Title: Experimental detection of stimulated Hawking thermal radiation from analog white holes

Date: Sep 15, 2010 02:00 PM

URL: http://pirsa.org/10090068

Abstract: TBA

HAWKING 1974.

QUANTUM FIELD THEORY IN B.H. Spacetime.

QUANTUM INSTABILITY. near Horizon

$$T = \frac{1}{8\pi M}\left(\frac{\hbar c^3}{k_B G}\right)$$

$$\approx \frac{10^{-5}\,K}{M/M_\odot}$$

$$dE = T\,dS$$

$$S = \frac{1}{4}\,\frac{\text{Area}}{\ldots}$$

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IN B.H. space time.

QUANTUM INSTABILITY.

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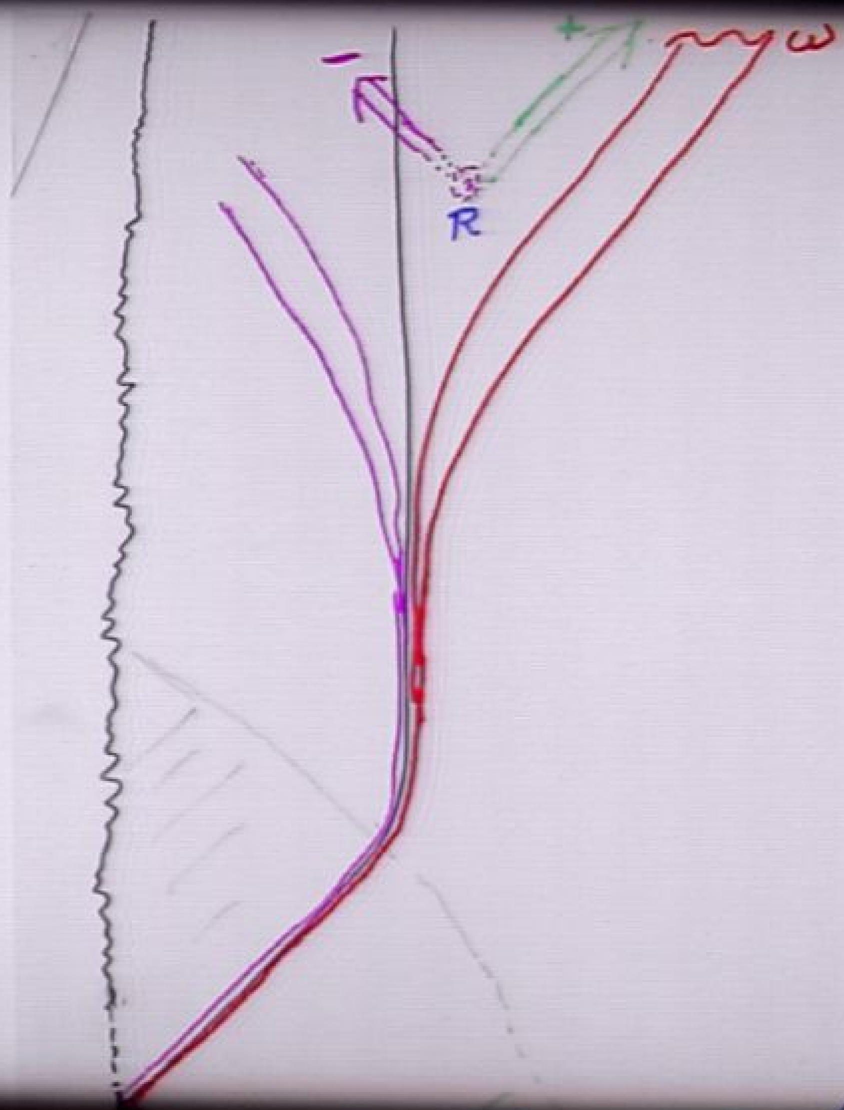
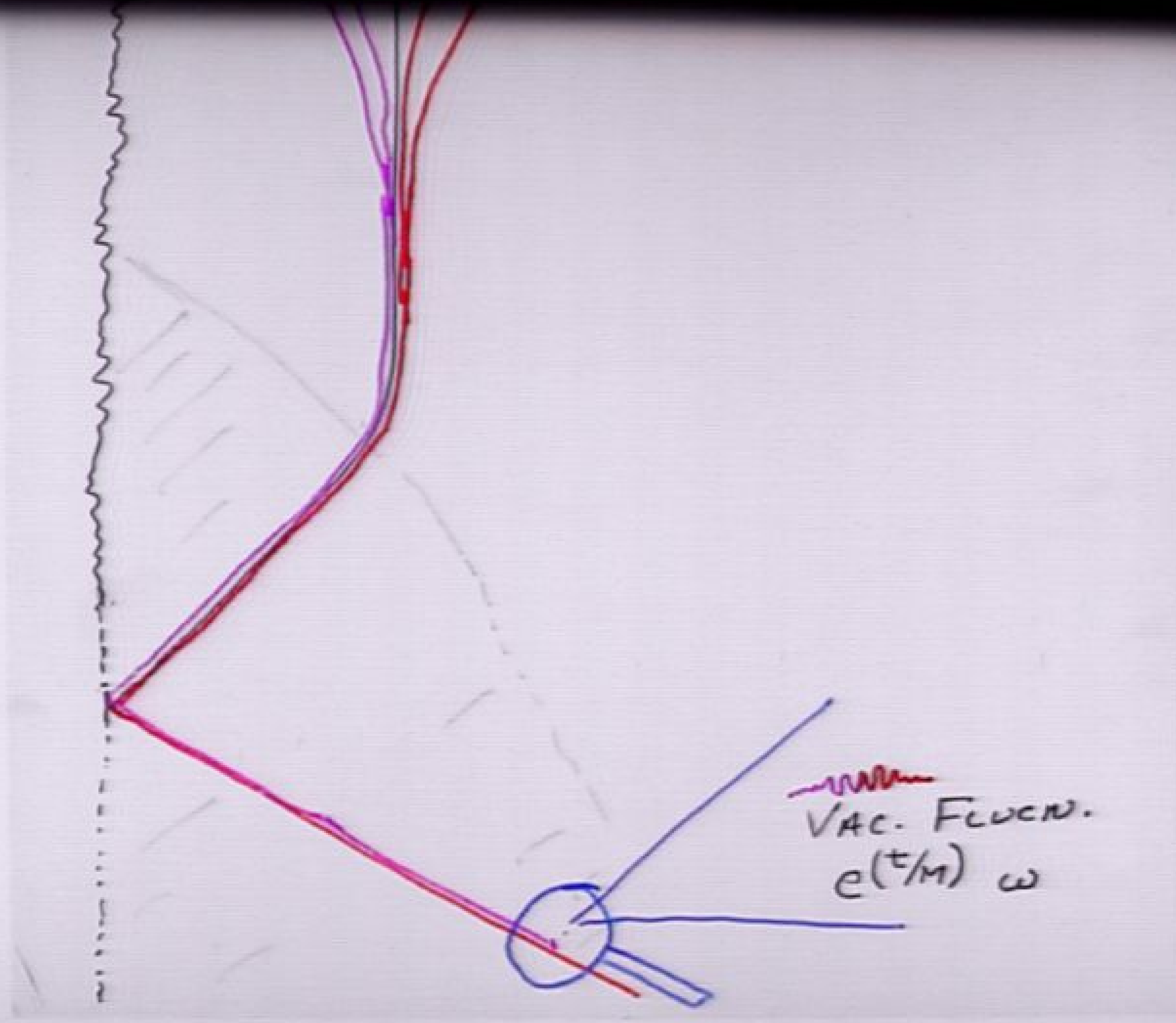
[Christodoulo & Hawking → Area increases classically - pos. energy]



−
+
R
ω


VAC. FLUCN.
e(t/M) ω

CONSEQUENCE

a) B. H. Behaves Like THERMODYNAMIC OBJECT (STAT MECH)

b) Information Paradox

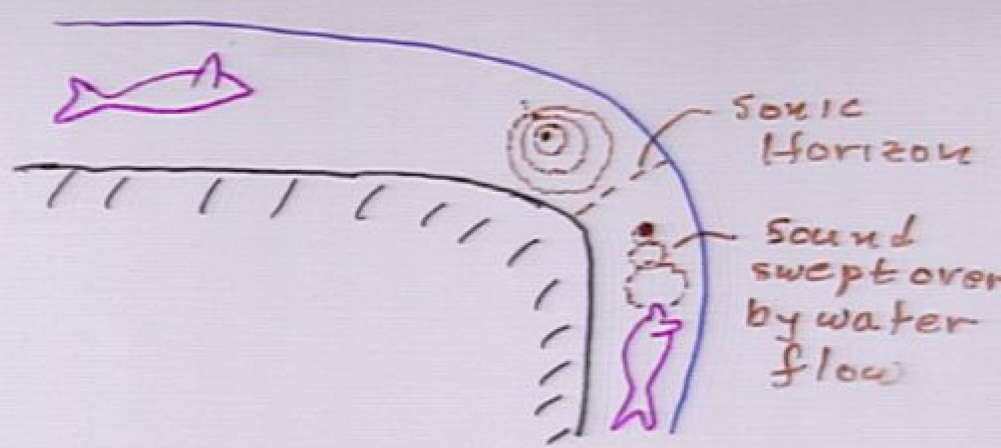
---

a). Maxwell, Boltzman, Gibbs,...
Thermodynamics result of microscopic physics of atoms.

Entropy = $k \ln(\# \text{states})$

What are states of B.H.?

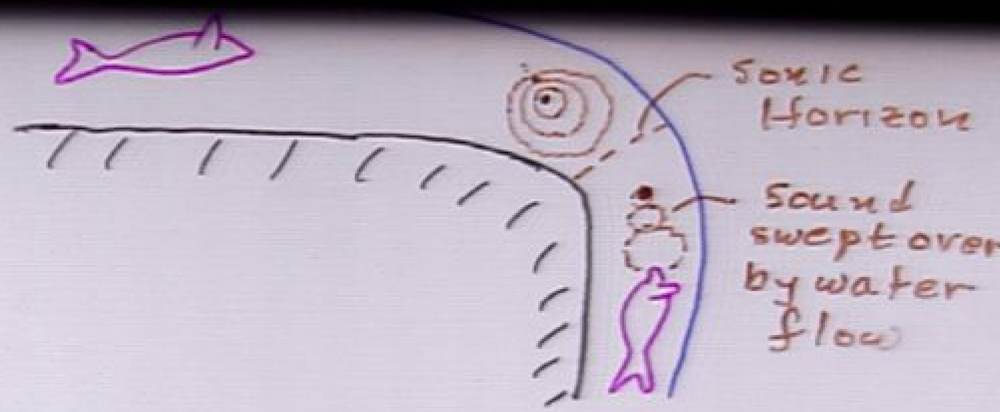
Dumb Holes



Equations of motion of sound → Same as eqn motion of scalar field in geometry of B.H.

$$T = \frac{1}{4\pi}\frac{\hbar}{k c}\frac{d(c^2 - v^2)}{dr}$$

(Note – T does not depend on



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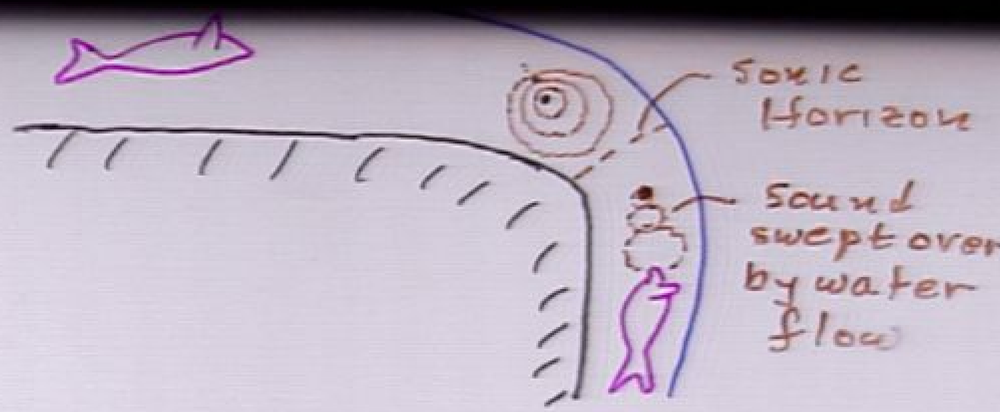

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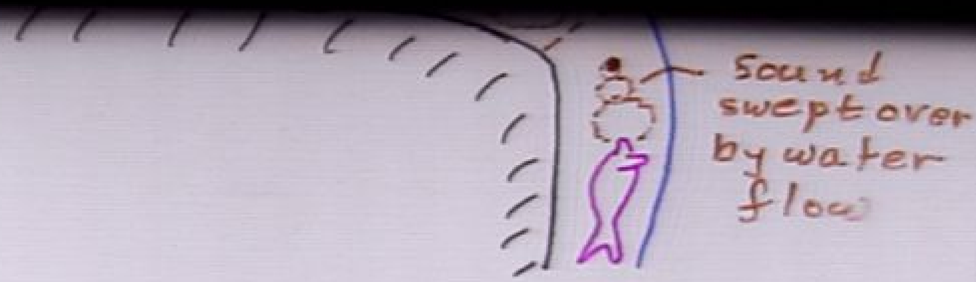

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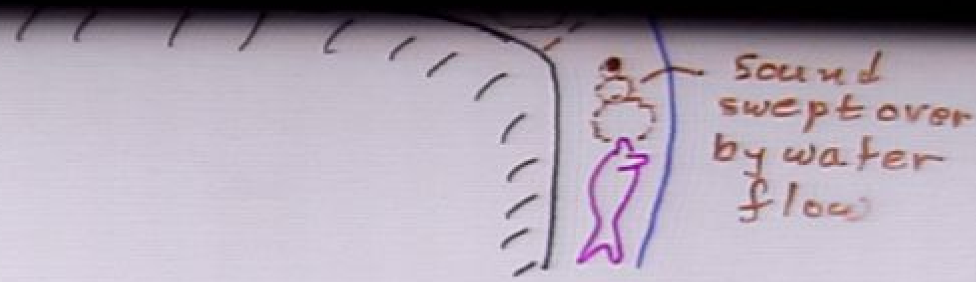

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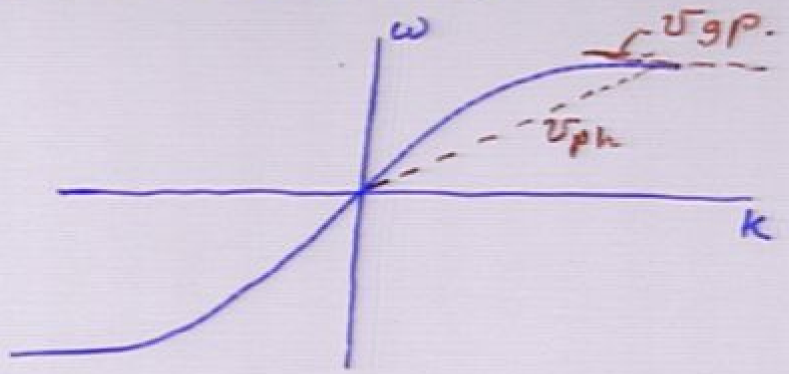
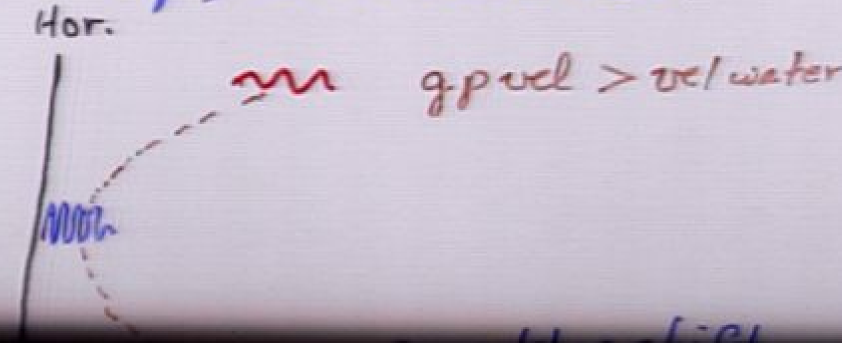
Same exponential Frequency?

Ted Jacobson (90's)



Dispersion Reln changes at high freq, wavenumber.



