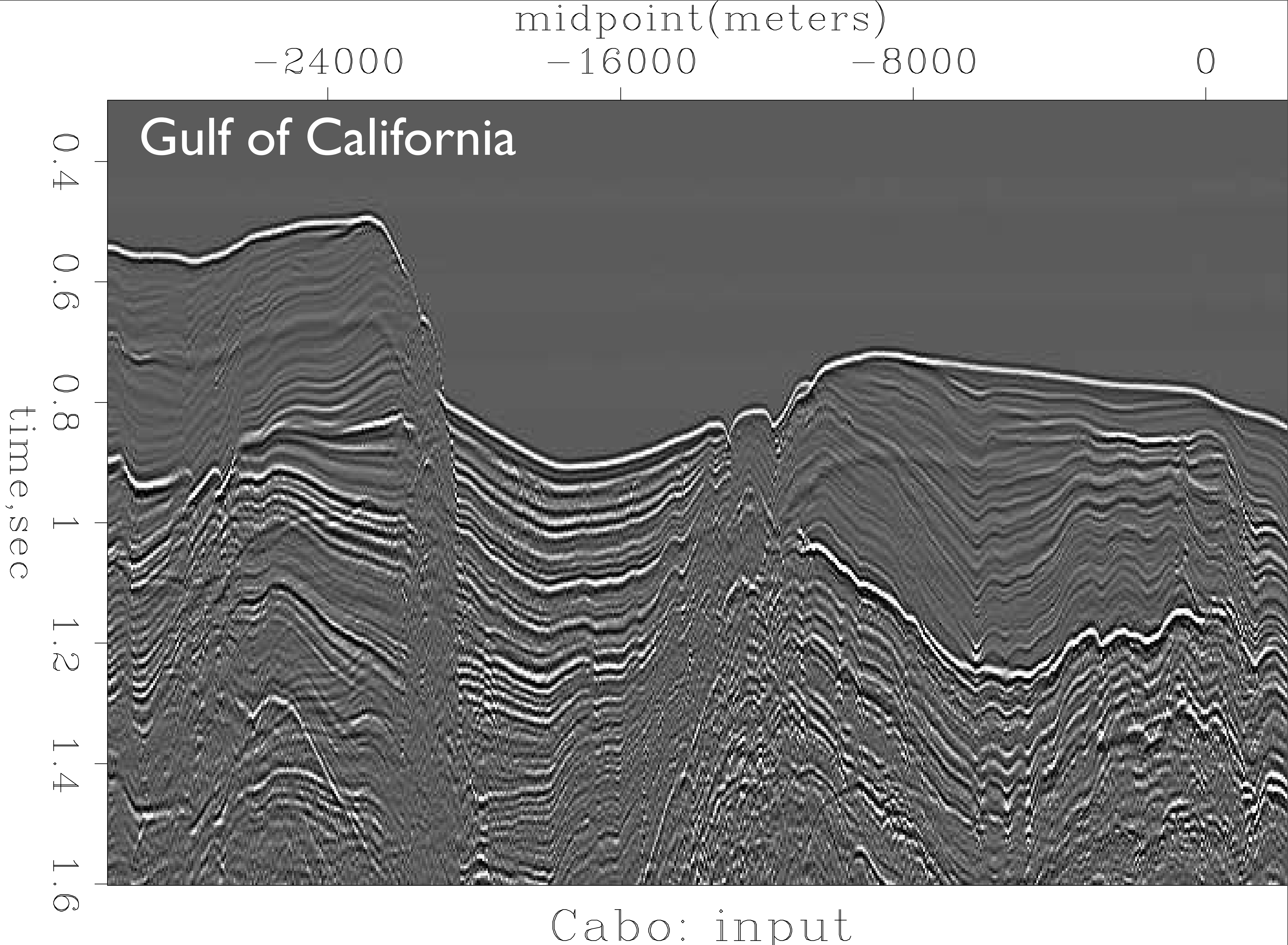


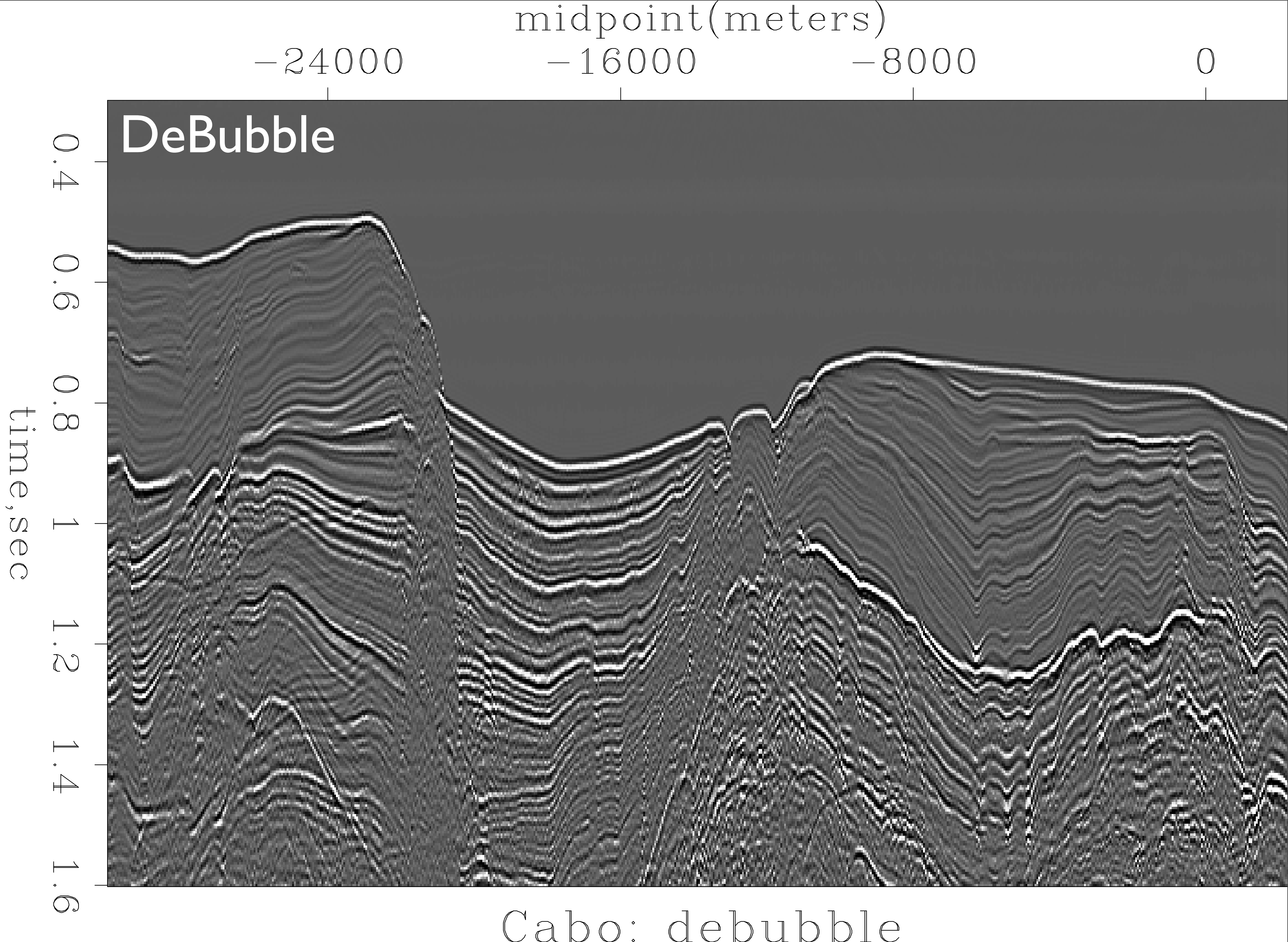
midpoint(meters)
0
20000
40000
60000
80000
1.6
1.8
2
2.2
2.4
2.6
2.8
3
time,sec
DeBubble
GOM: debubble