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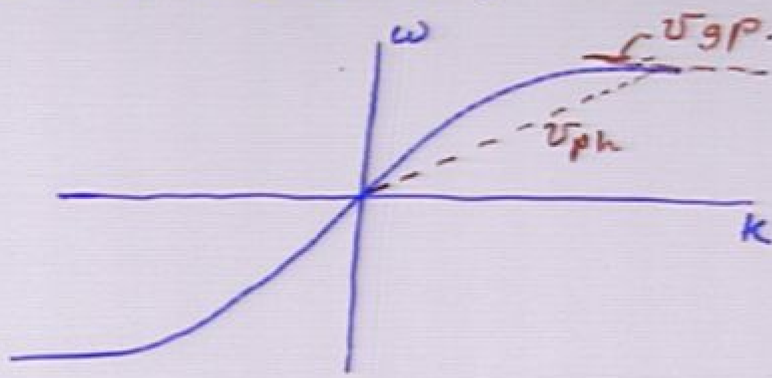

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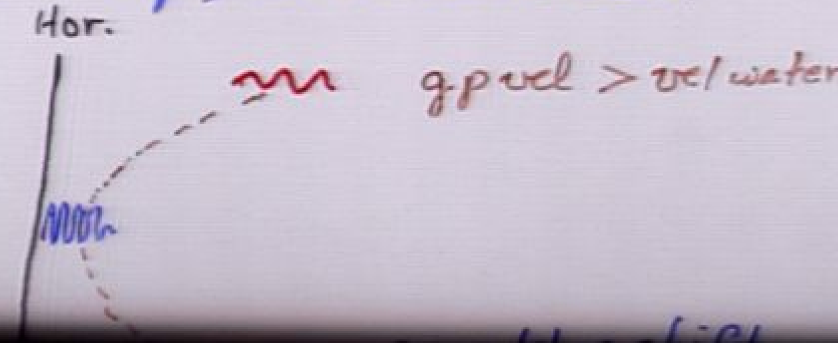

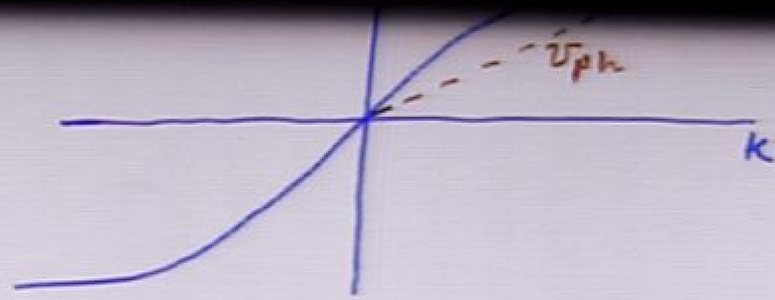

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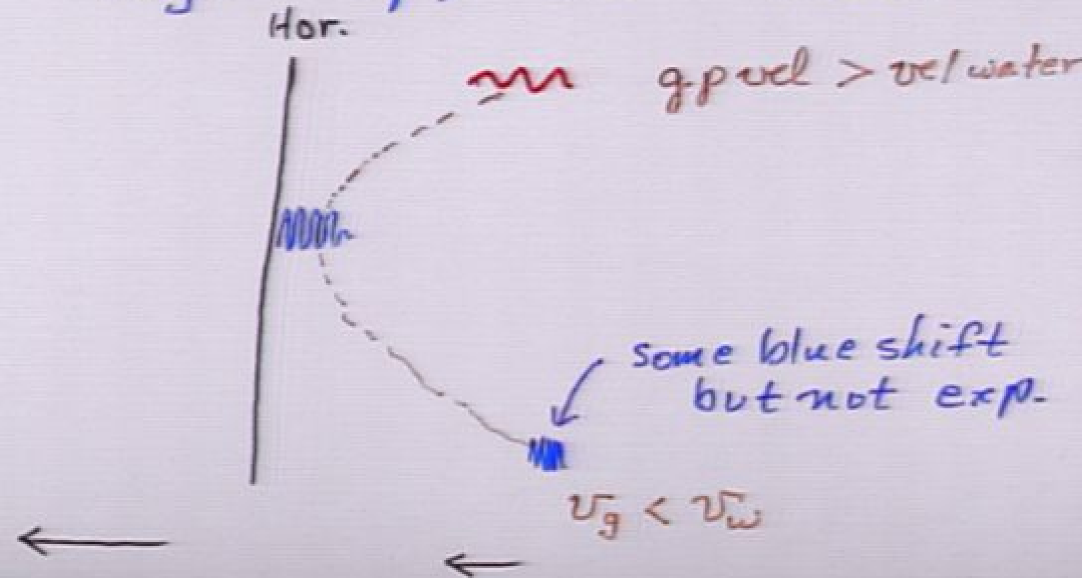
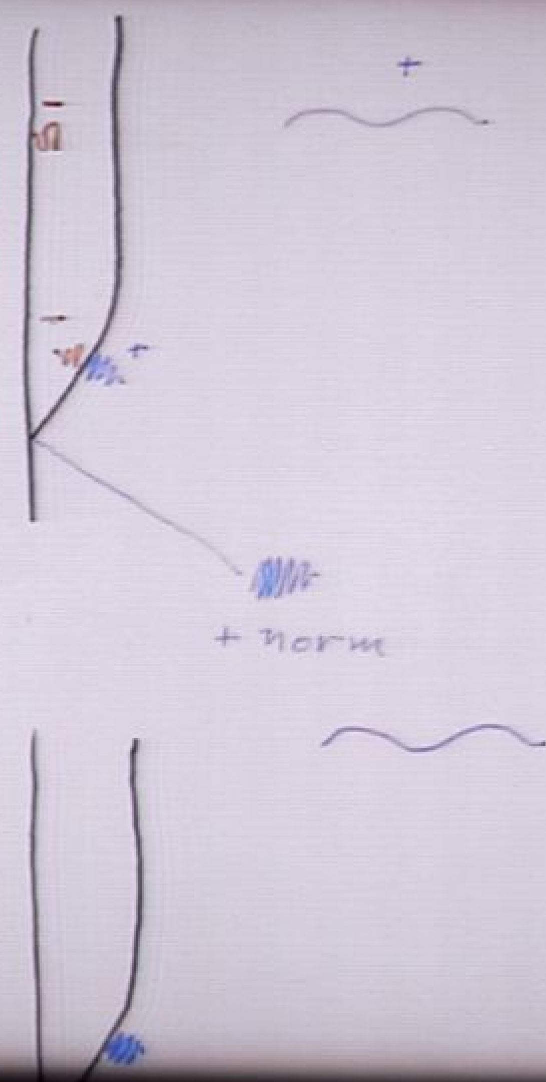


Temp. determined by "last" horizon.

- Particle creation is low freq, long wavelenth process - not a "near horizon process.

No subtle structure of horizon determines radiation


+ norm


+ norm

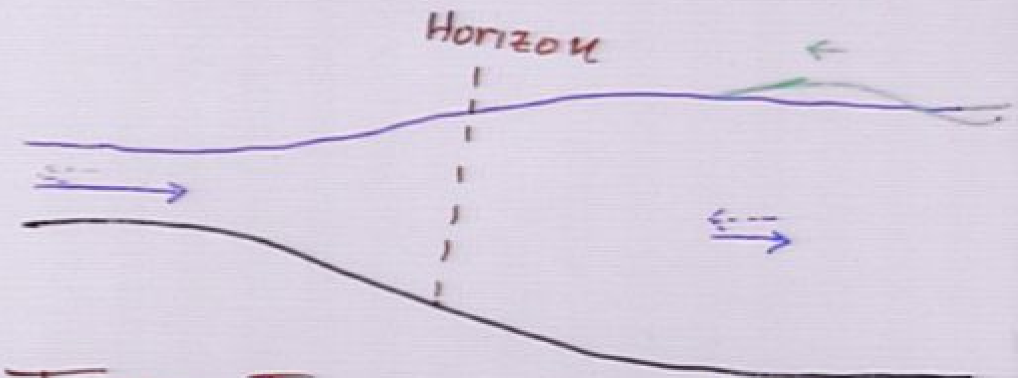
DERIVATION NONSENSE.

But is it right?

Experiment

↓

Cannot get small B.H.



TIME INVERSE of B.H.

Does the wave pile up to e^{10^5}?

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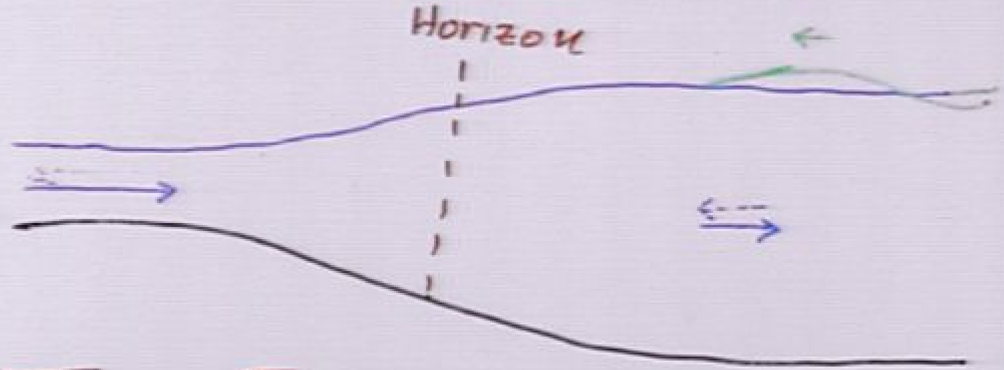

TIME INVERSE of B.H.

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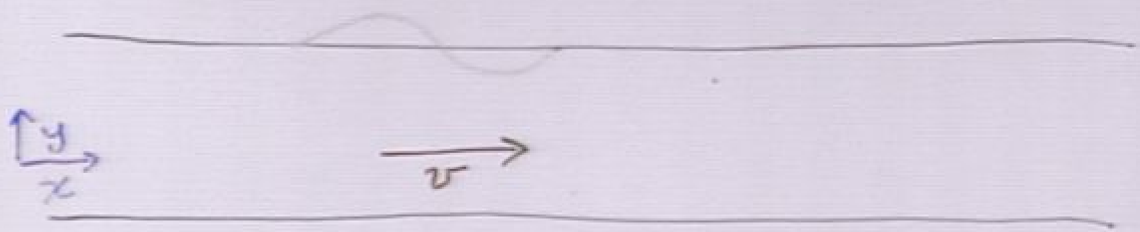
Wave Eqn of gravity waves.

Const Depth.



$$\vec{\nabla}\cdot\vec{v} = \vec{\nabla}\times\vec{v} = 0$$

$$v = \nabla\psi$$

Bottom $\quad v_y = 0$

Top $\quad p = 0$

$$\partial_t \vec{v} + \vec{v}\cdot\vec{\nabla}\vec{v} = -\nabla\frac{p}{\rho} - \nabla g y$$

$$\Downarrow$$

$$\ldots + gy = \text{const}$$

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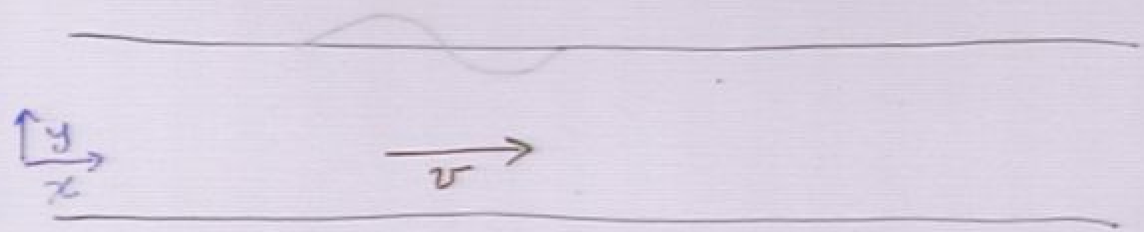

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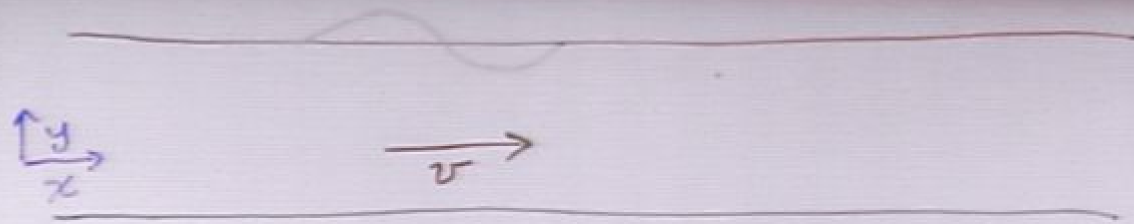
$$\dot{\psi} + \tfrac{1}{2}v^2 + p + gy = \text{const}$$



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$$(\partial_t + \vec{v}\,\partial_x)^2\, \delta\psi_s - g(i\partial_x)\tanh(i\partial_x y_0)\,\delta\psi_s = 0$$

$$\vec{v} = 0$$

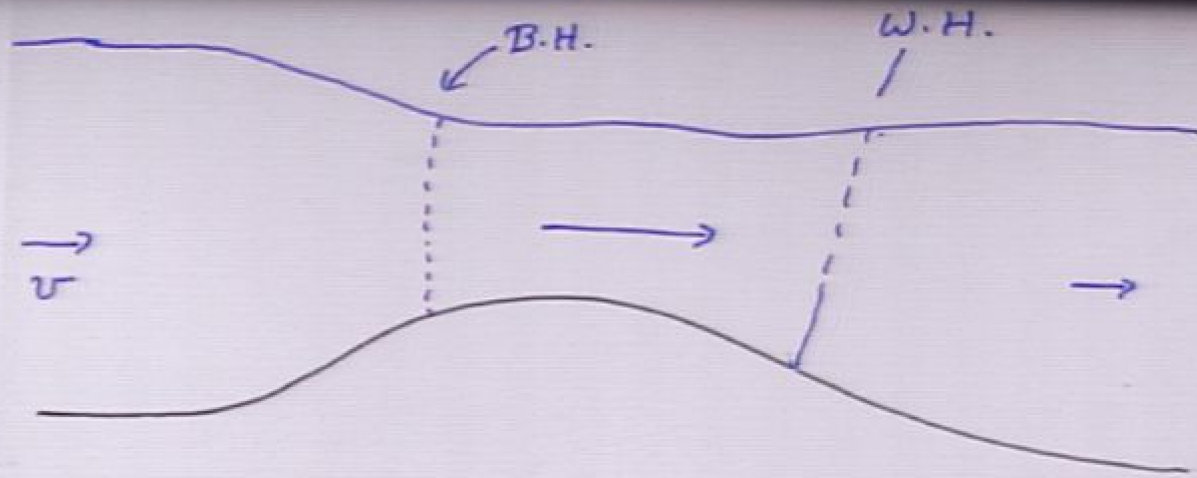
$$\omega = \pm\sqrt{g k \tanh k y_0}$$

$k y_0 < 1 \Rightarrow$ shallow water wave

$k y_0 > 1 \Rightarrow$ deep water wave.

[If surface tension

$$\omega = \pm\sqrt{(g k + \sigma k^3)\tanh k y_0} \quad]$$



$$\vec{w} = \vec{e}_z \times \vec{v}$$

$$\nabla \cdot \vec{w} = \nabla \times \vec{w} = 0 \implies \vec{w} = \nabla \phi .$$

Use ψ, ϕ as coordinates.

$$I = \int \Big[\frac{1}{v^2 G} \left| (\partial_t + v^2 \partial_\phi) \delta\psi \right|^2$$

[illegible]

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Use ψ, ϕ as coordinates.

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v^2 = Bkgnd velocity

$\delta\psi$ = fluctn of vel. potential at surface.

$$[x, p] = i\hbar$$

$$a = e^{\theta} x + i e^{-\theta} p$$

$$[a, a^{+}] = 1 \Rightarrow a|0\rangle_{\theta} = 0$$

Energy

$$H = \frac{p^2}{2m} + \frac{k}{2} x^2$$

$$e^{\theta} = \sqrt{km}$$

$|0\rangle_{\ln\sqrt{km}} \rightarrow$ Min. Energy.

No Necessity links a to H

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No Necessity links a to H

2 mode Squeezed State.

$\underbrace{a, b}_{\text{input}}$ $\qquad$ $\underbrace{c, d}_{\text{Output}}$

$$c = \cosh\psi \; a + \sinh\psi \; b^{+}$$

$$d = \cosh\psi \; b + \sinh\psi \; a^{+}$$

Assume initial state

$$a\,|0\rangle_{ab} = b\,|0\rangle_{ab} = 0$$

$$a = \cosh\psi \; c - \sinh\psi \; d^{+}$$

$$b = \cosh\psi \; d - \sinh\psi \; c^{+}$$

$$\rho_c = Tr_d\, |0\rangle_{ab}\langle 0|_{ab}$$

$$= N \exp\left[\ln(\tanh\psi)\, c^{\dagger}c\right]$$

Thermal State

$$\frac{\omega}{kT} = \ln(\tanh\psi)$$

In terms of the c, d vacuum, the a, b vac. is a Two mode squeezed state + a thermal state (excess noise) for any one.

$$a|\phi\rangle = \phi|\phi\rangle$$
$$b|\phi\rangle = 0$$

$$\langle\phi|C|\phi\rangle = \cosh(\psi)\,\phi\langle\phi|\phi\rangle$$

AMPLIFIER.

The amplitude of output is a multiple of input amplitude.

(Phase insensitive - does not depend on complex phase of ϕ).

Noise

Assume ϕ real

$\Downarrow$

$$\langle\phi|\frac{c+c^{+}}{\sqrt{2}}|\phi\rangle = \cosh(\psi)\,\langle\phi|\frac{a+a^{+}}{\sqrt{2}}|\phi\rangle$$

$$\langle\phi|\,\Delta^{2}\left(\frac{c+c^{+}}{\sqrt{2}}\right)|\phi\rangle = (\cosh^{2}\psi+\sinh^{2}\psi)\,\langle\phi|\Delta^{2}\left(\frac{a+a^{+}}{2}\right)|\phi\rangle$$

Noise amplified plus addn noise introduced

BLACK HOLE

a). BLACK HOLE ACTS AS
LINEAR AMPLIFIER

↓

EXCESS NOISE

⇓

HAWKING RADIATION

[DOES NOT AMPLIFY ENERGY
BUT AMPLITUDES]

b). CLASSICAL BEHAVIOUR
of AMPLIFIER ($\cosh(\gamma)$)
Determines QUANTUM

Black Holes.

- SAME PARTICLE CREATION AS BLACK Holes.

b). LINEAR QUANTUM SYSTEM.

- QUANTUM BEHAVIOUR COMPLETELY DETERMINED BY CLASSICAL BEHAVIOUR

EXPERIMENT

U.B.C.

(-suggested R. Schützhold + WU
 -prelim. exp G. Rousseaux (Nice)

- S. Weinfurtner
  T. Tedford (hydro. engineer)
  G. Lawrence (C. Eng.)
  M. Penrice (u.grad)
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Experimental verification of the thermal character of black hole radiation

Silke Weinfurtner, Ted Tedford, Matt Penrice,
W. Unruh, Greg Lawrence

Arxiv : 1008.1911

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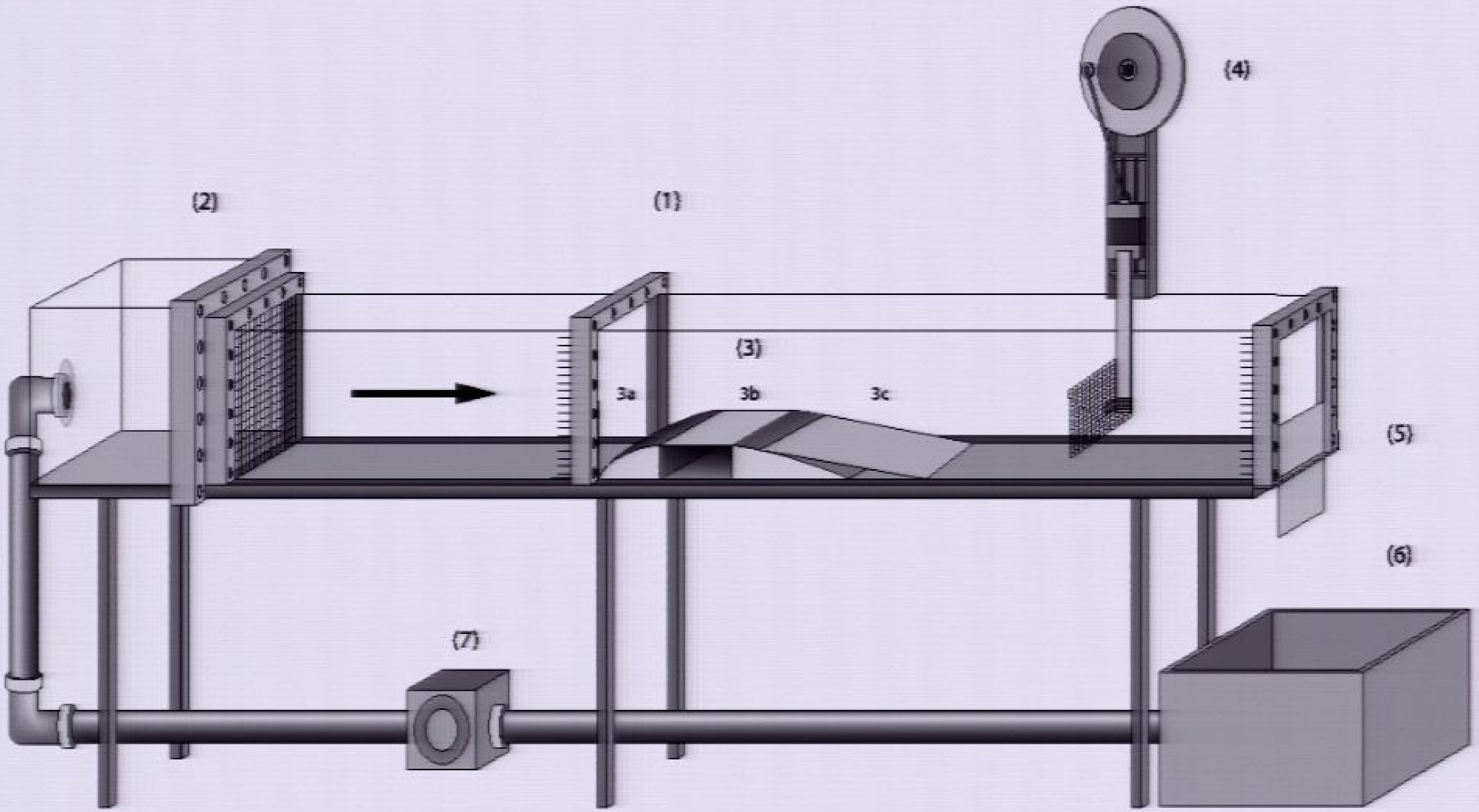
(4)
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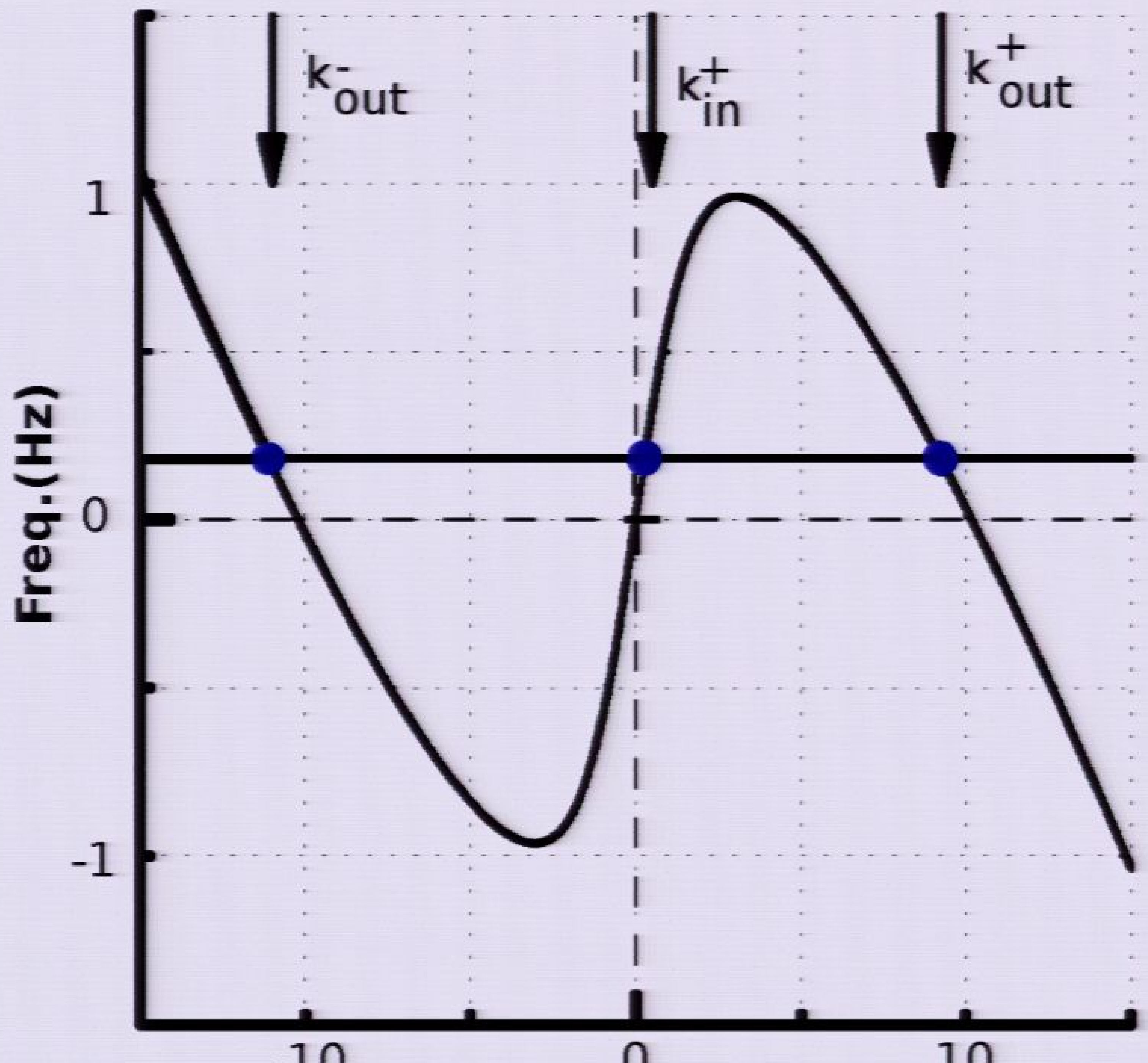
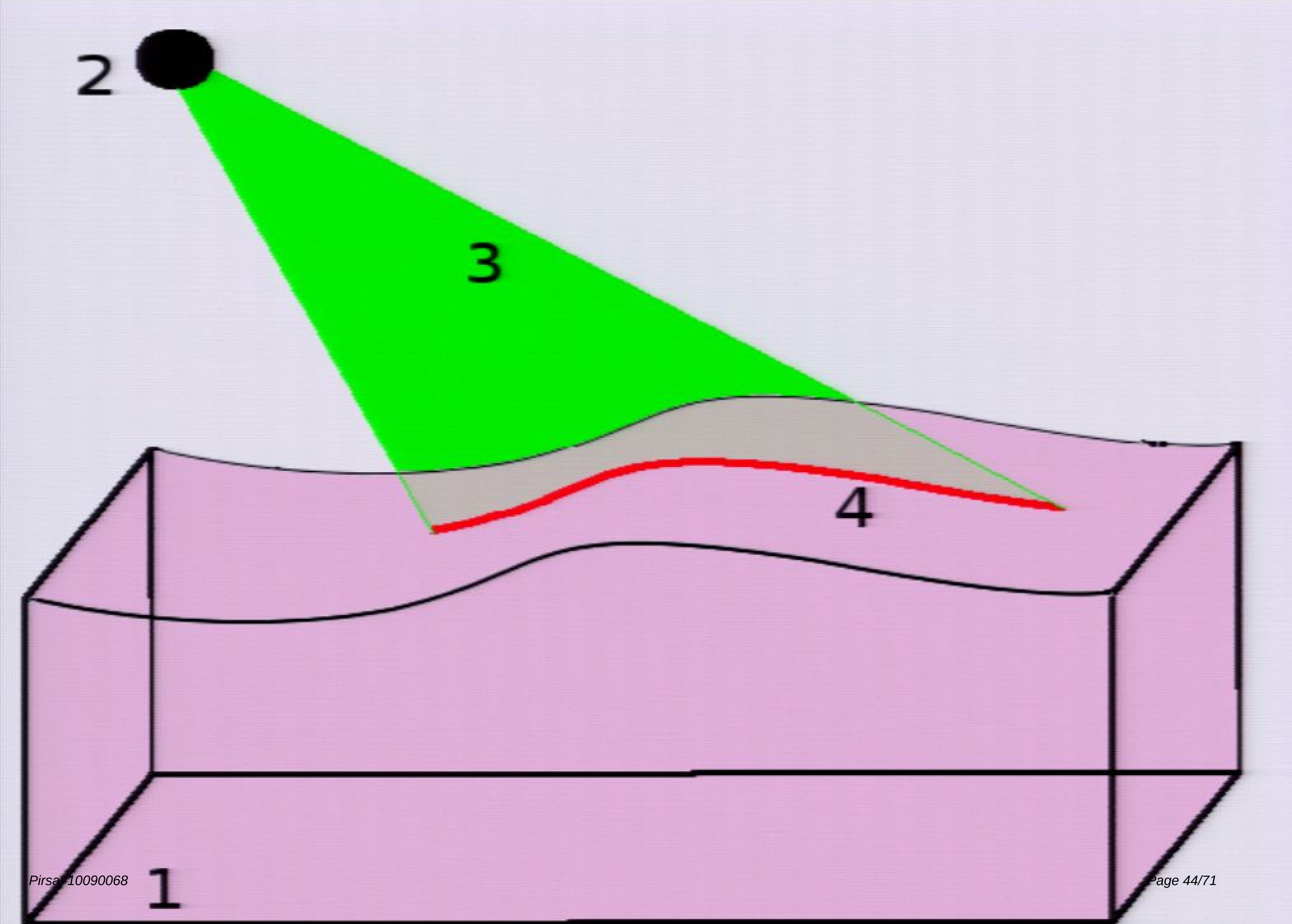
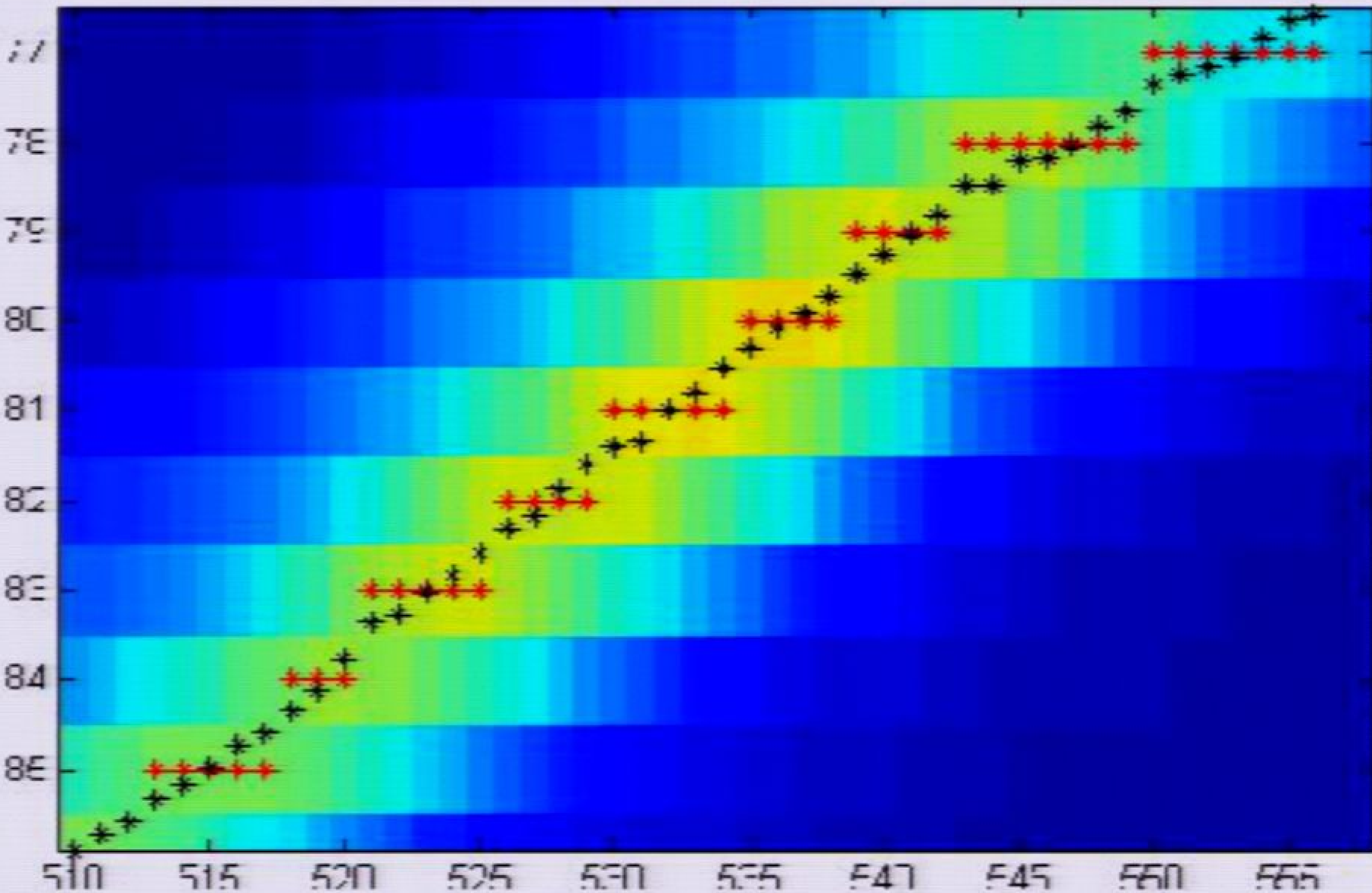
(1)
(3)
3a
3b
3c
(5)
(6)
(7)