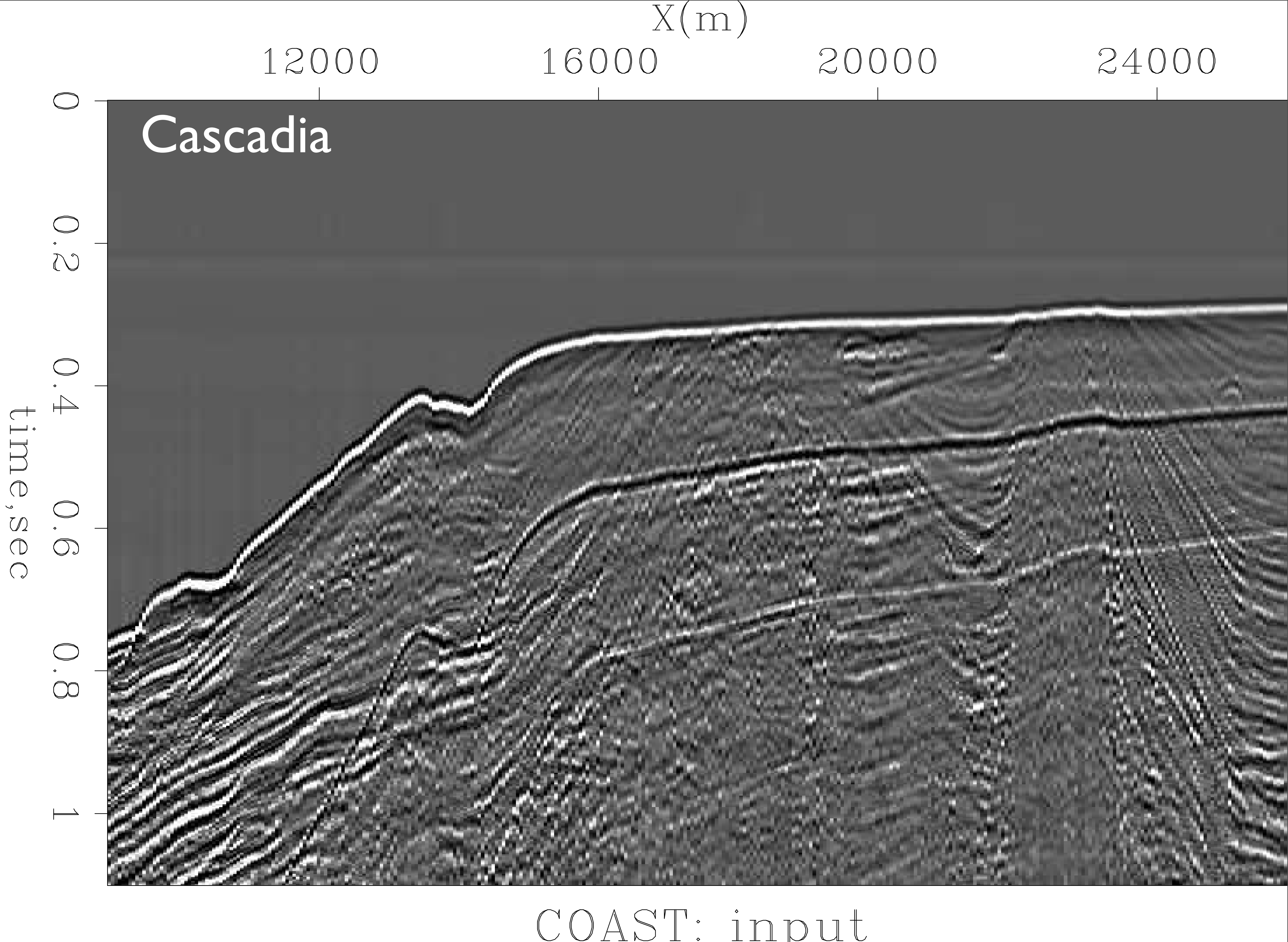

midpoint(meters)
−24000
−16000
−8000
0
Gulf of California
time,sec
0.4
0.6
0.8
1
1.2
1.4
1.6
Cabo: input