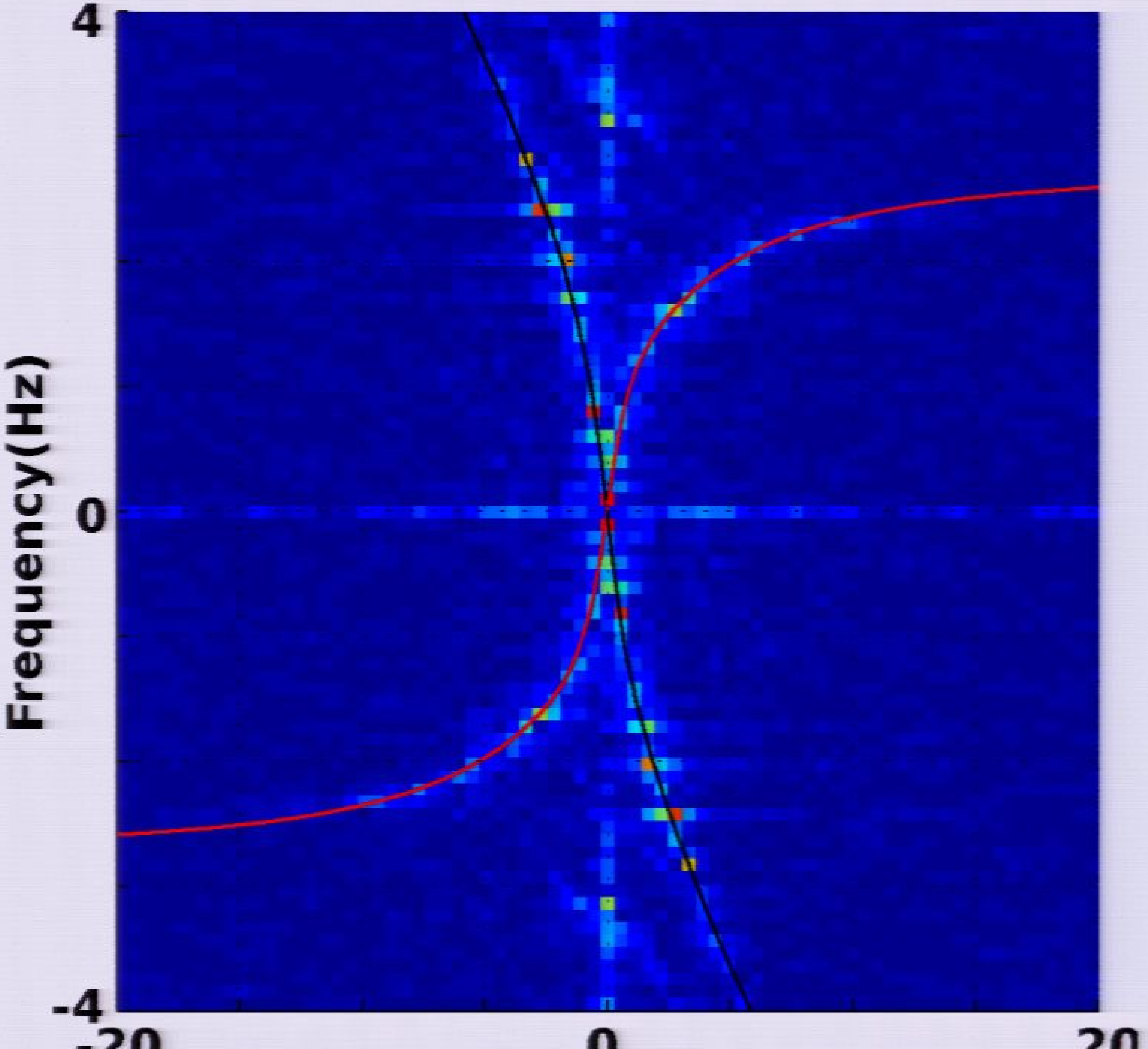


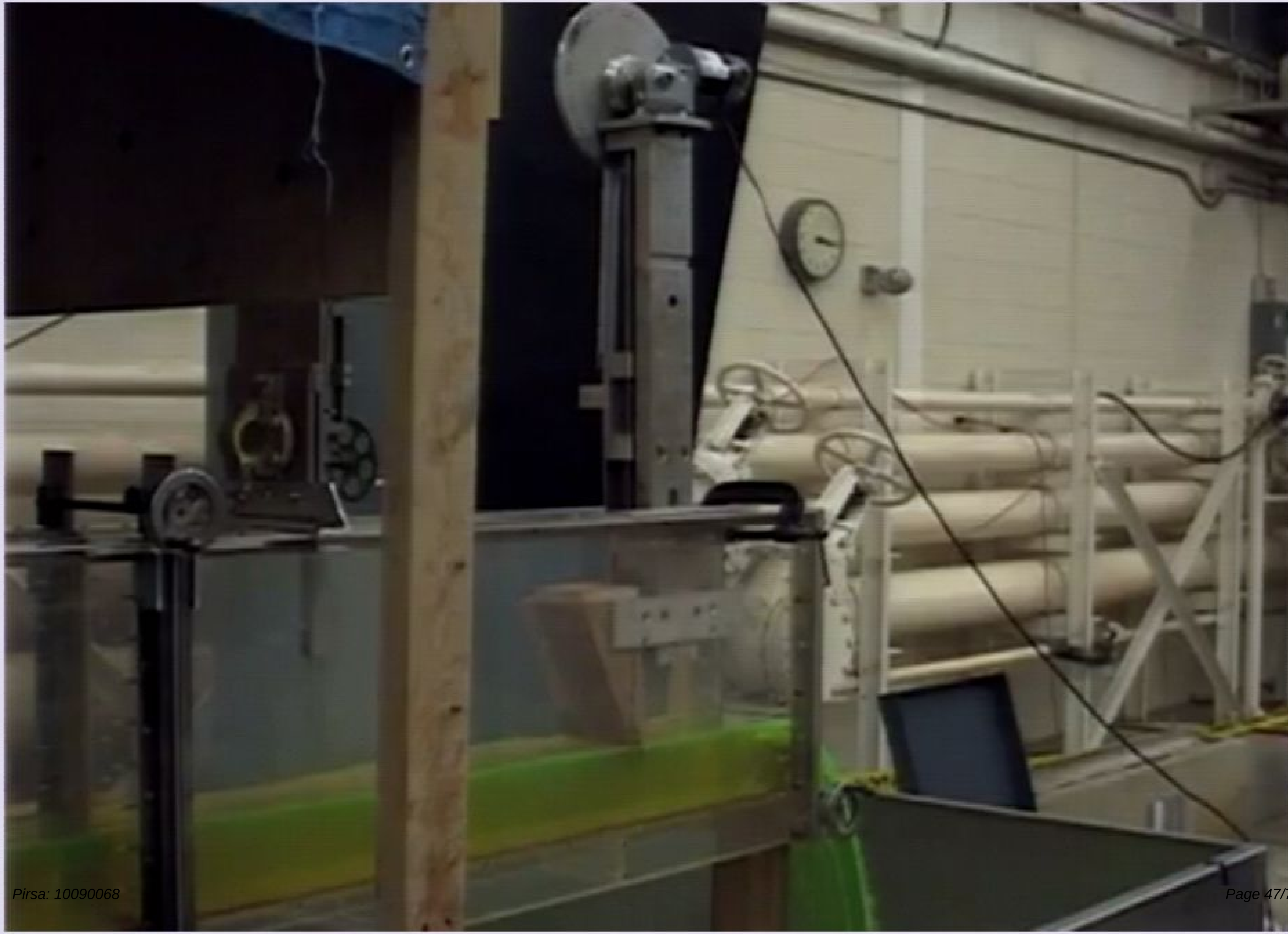
k^-_{out}
k^+_{in}
k^+_{out}
1
0
-1
Freq.(Hz)

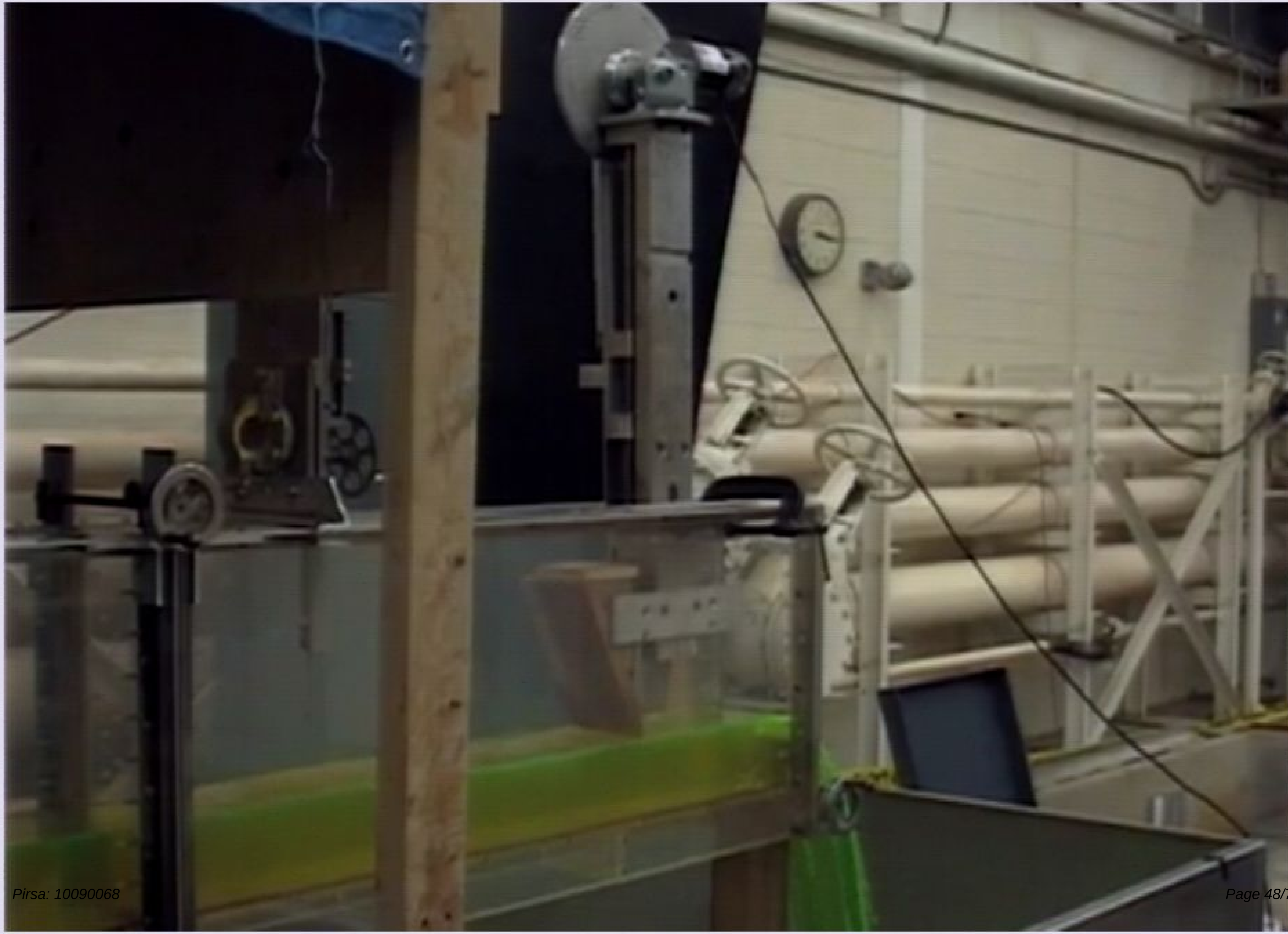

2
3
4
1

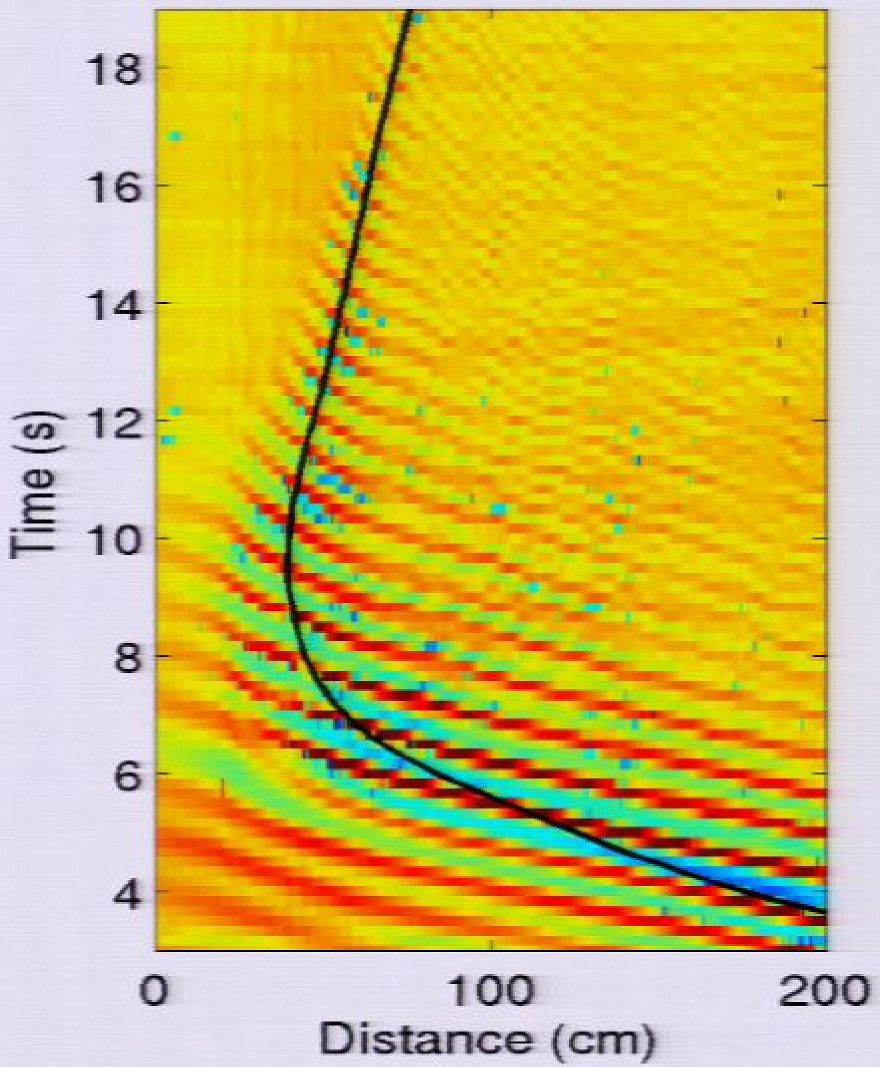


Sub Pixel Resolution

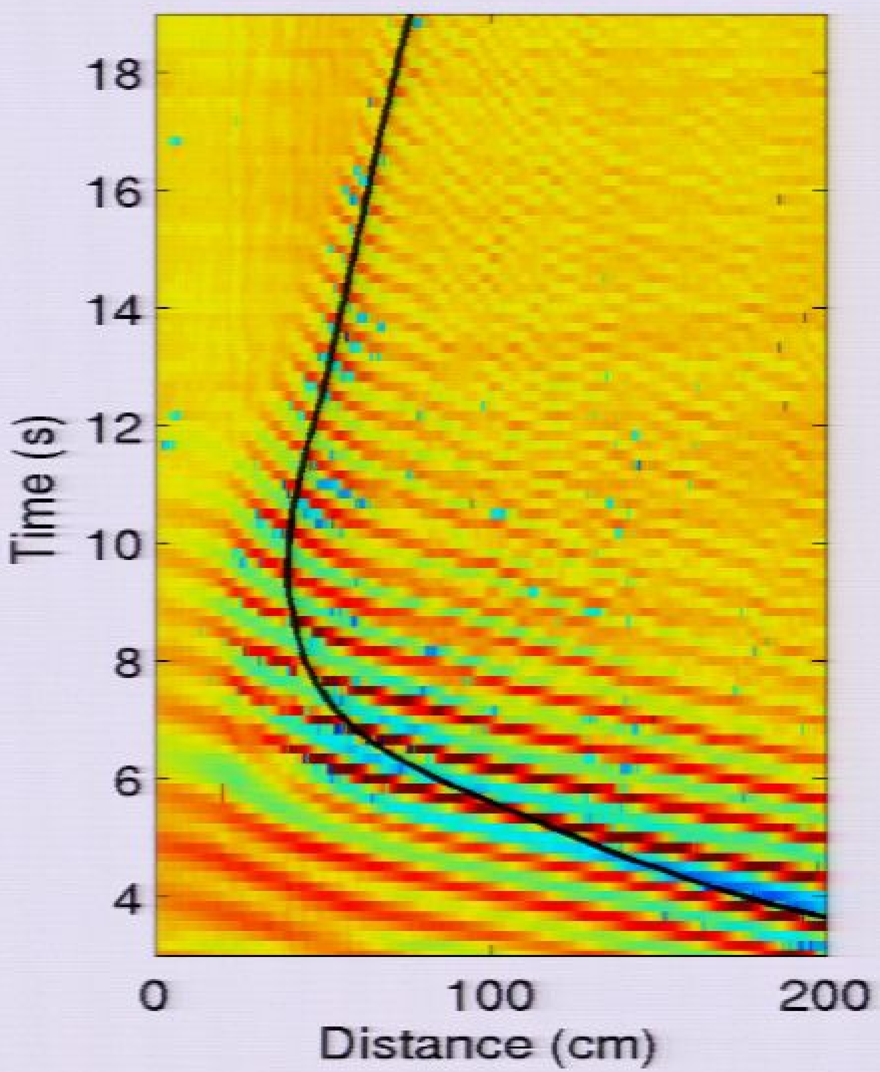

4
Frequency(Hz)
0
-4
-20
0
20







18
16
14
12
10
8
6
4
Time (s)
0
100
200
Distance (cm)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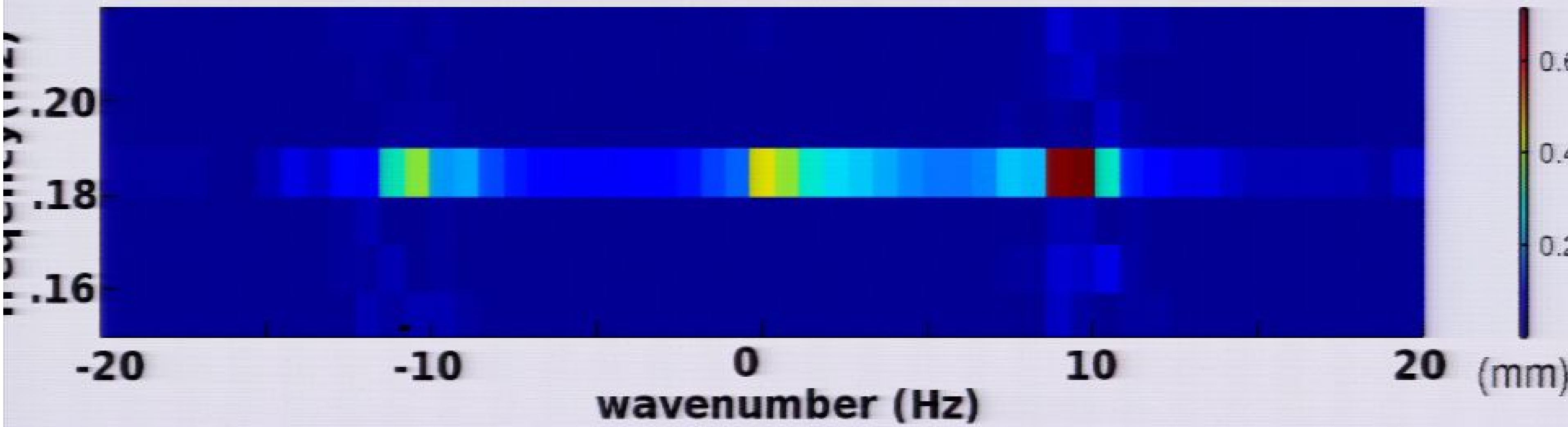
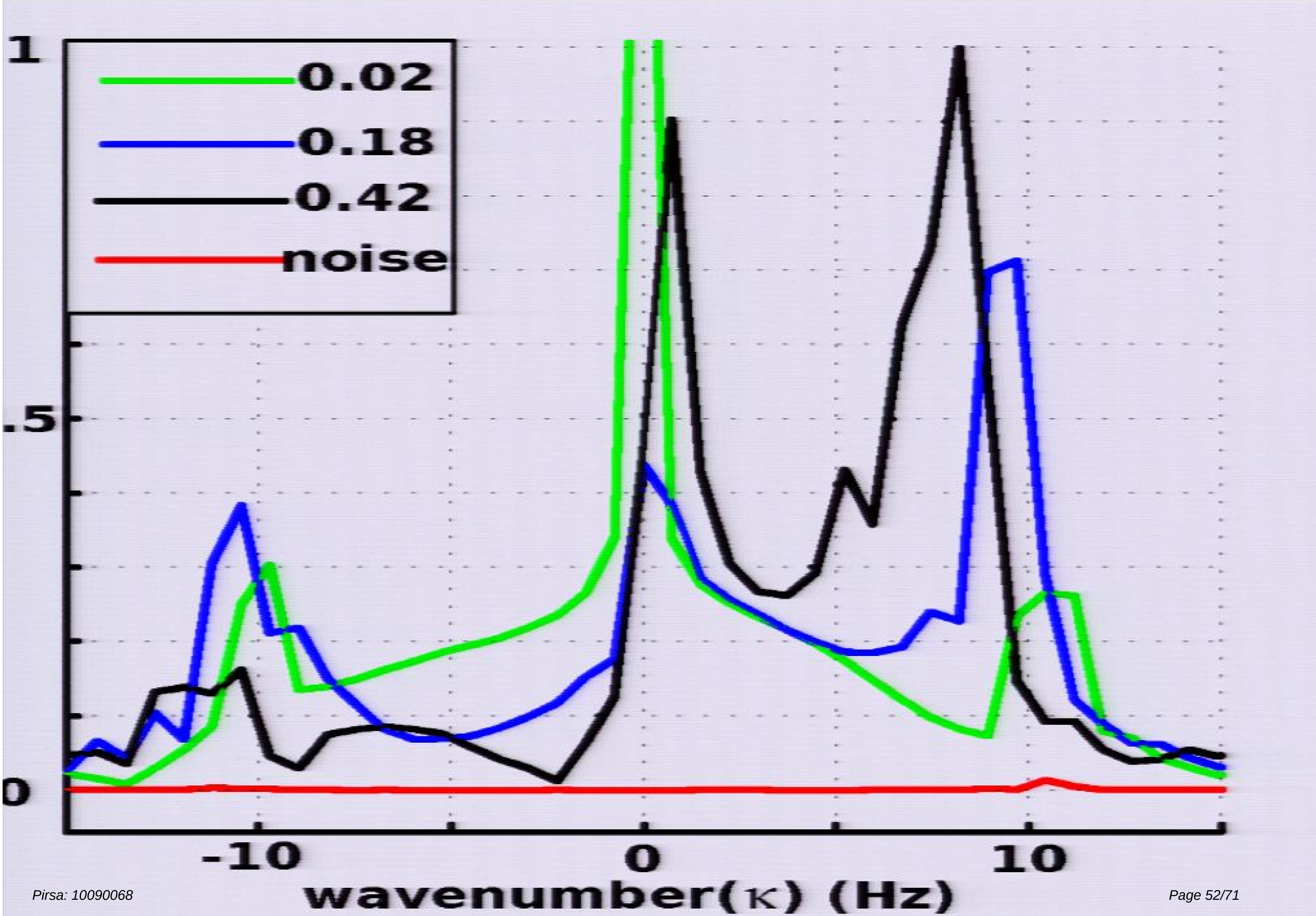
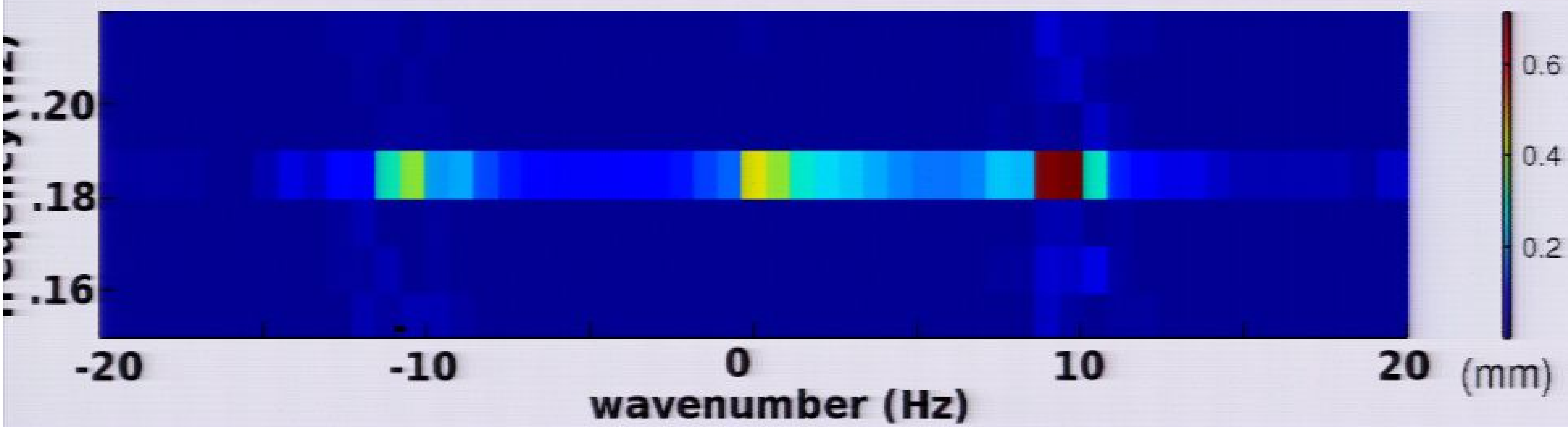


.20
.18
.16
-20
-10
0
10
20
wavenumber (Hz)
0.6
0.4
0.2
(mm)


1
.5
0
0.02
0.18
0.42
noise
-10
0
10
wavenumber(κ) (Hz)


.20