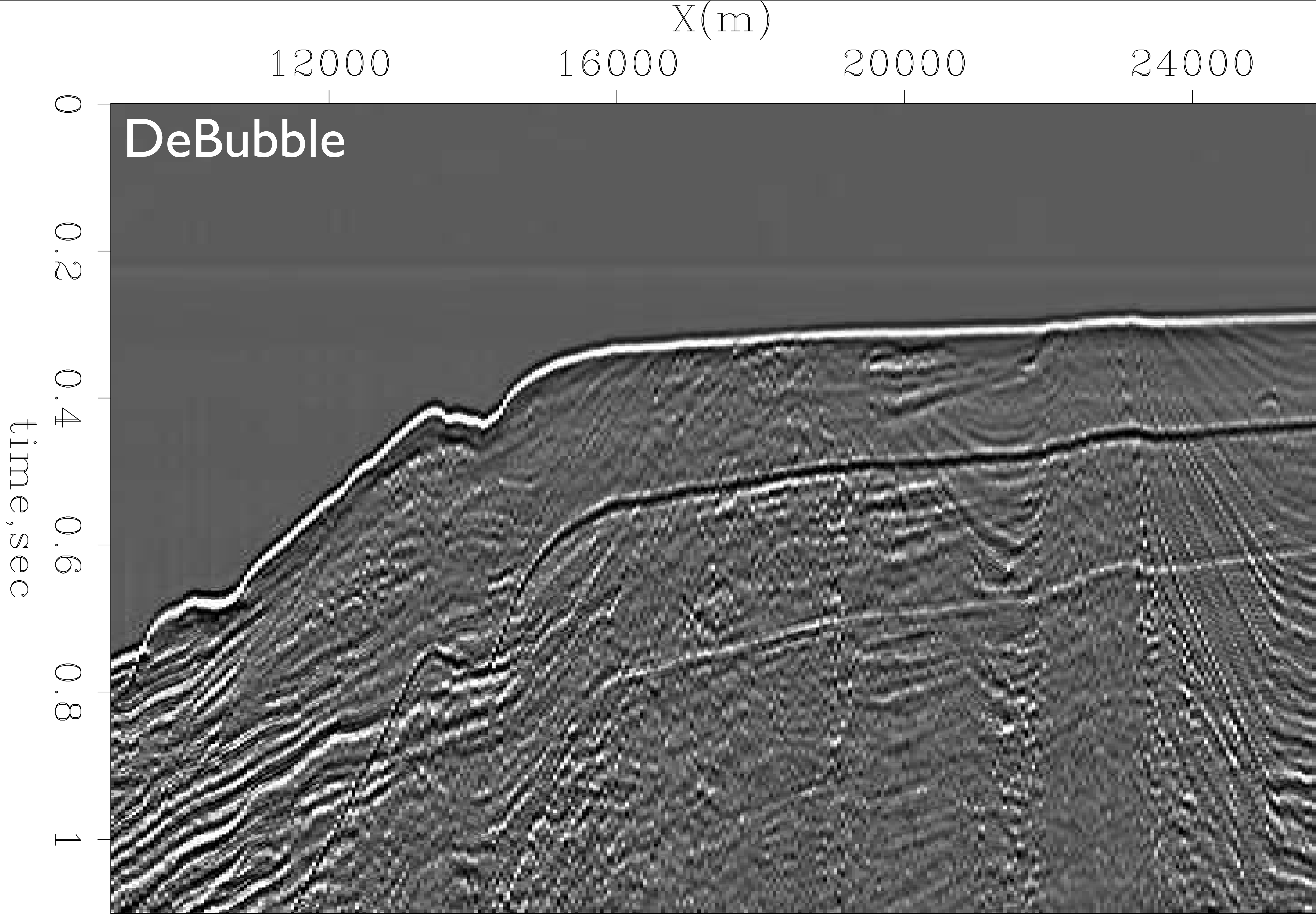
Cabo: debubble


midpoint(meters)
−24000
−16000
−8000
0
Gulf of California
0.4
0.6
0.8
1
1.2
1.4
1.6
time,sec
Cabo: input

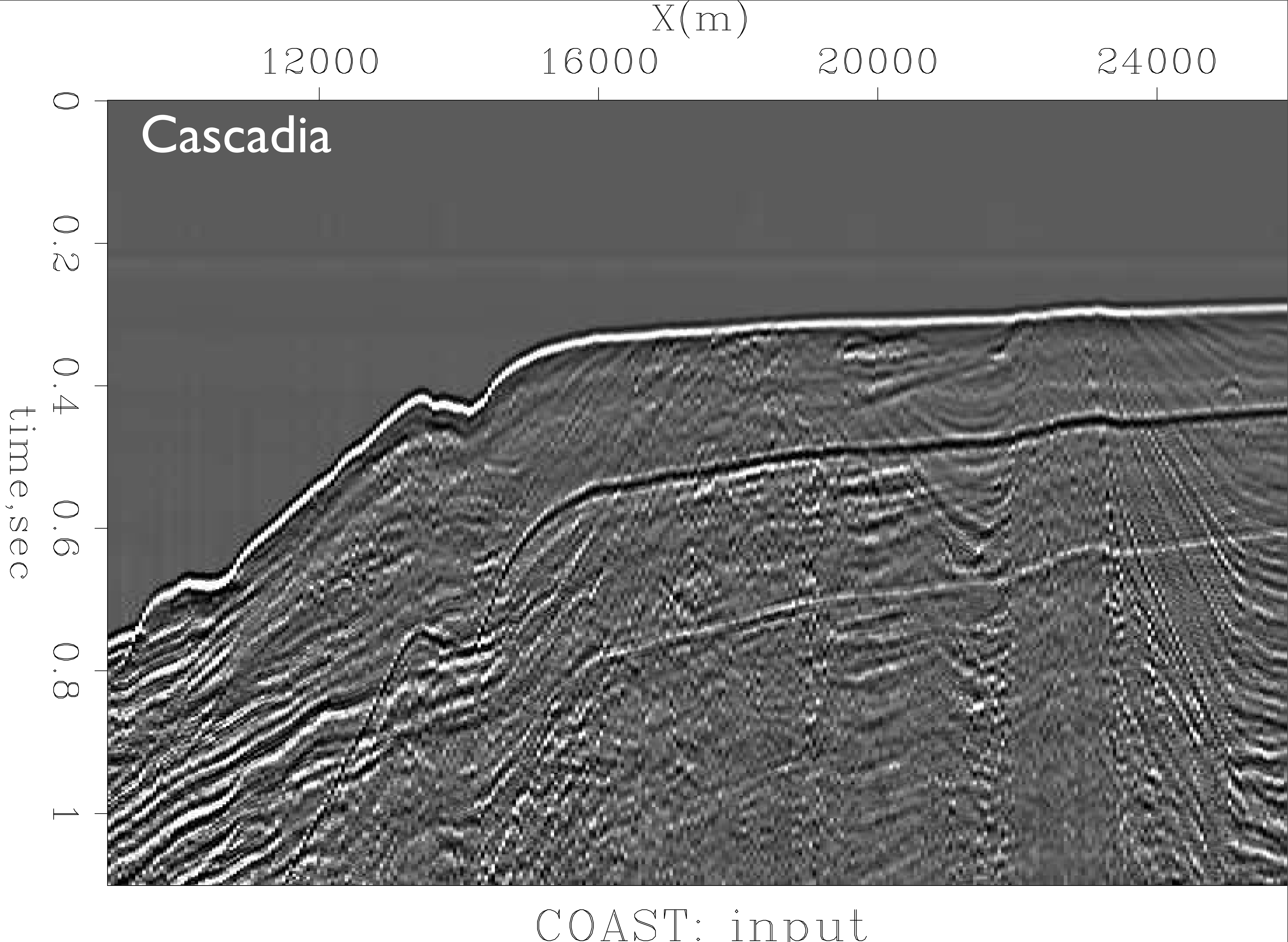

midpoint(meters)
-24000
-16000
-8000
0
DeBubble
time,sec
0.4
0.6
0.8
1
1.2
1.4
1.6
Cabo: debubble