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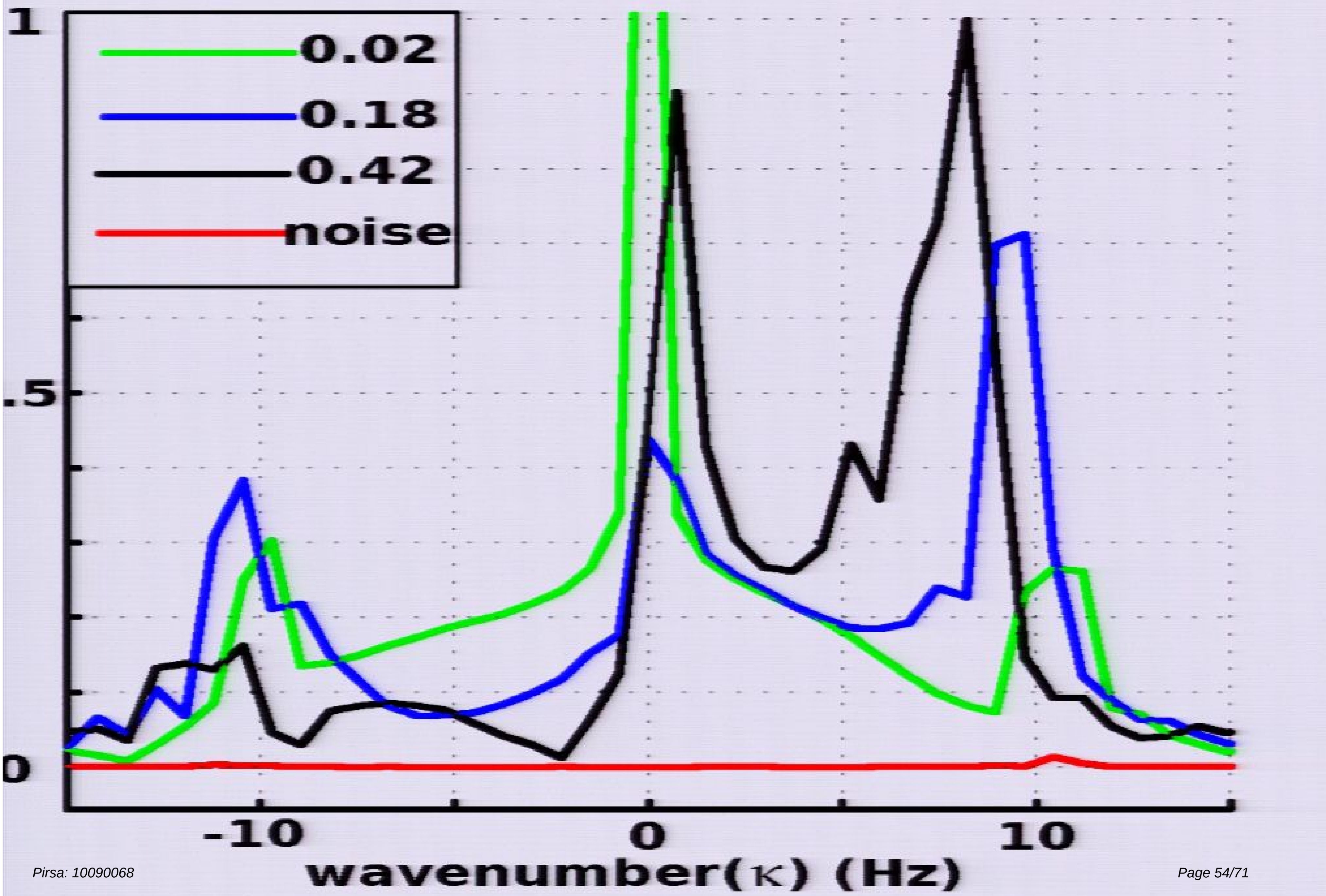

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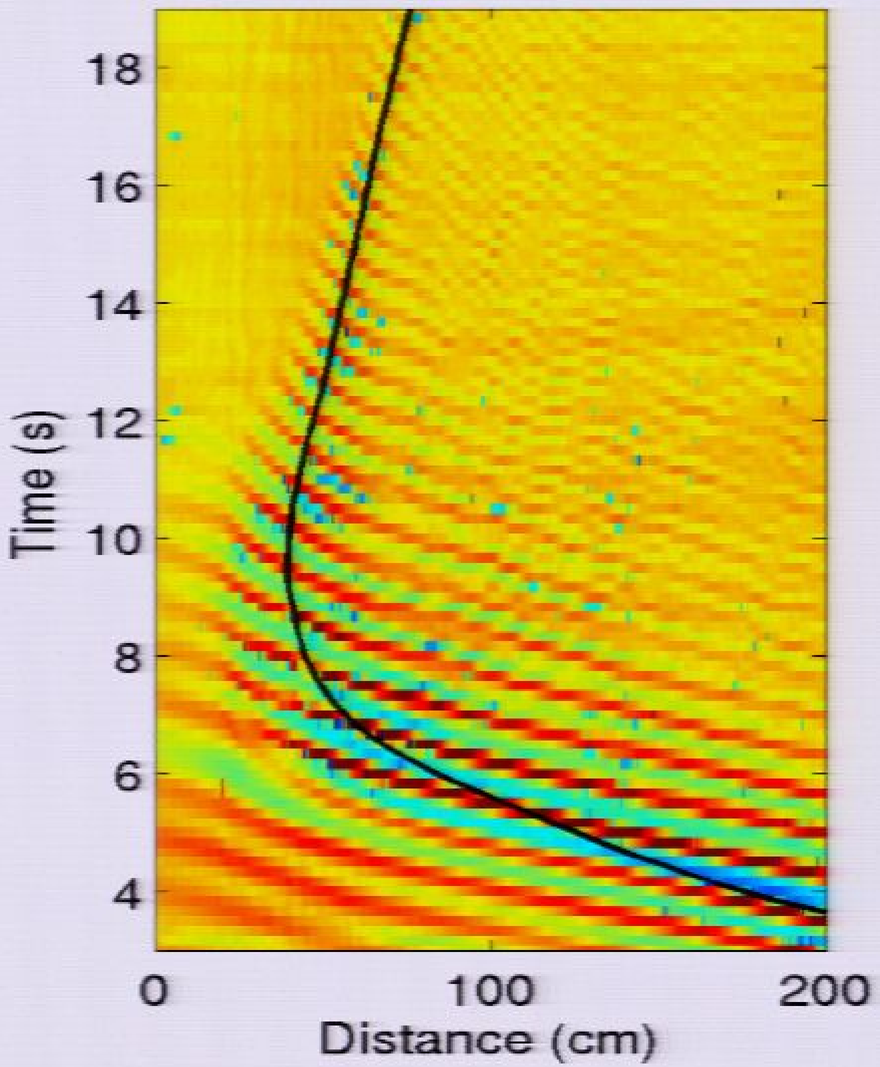
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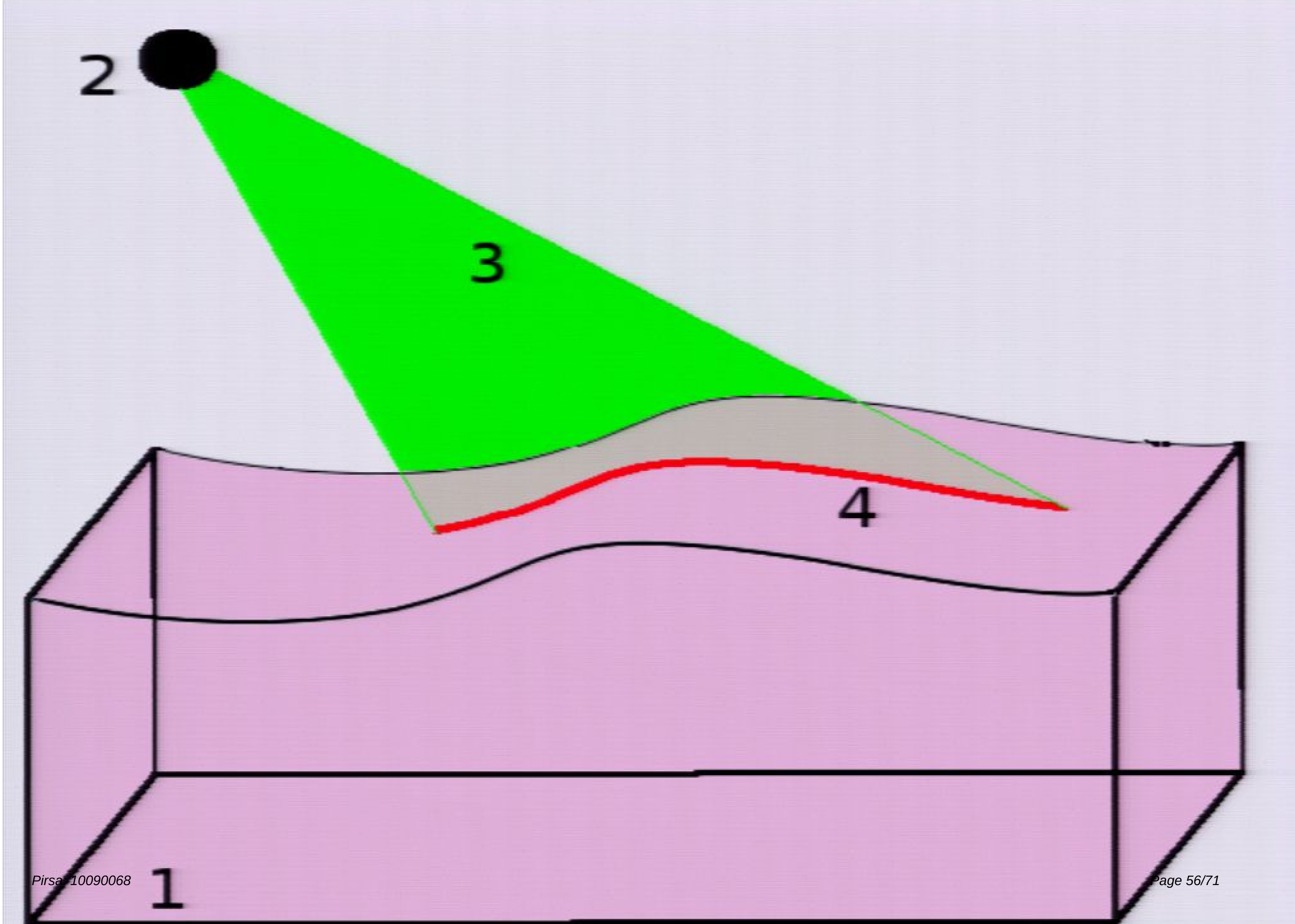
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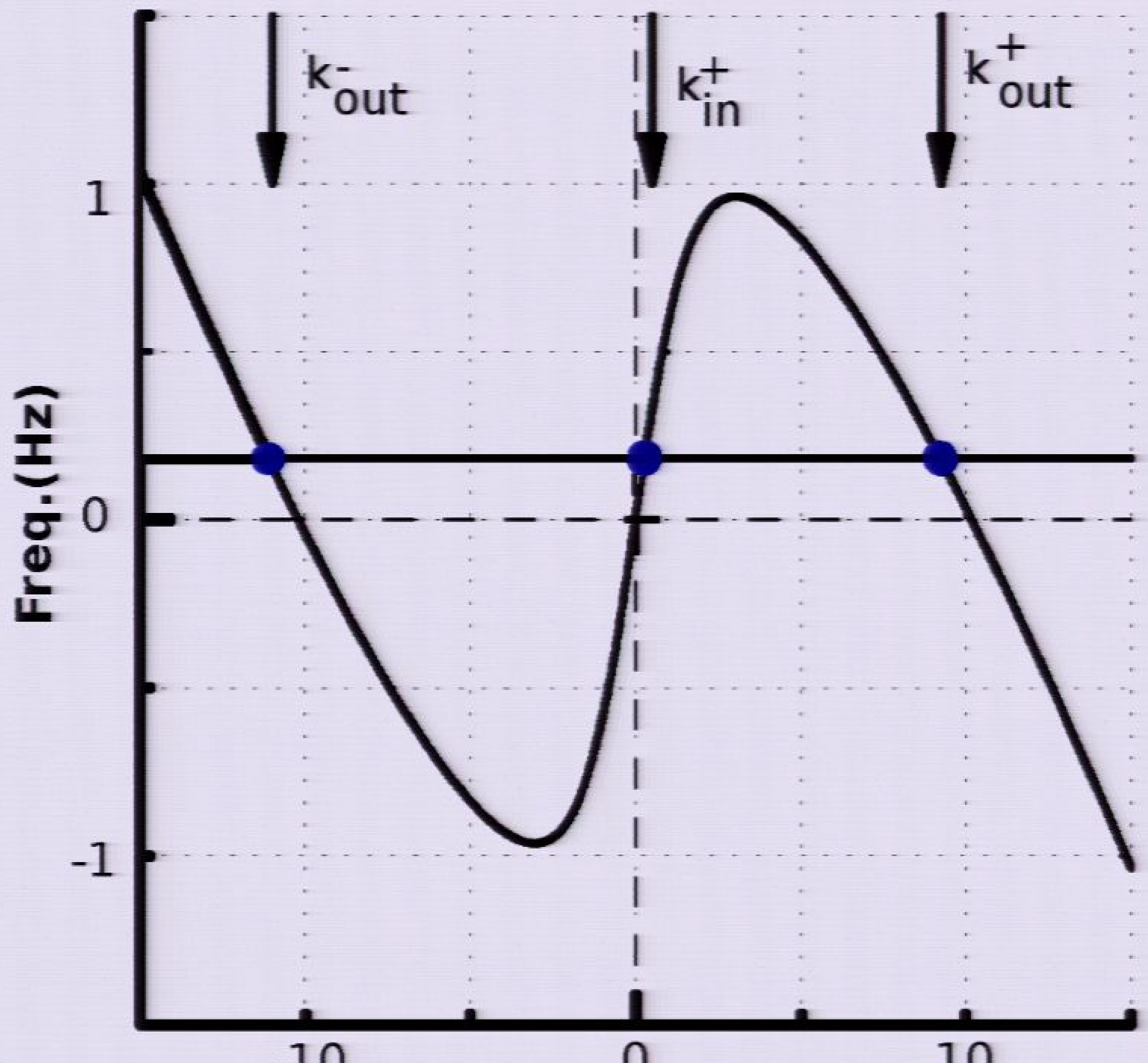
k^-_{out}
k^+_{in}
k^+_{out}
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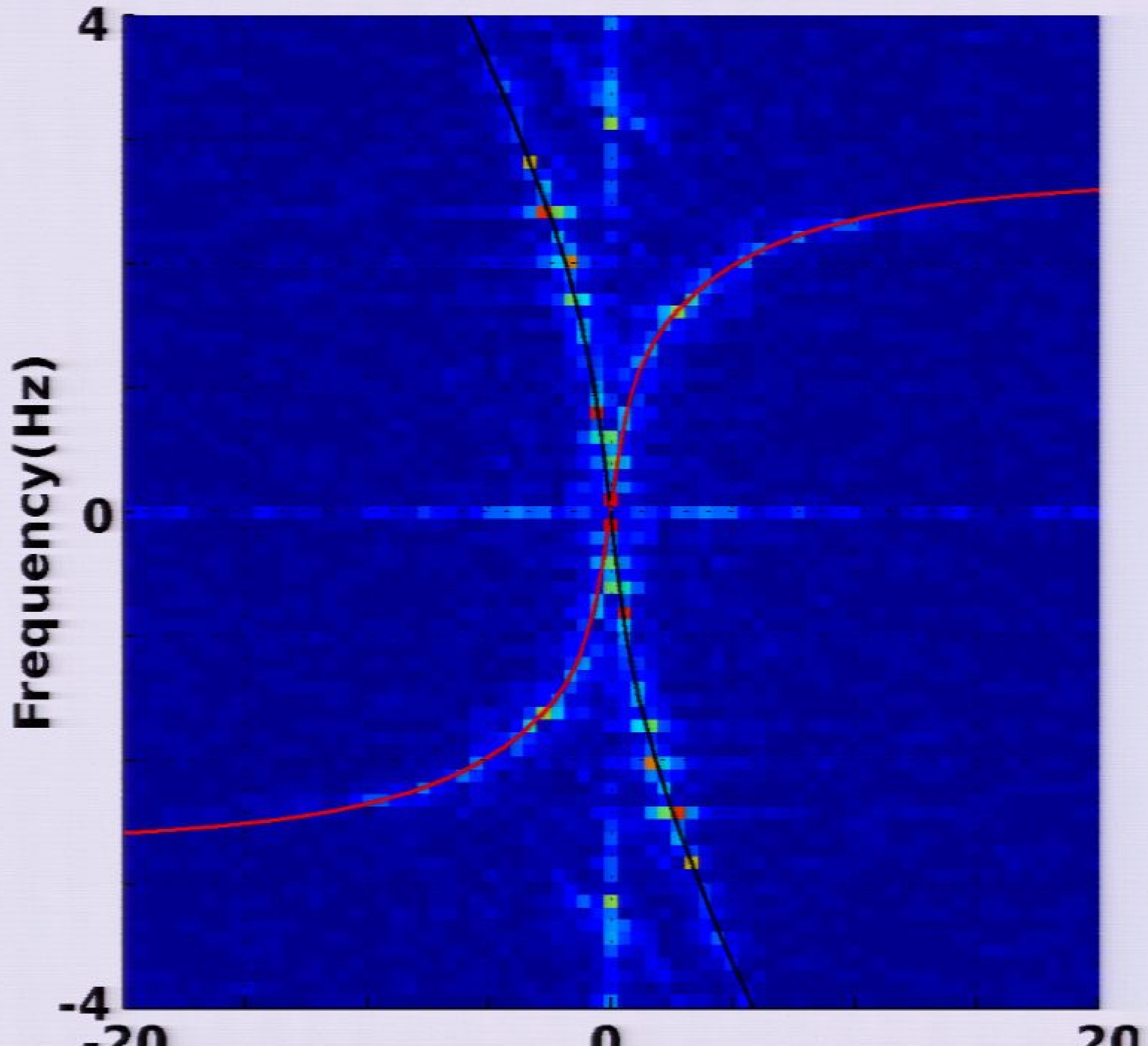
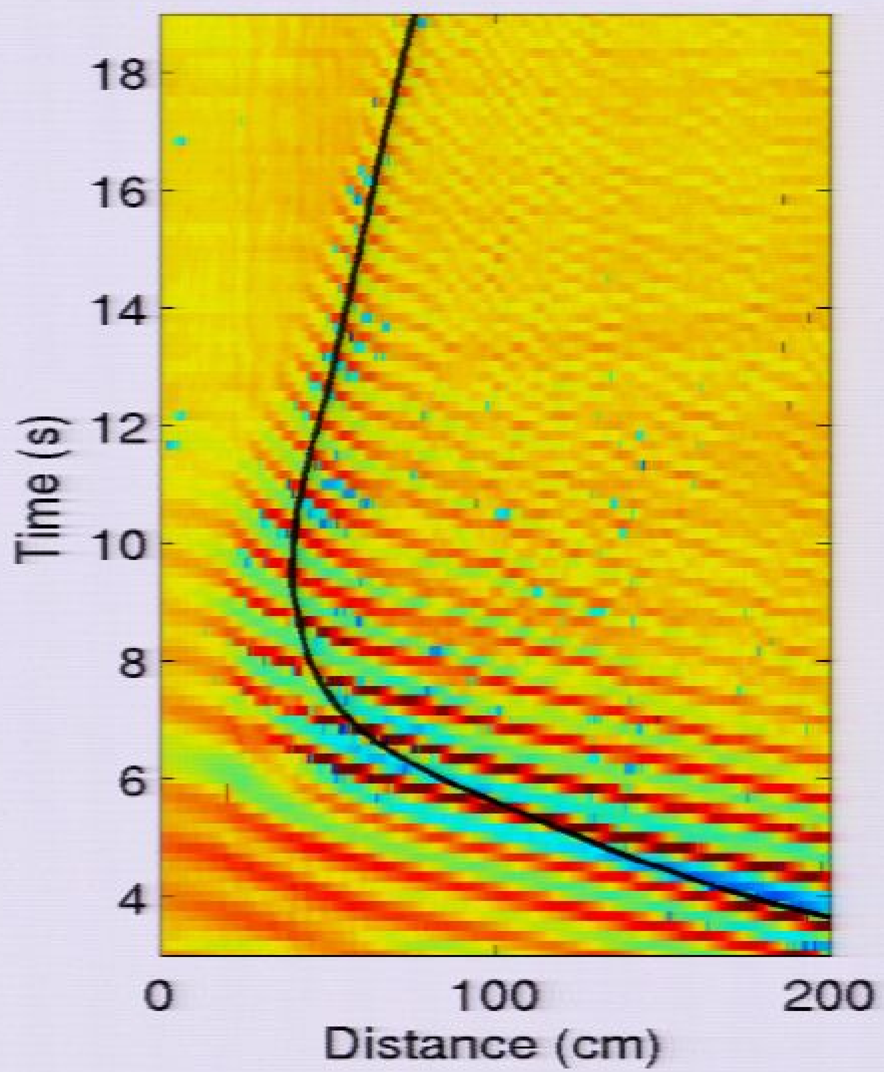
Freq.(Hz)
-10
0
10



4
Frequency(Hz)
0
-4
-20
0
20



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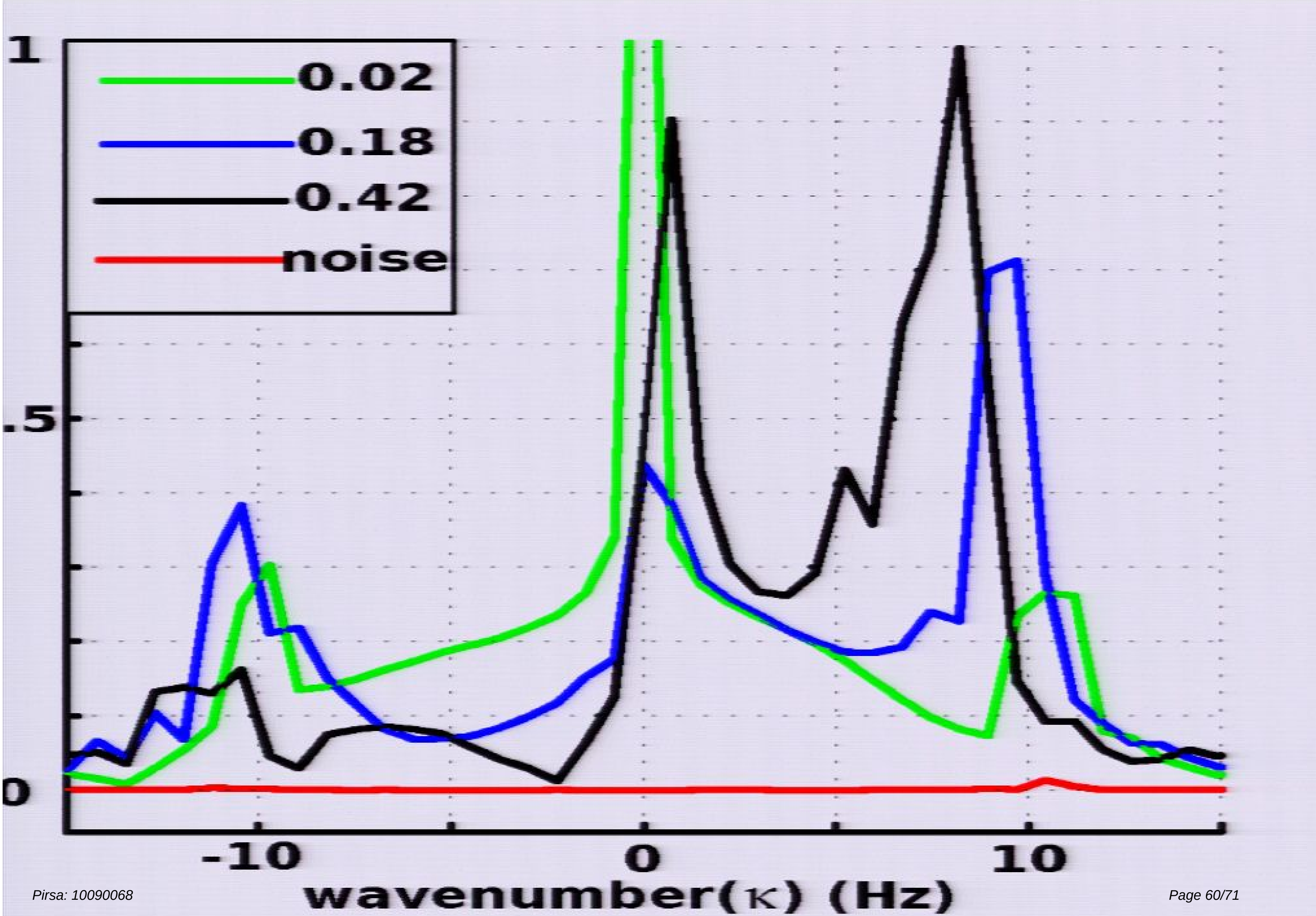
Distance (cm)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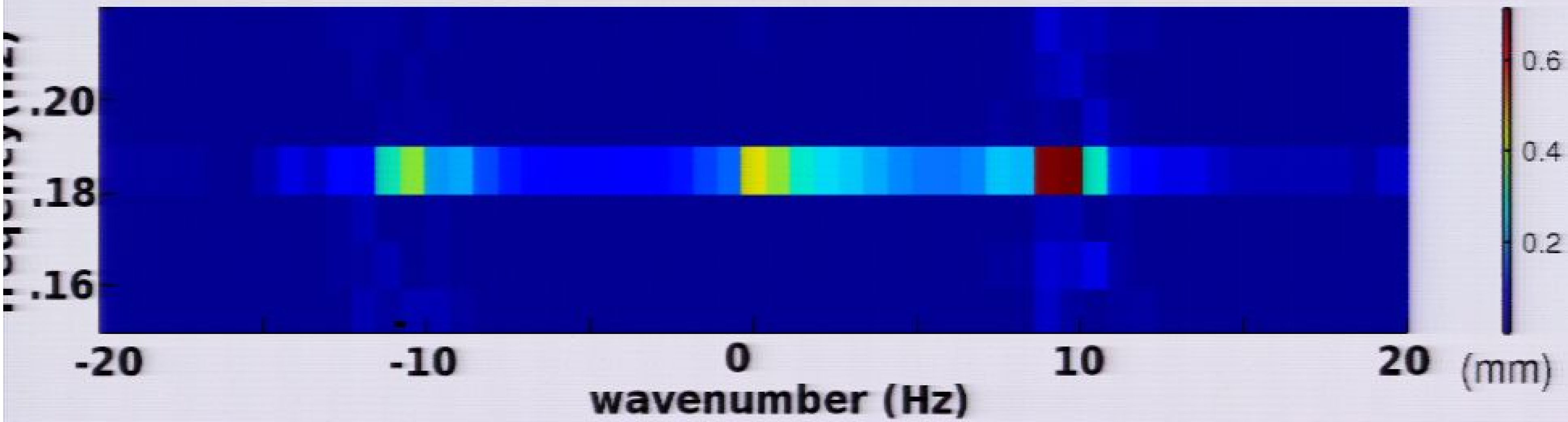
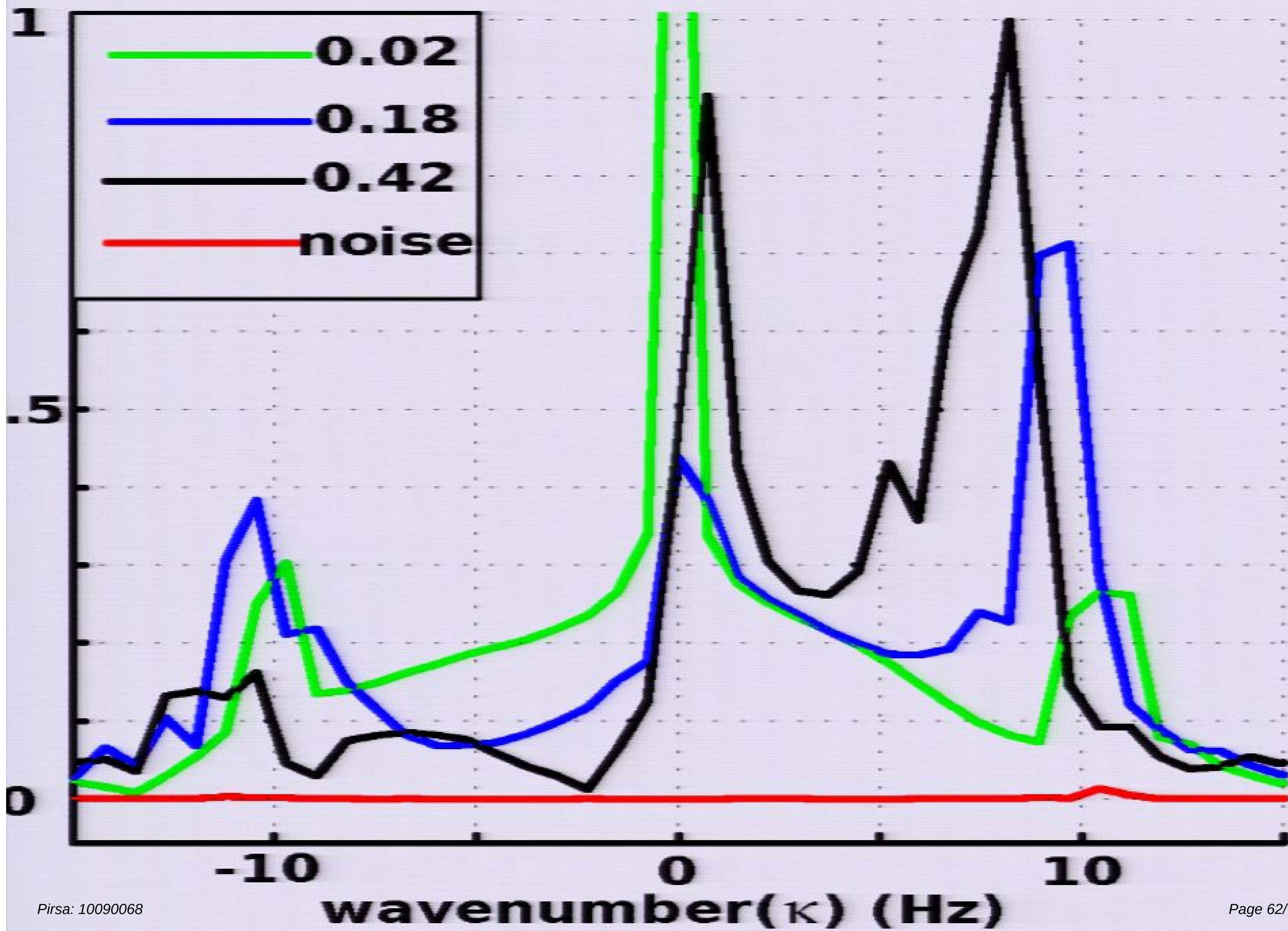
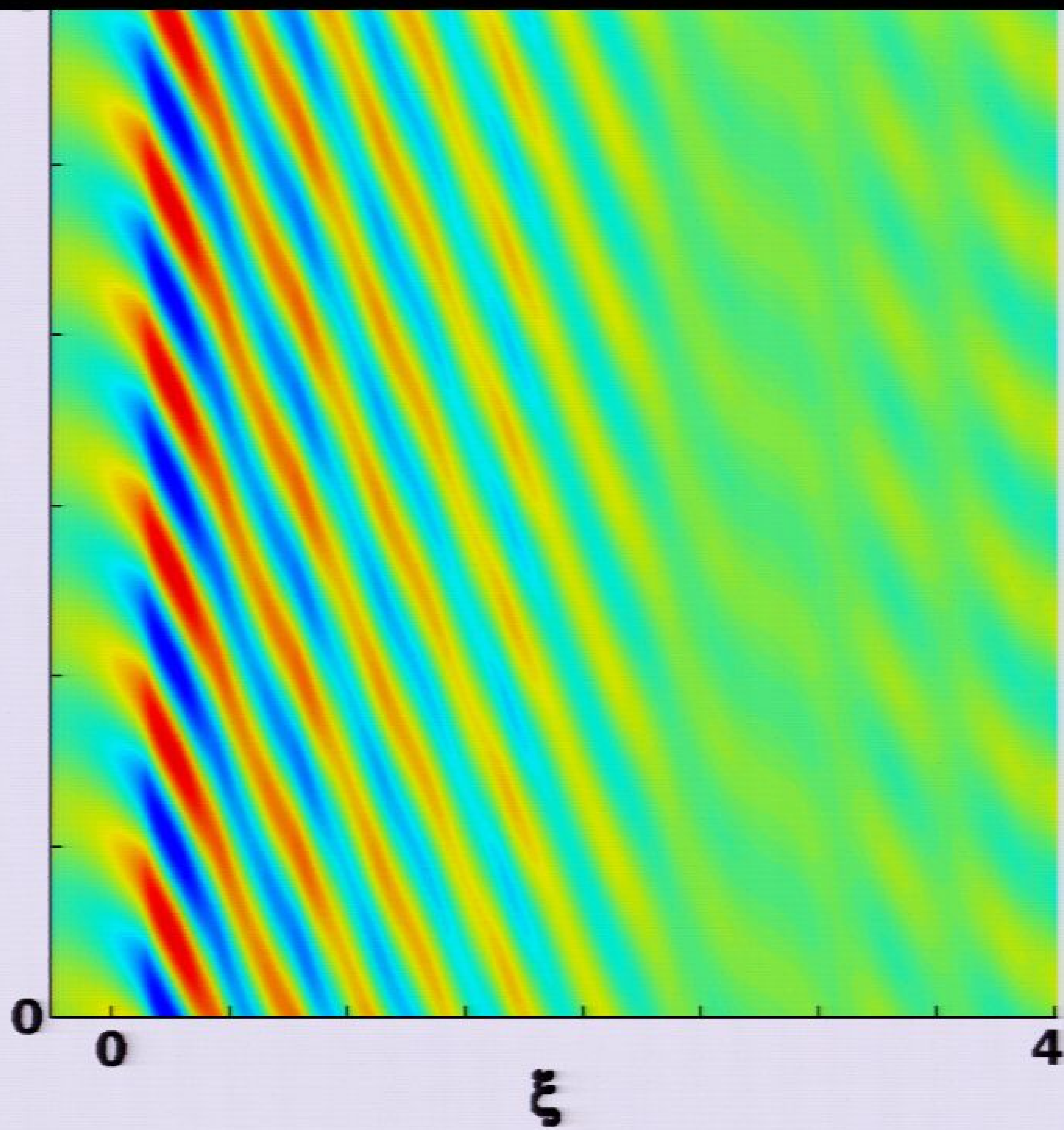
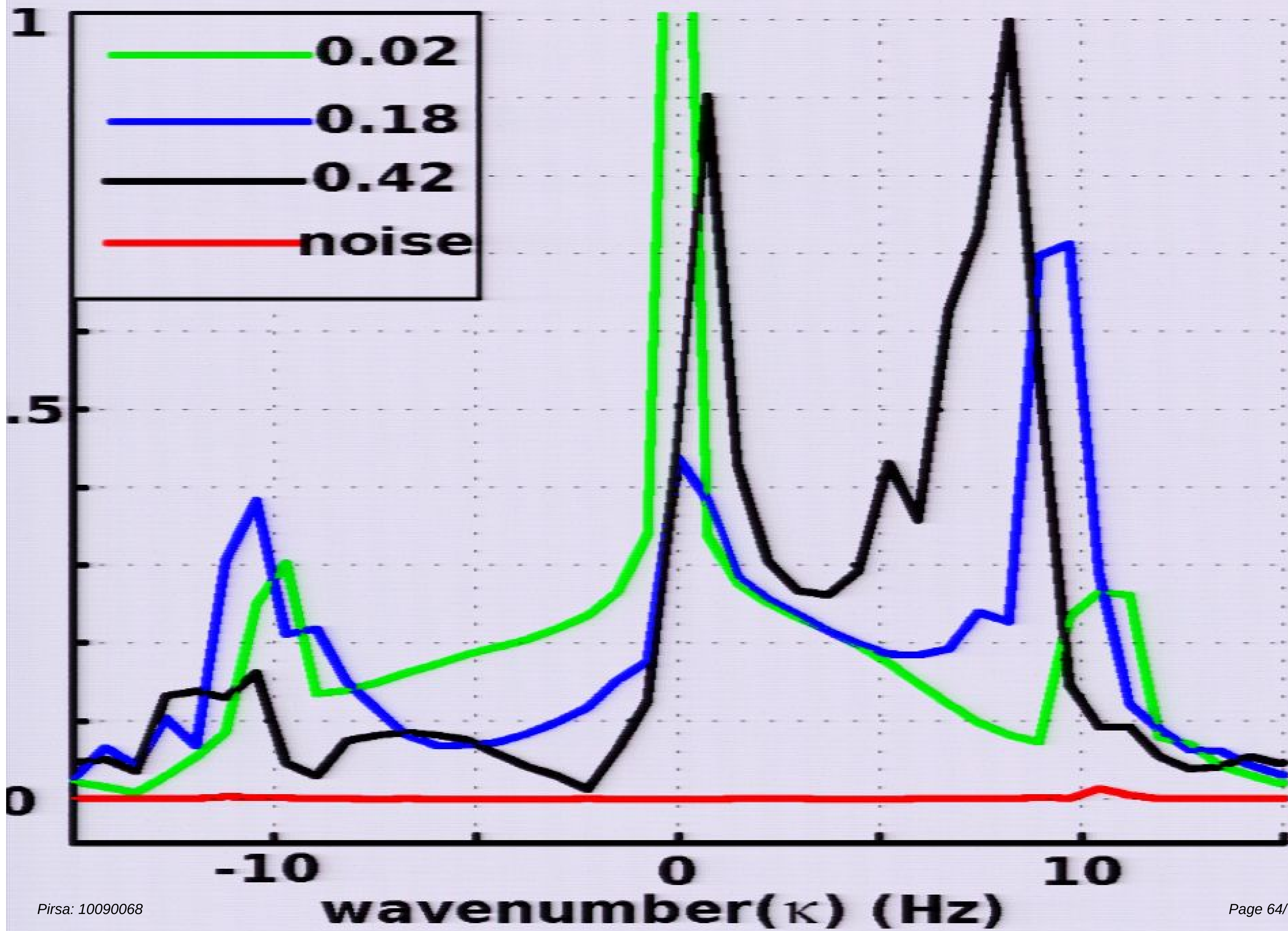
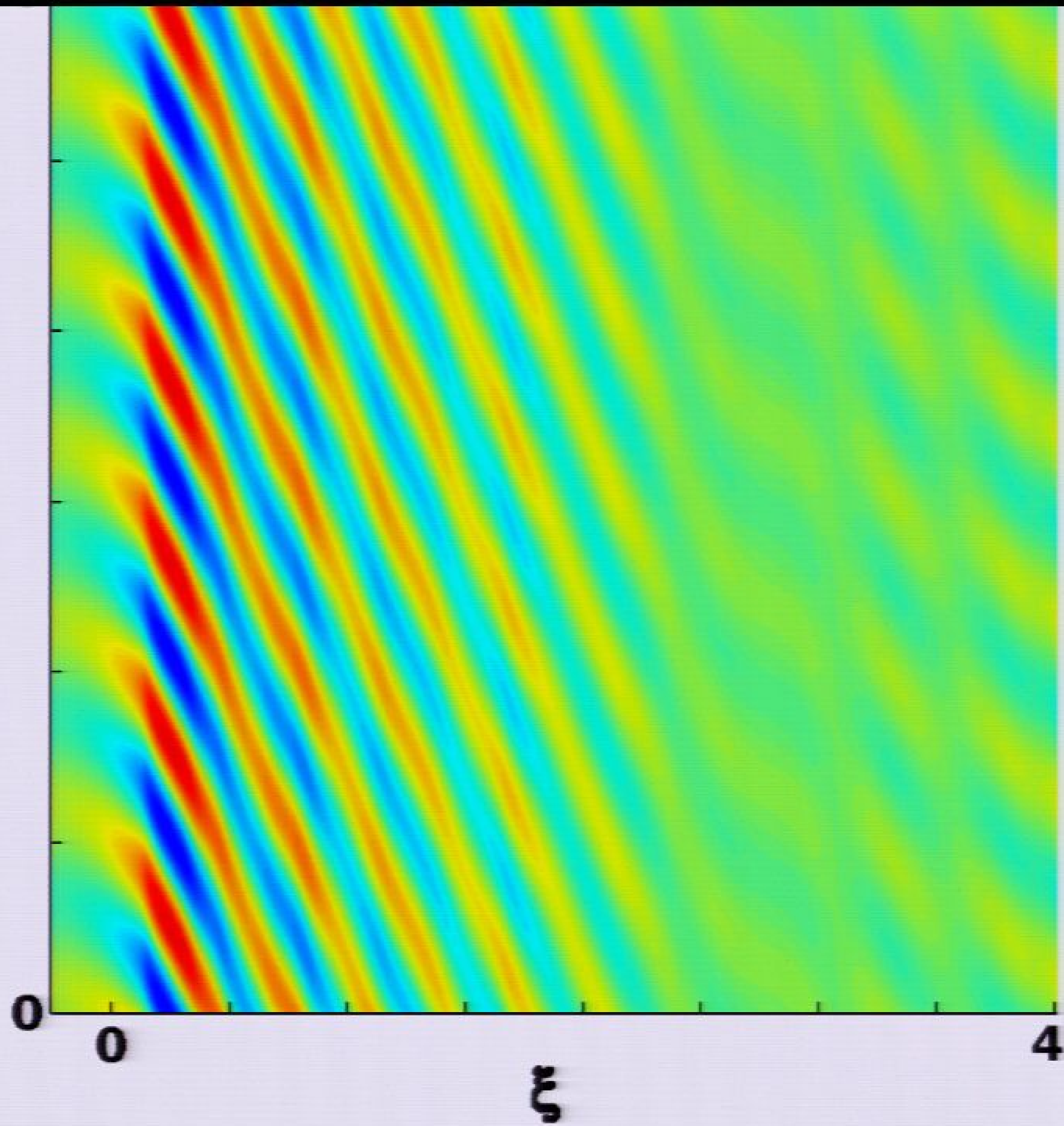
0
10
wavenumber(κ) (Hz)

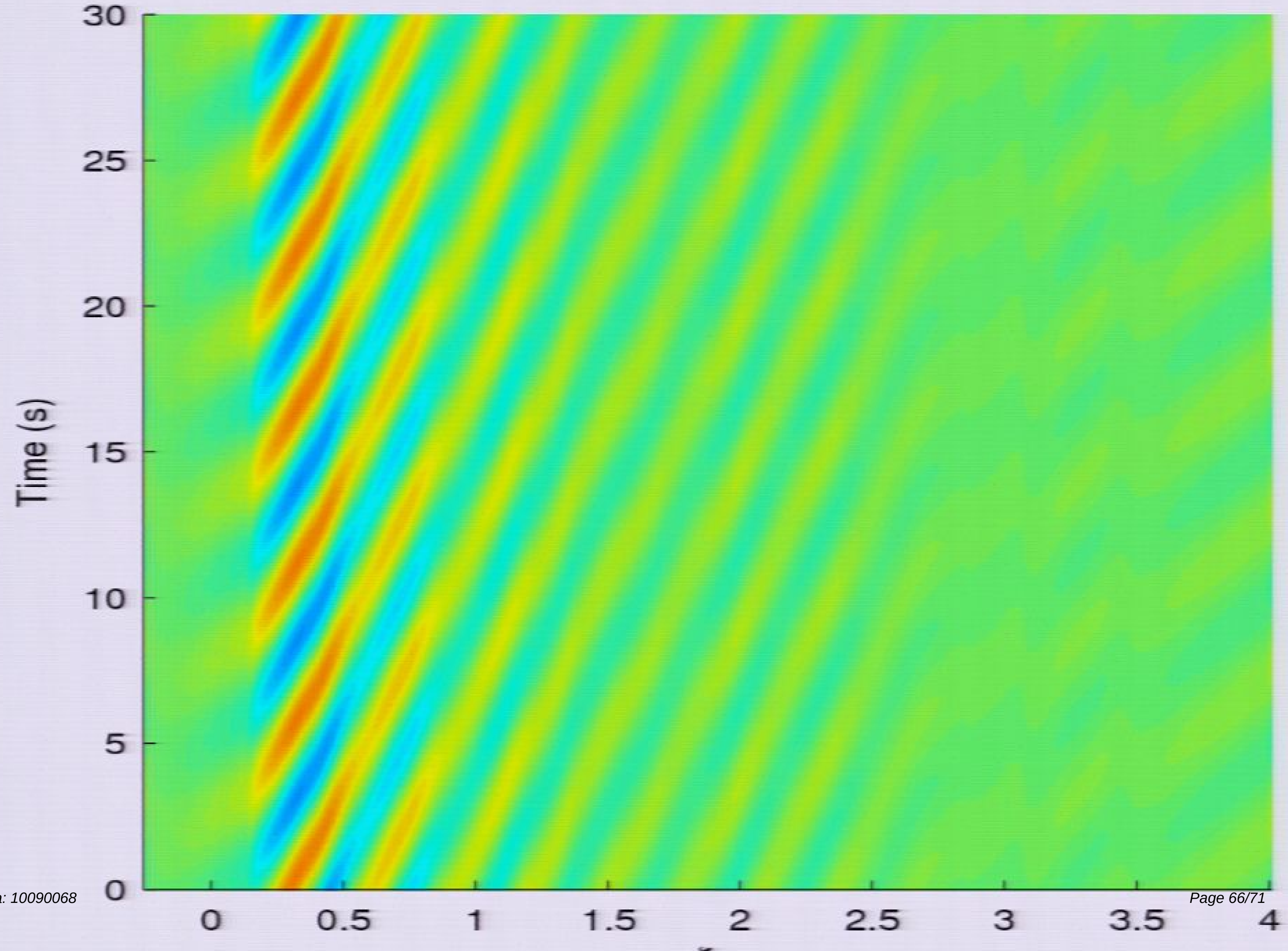

.20
.18
.16
0.6
0.4
0.2
-20
-10
0
10
20
(mm)
wavenumber (Hz)