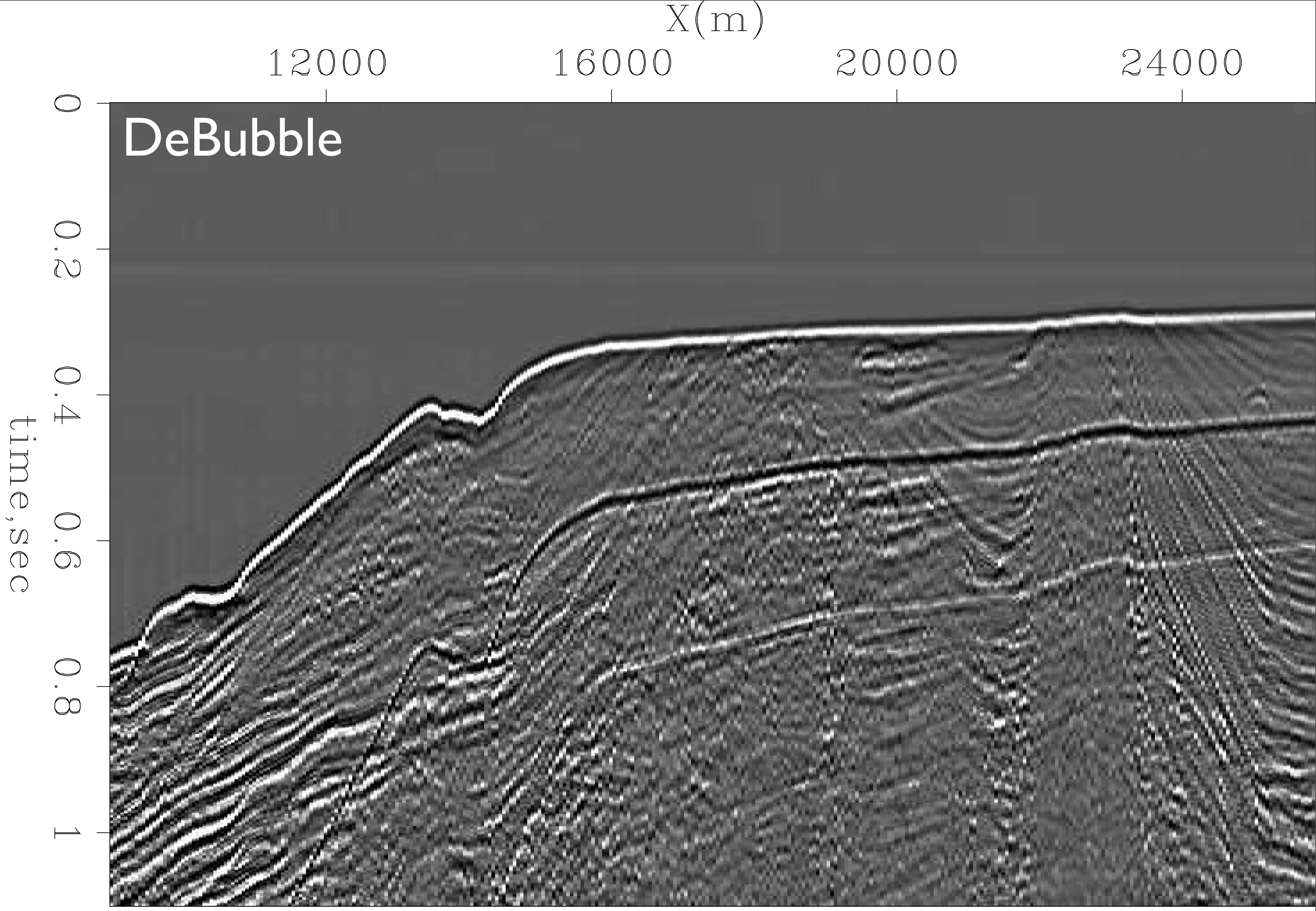


X(m)
12000
16000
20000
24000
Cascadia
time,sec
0
0.2
0.4
0.6
0.8
1
COAST: input



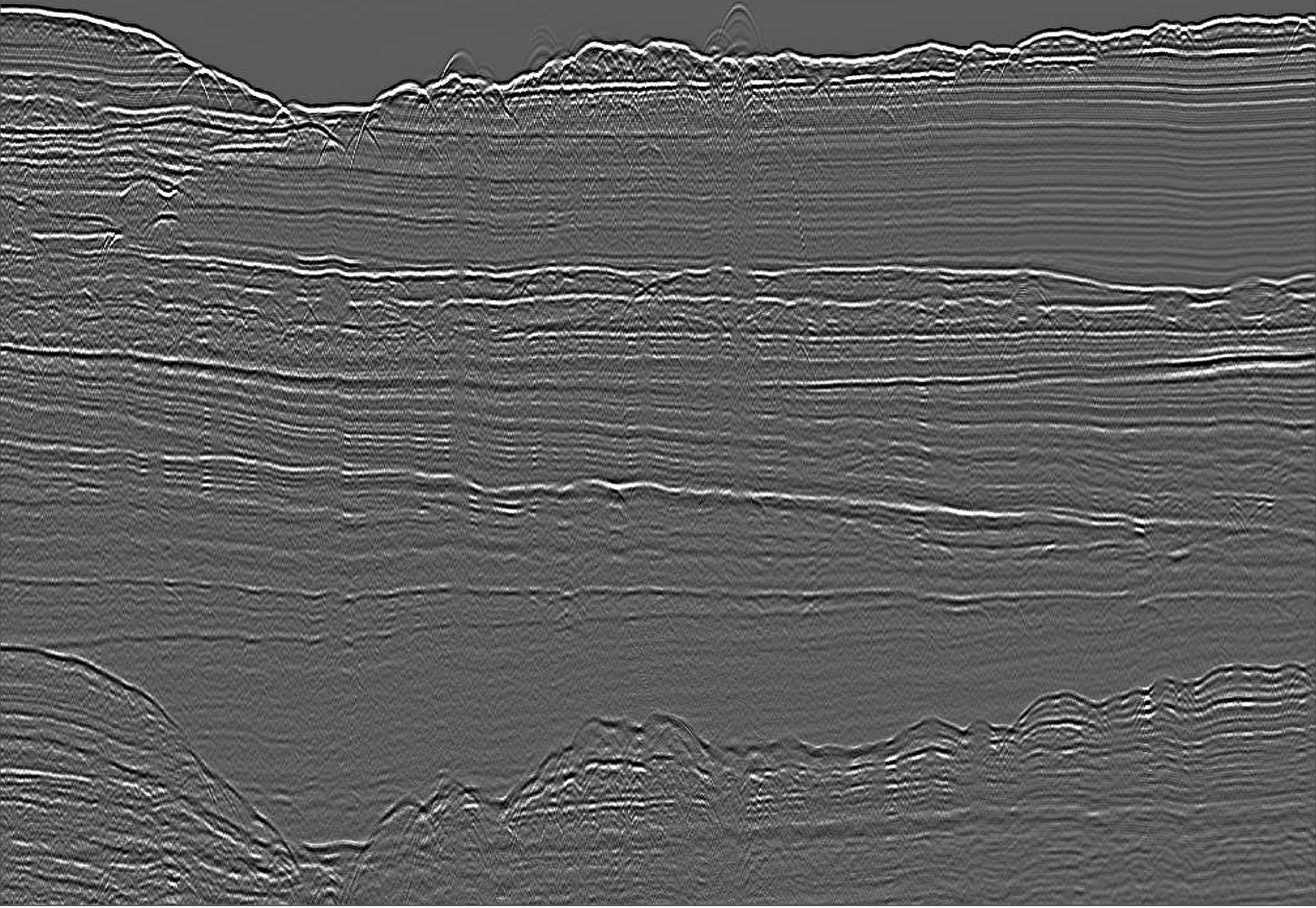
COAST: debubble


X(m)
12000
16000
20000
24000
Cascadia
time,sec
0
0.2
0.4
0.6
0.8
1
COAST: input

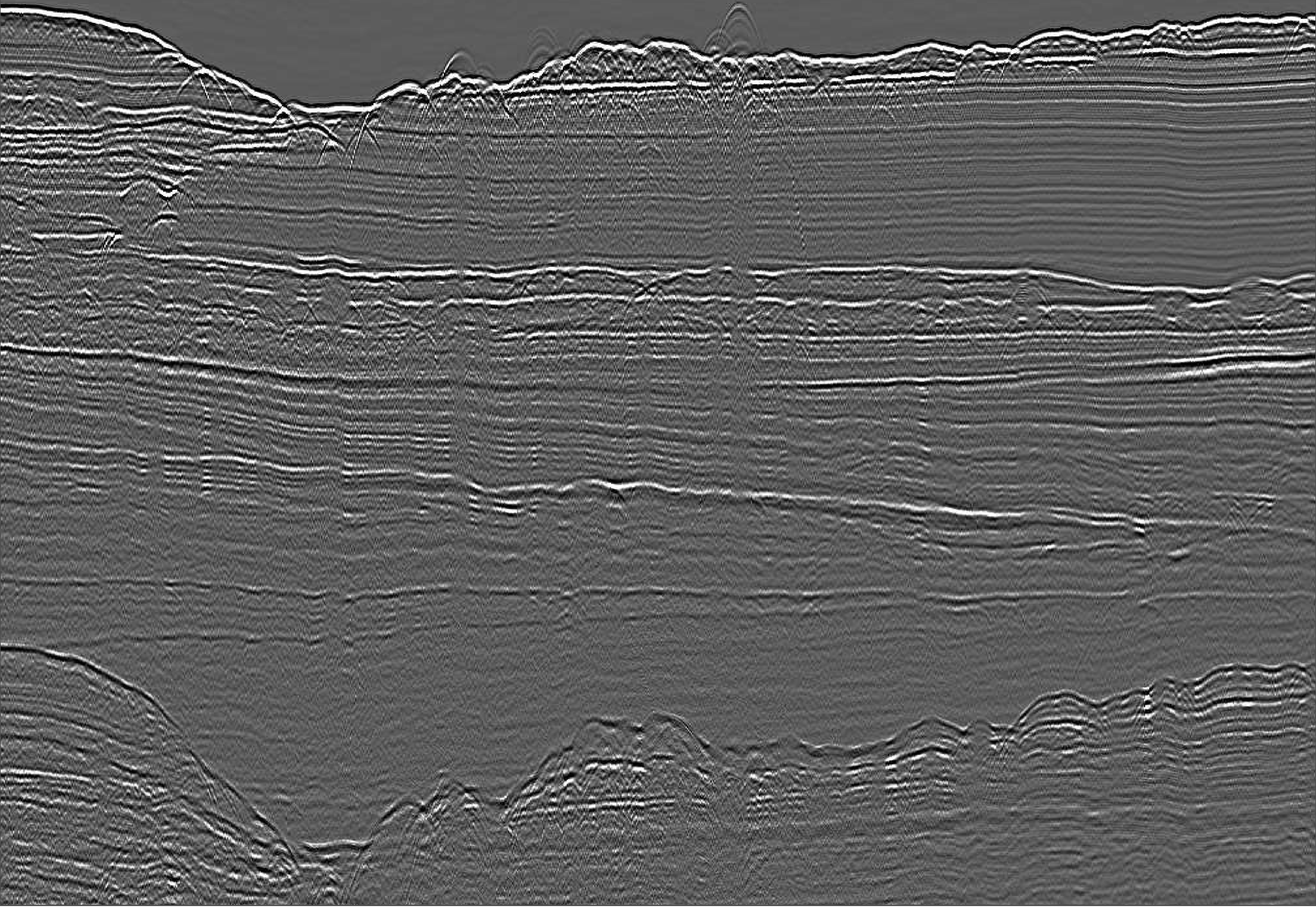


COAST: debubble

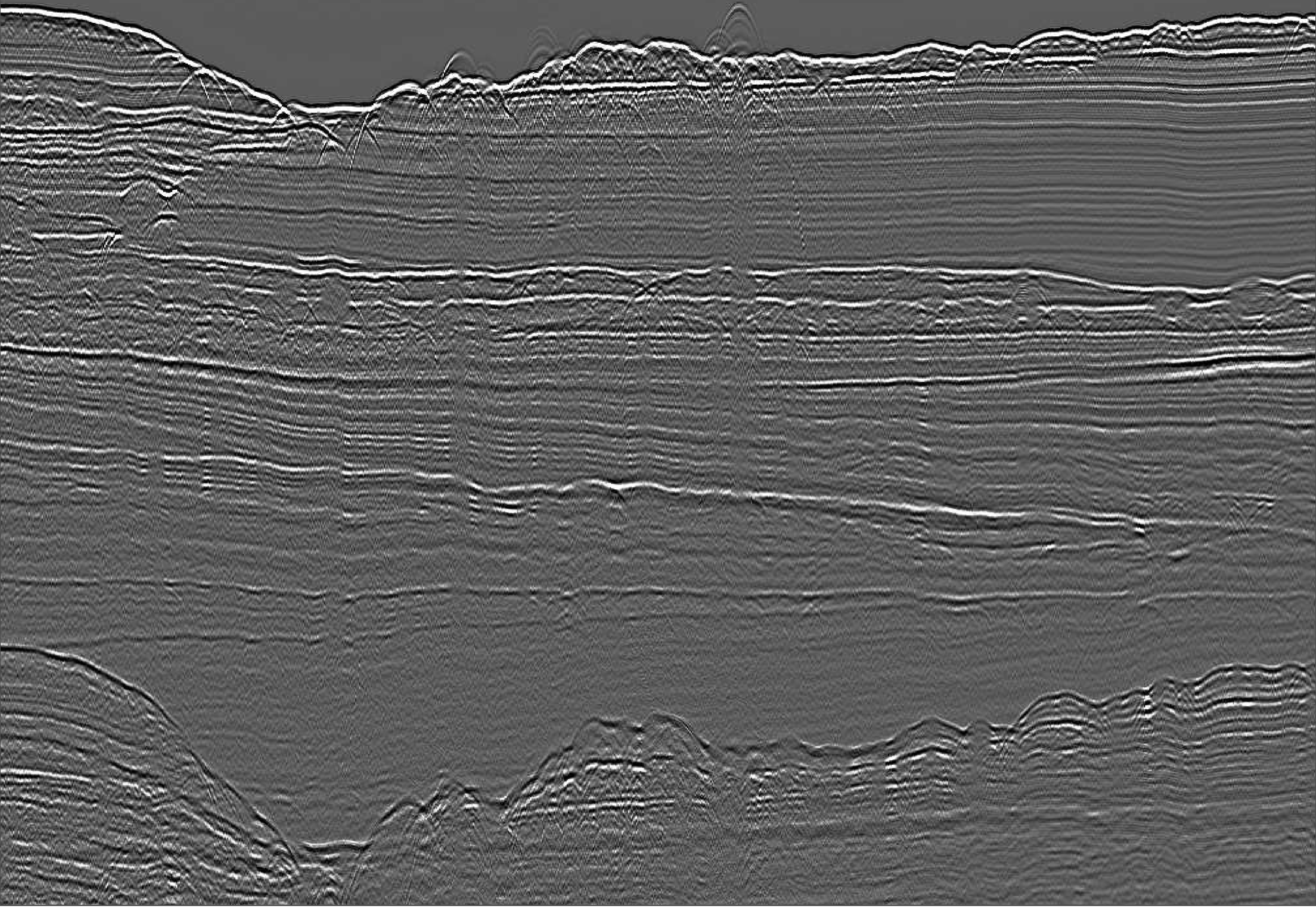
CVX



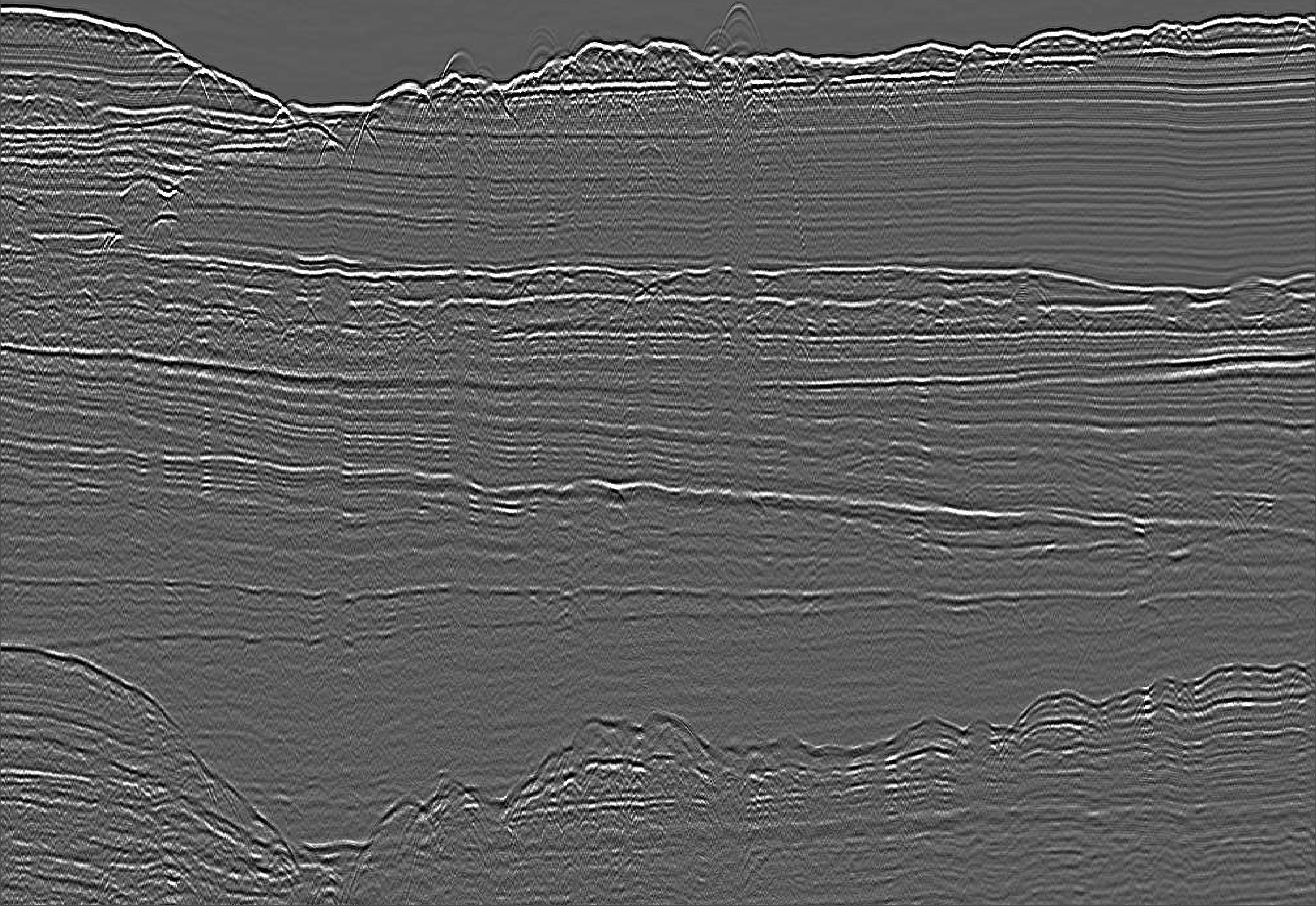
DeBubble



CVX



DeBubble



Same parameter for all four data sets:

60ms

CONCLUSIONS

It's easy.
It's fun.
It really works.
Try it!

ON-GOING AND FUTURE WORK

Angle dependence

Inverse modeling

-Optimization
-Robust norms
-Gain after decon

We need data

We seek 2ms marine streamer lines.

We do not need precise locations.

We love salt.

We don't like dealing with IP lawyers.

ACKNOWLEDGEMENT

For data we thank Western Geophysical (Gulf of Mexico) and Lizzaralde et al (Baja), Steve Holbrook, COAST Cascadia Open Access Seismic Transects, and Chevron Australia

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

Stew Levin, for assistance with input.

For support, we thank the sponsors of the Stanford Exploration Project (SEP). Hooray!

STANFORD
EXPLORATION PROJECT

To repeat

go to Youtube.com

Search for

"Jon Claerbout practice talk".