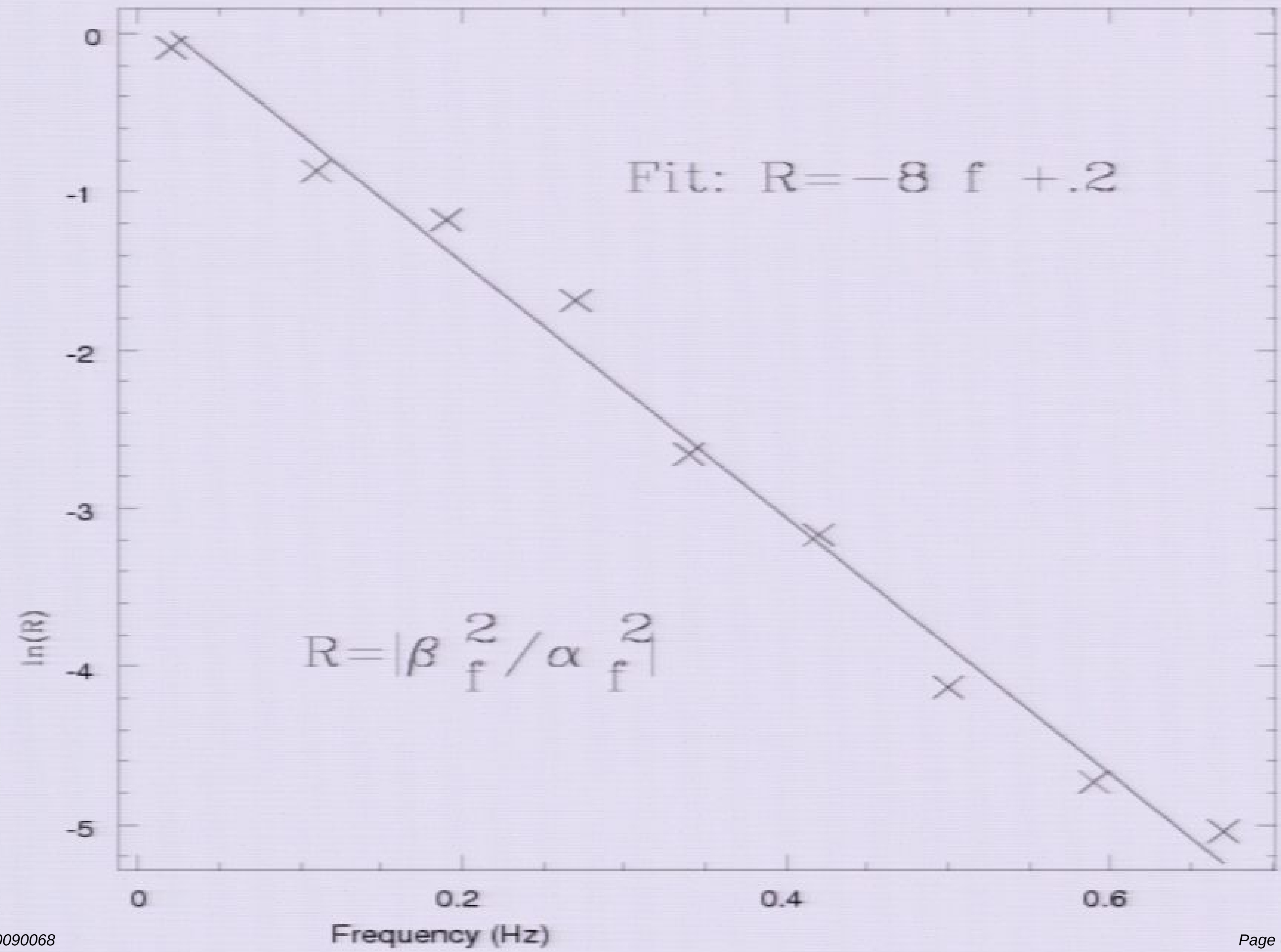

0.02
0.18
0.42
noise
1
.5
0
-10
0
10
wavenumber(κ) (Hz)

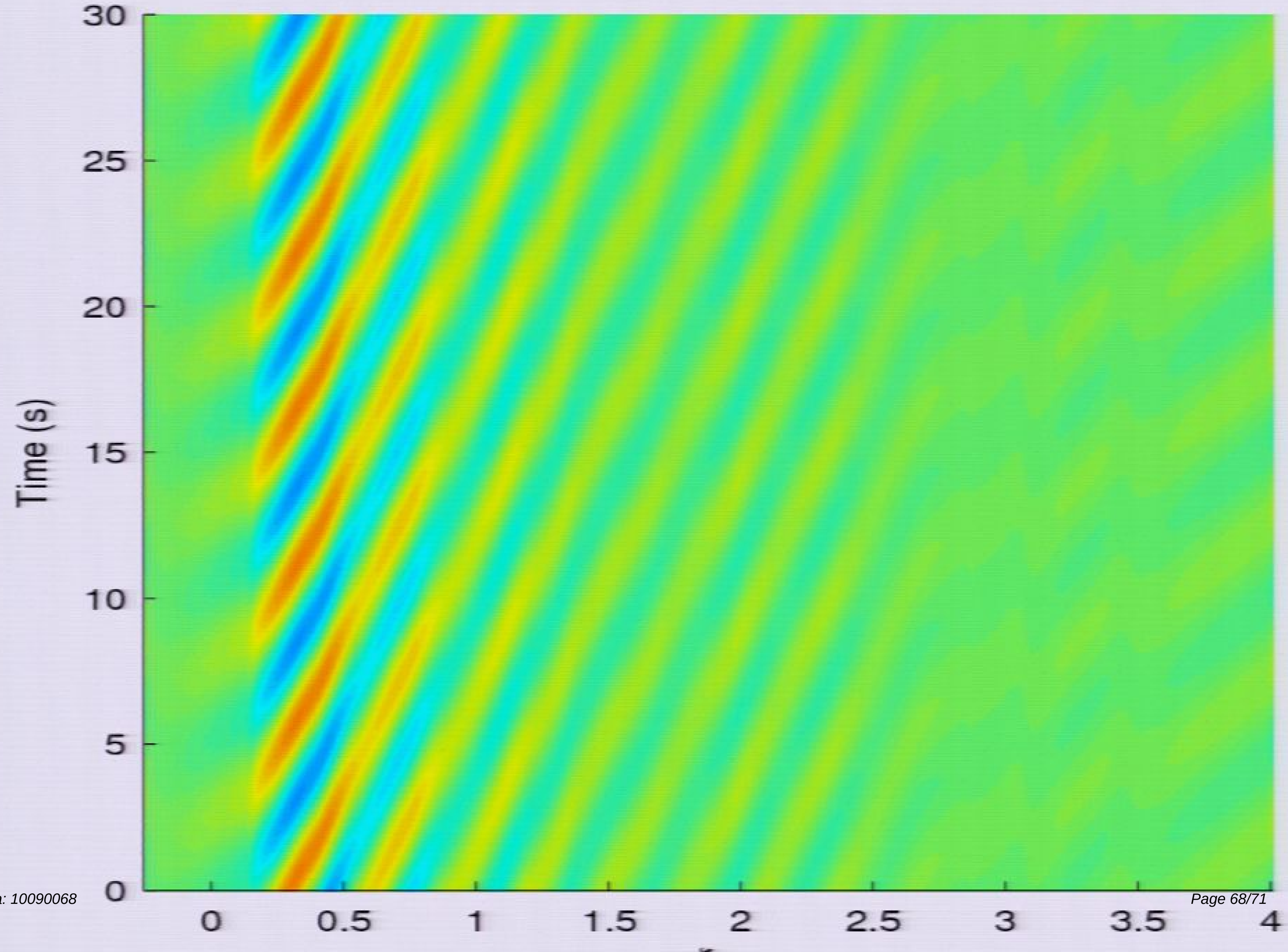

0
0
4
ξ

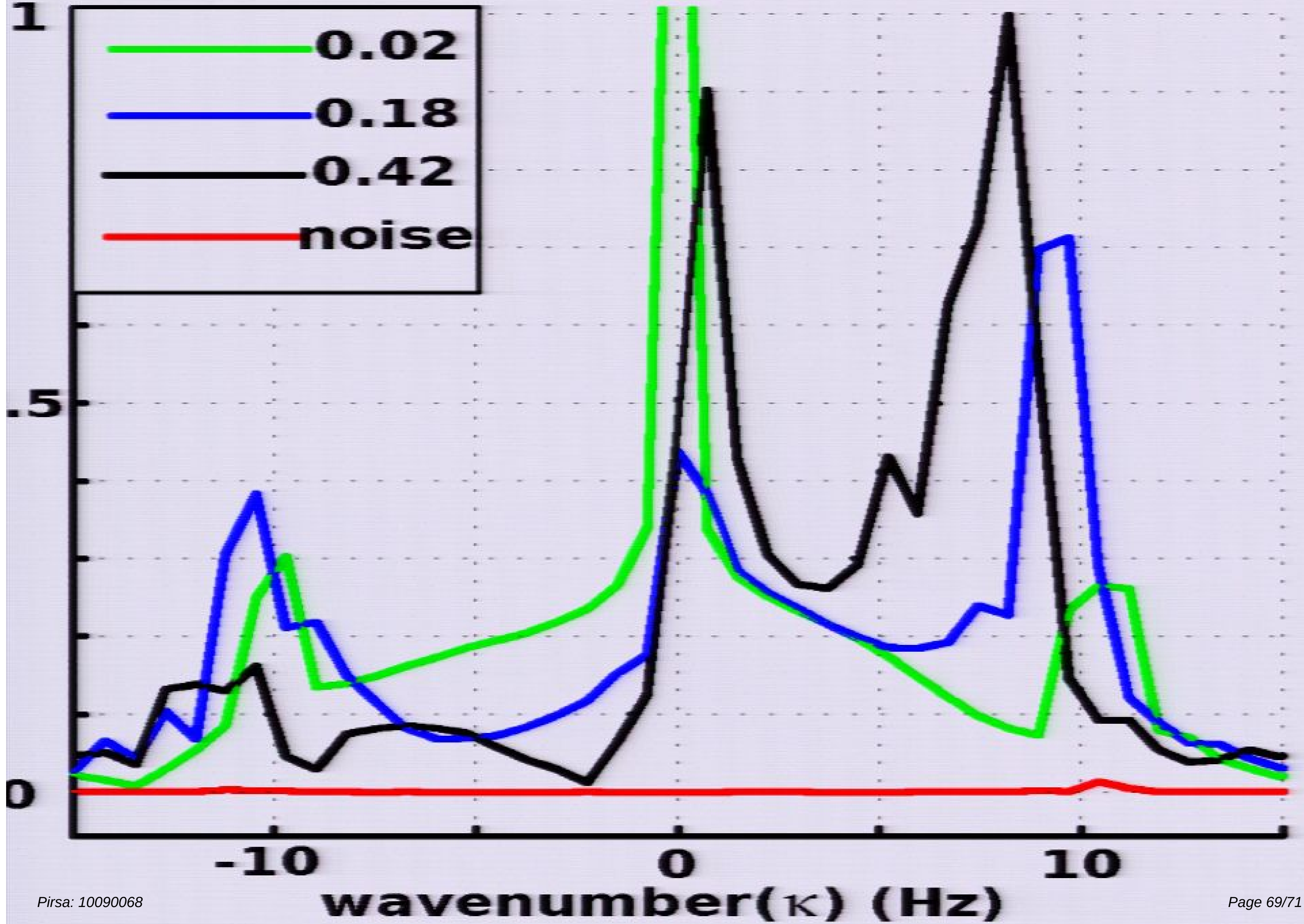

1
.5
0
0.02
0.18
0.42
noise
-10
0
10
wavenumber(κ) (Hz)


0
0
4
ξ

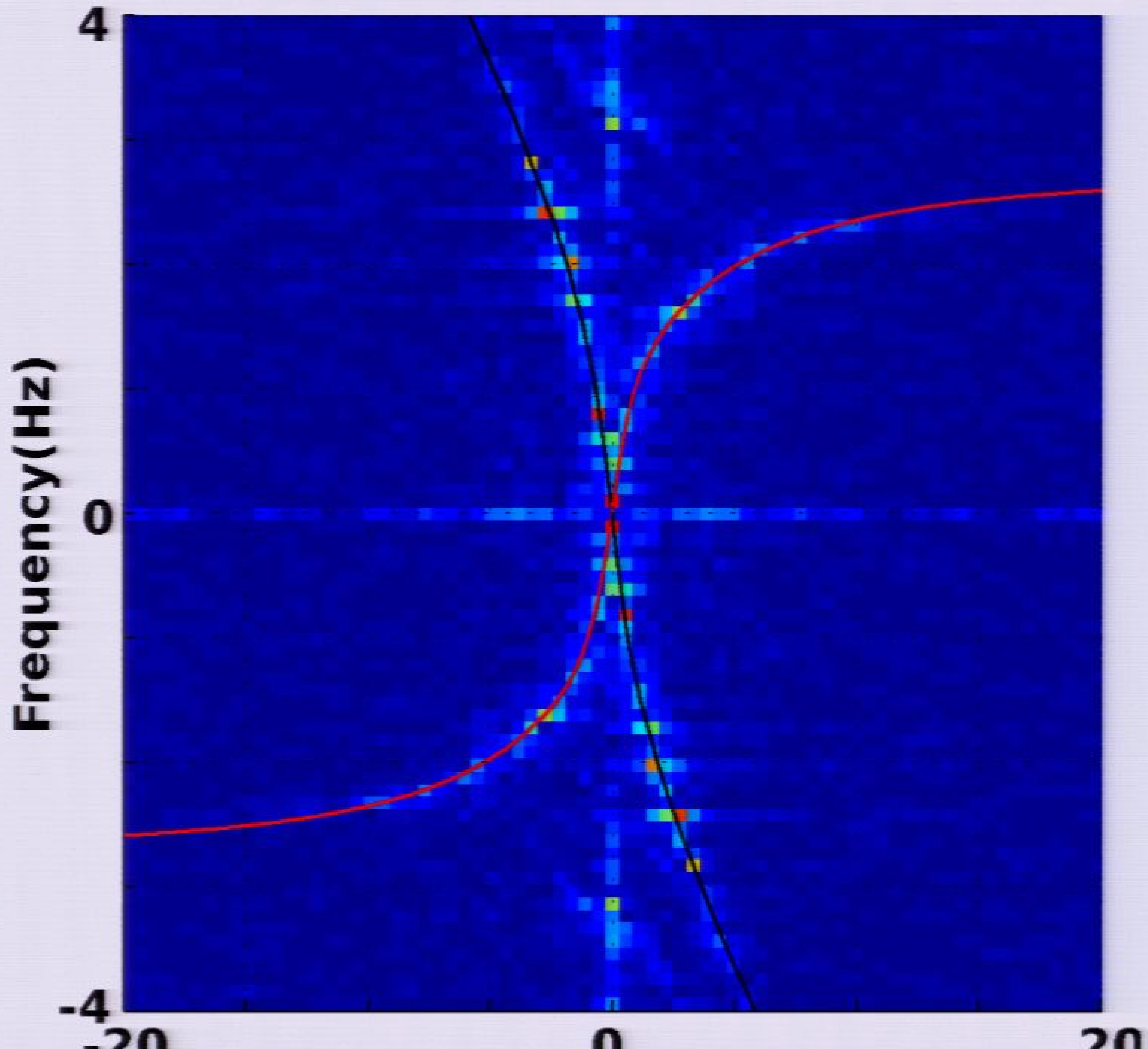

Time (s)
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4

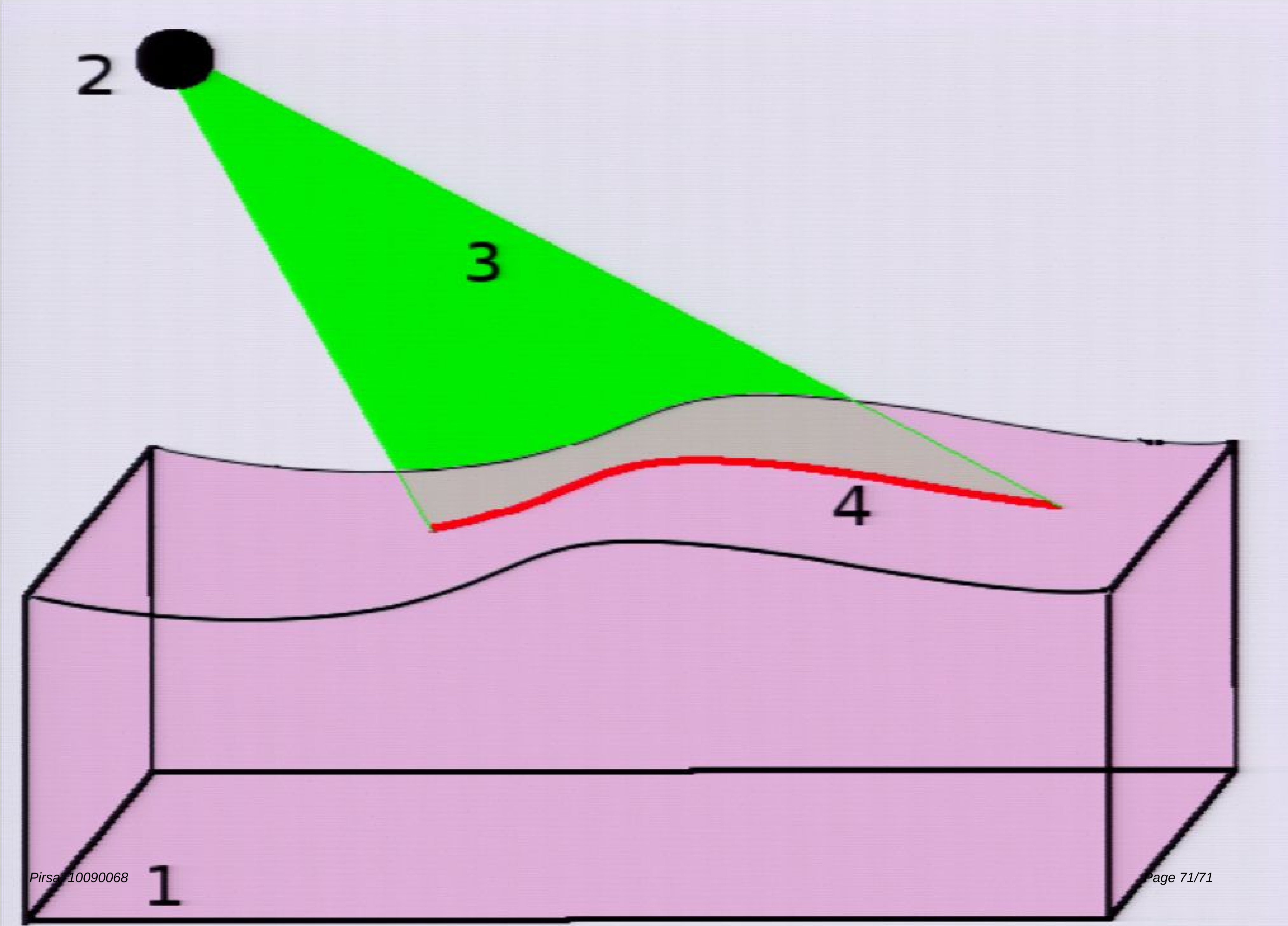

Fit: R=−8 f +.2
R=|β f 2/α f 2|
ln(R)
Frequency (Hz)
0
-1
-2
-3
-4
-5
0
0.2
0.4
0.6


Time (s)
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4



0.02
0.18
0.42
noise
1
.5
0
-10
0
10
wavenumber(κ) (Hz)


4
Frequency(Hz)
0
-4
-20
0
20


2
3
4
1