finis

finis

The End

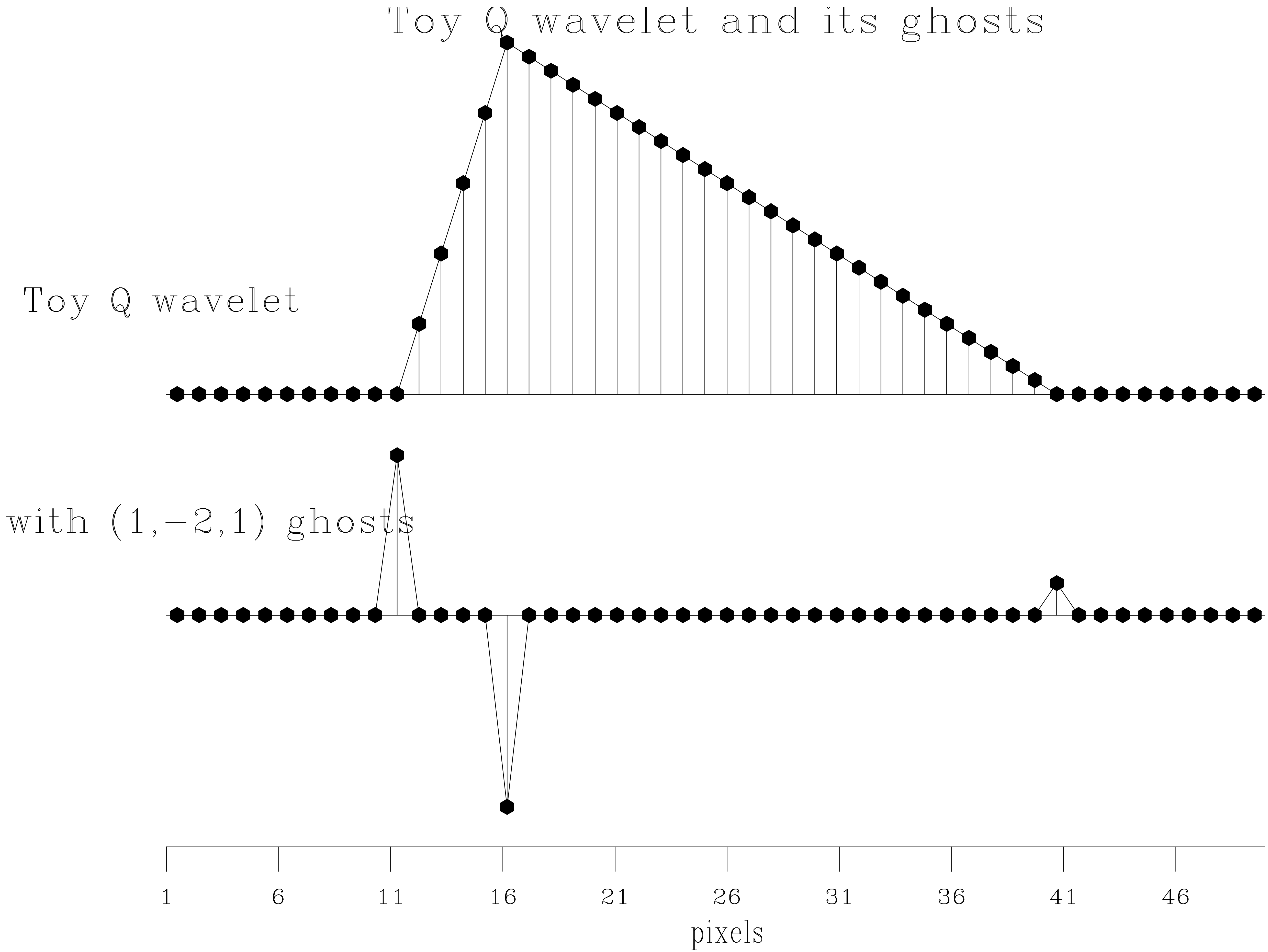
I need to think about the remarks I make at the very beginning, before my title slide is available.

Sal Kahn says, "Smile. Laugh."

Many years ago I saw sparker data in a muddy harbor.
What caught my eye was how easy it was
to distinguish hard rocks with one polarity
from gas pockets with the opposite polarity.

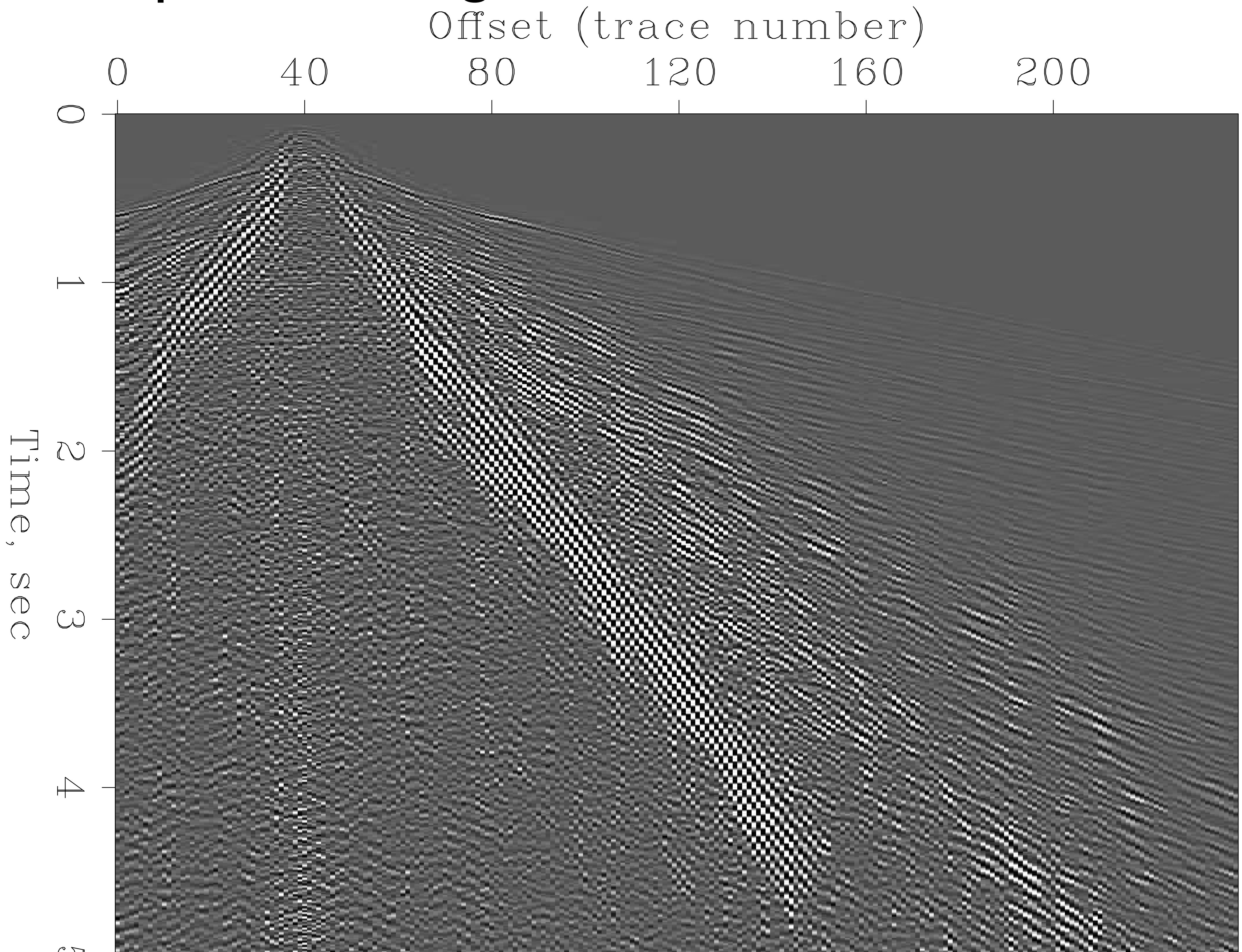
Why is it so difficult for us see polarity on our data?

In my old age, I have come to understand why.
We have been doing one thing wrong.
I'll tell you how to fix it.


Toy Q wavelet and its ghosts
Toy Q wavelet
with (1,−2,1) ghosts
1
6
11
16
21
26
31
36
41
46
pixels

0	1	0
0	0	0
a	b	c
d	e	f
g	h	i

Spatial aliasing on land, and on crossline



Gravel Plain shot profile

Conceptual

0	1	0
0	0	0
-1	0	-1
0	0	0
0	1	0

Least squares

0	1	0
0	0	0
a	b	c
d	e	f
g	h	i

Low velocity decon?

Want to see low frequency primaries
Want to rid of low velocity noises

1) specify a reject band

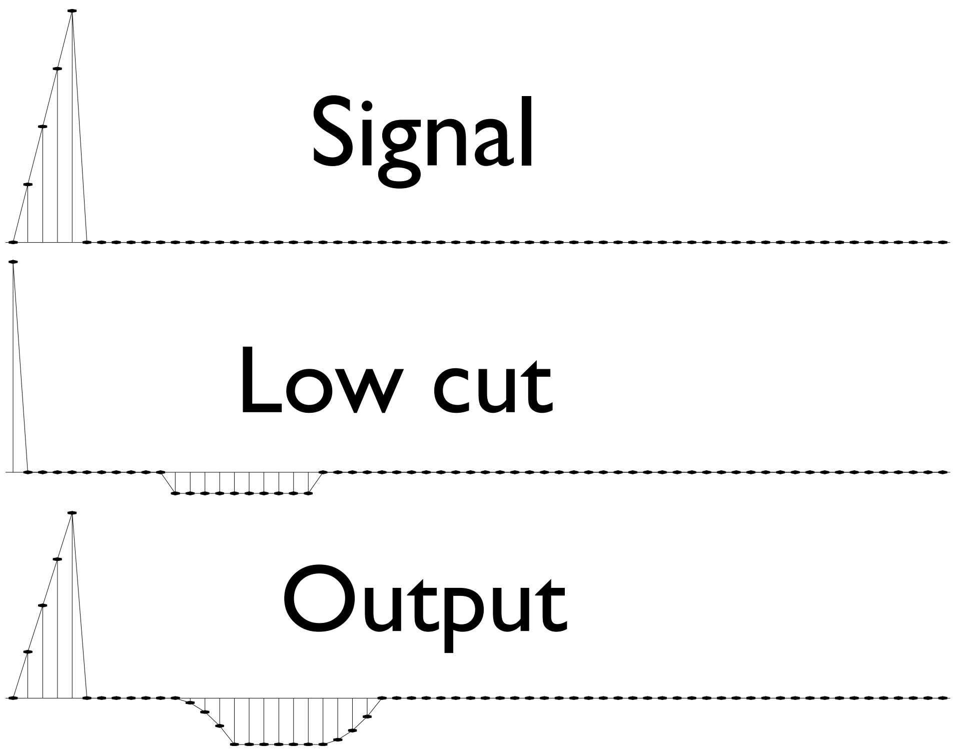
2) specify an accept band

3) Minimize energy subject to...

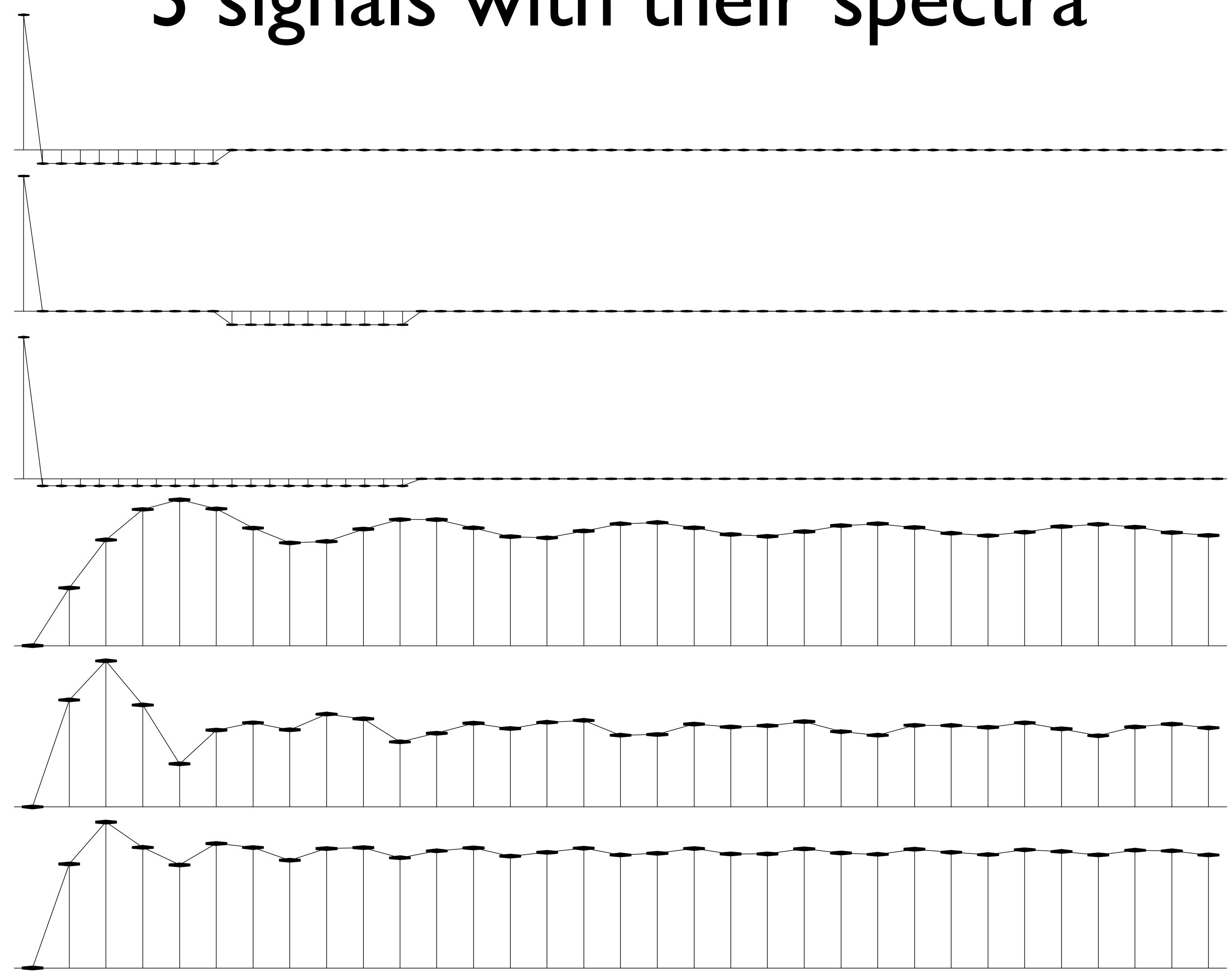
Now let us involve an additional FT over space. How about a low-velocity reject filter?

$$\begin{aligned}
e^{A+B+C} &= e^{A}\ e^{B}\ e^{C} \\
e^{\sum_{\tau=1}^{2048} u_\tau Z^\tau} &= e^{\sum_1^2}\ e^{\sum_3^{15}}\ e^{\sum_{16}^{2048}} \\
(\text{wavelet}) &= (\text{continuity})(\text{Ricker})(\text{bubble})
\end{aligned}$$

Gapped filter review



3 signals with their spectra



Steep Dip Decon, by Jon Claerbout SEP-77

Why no good results?
(too much noise in signal)

old programmer?
conceptual problem?