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Black hole physics in the laboratory

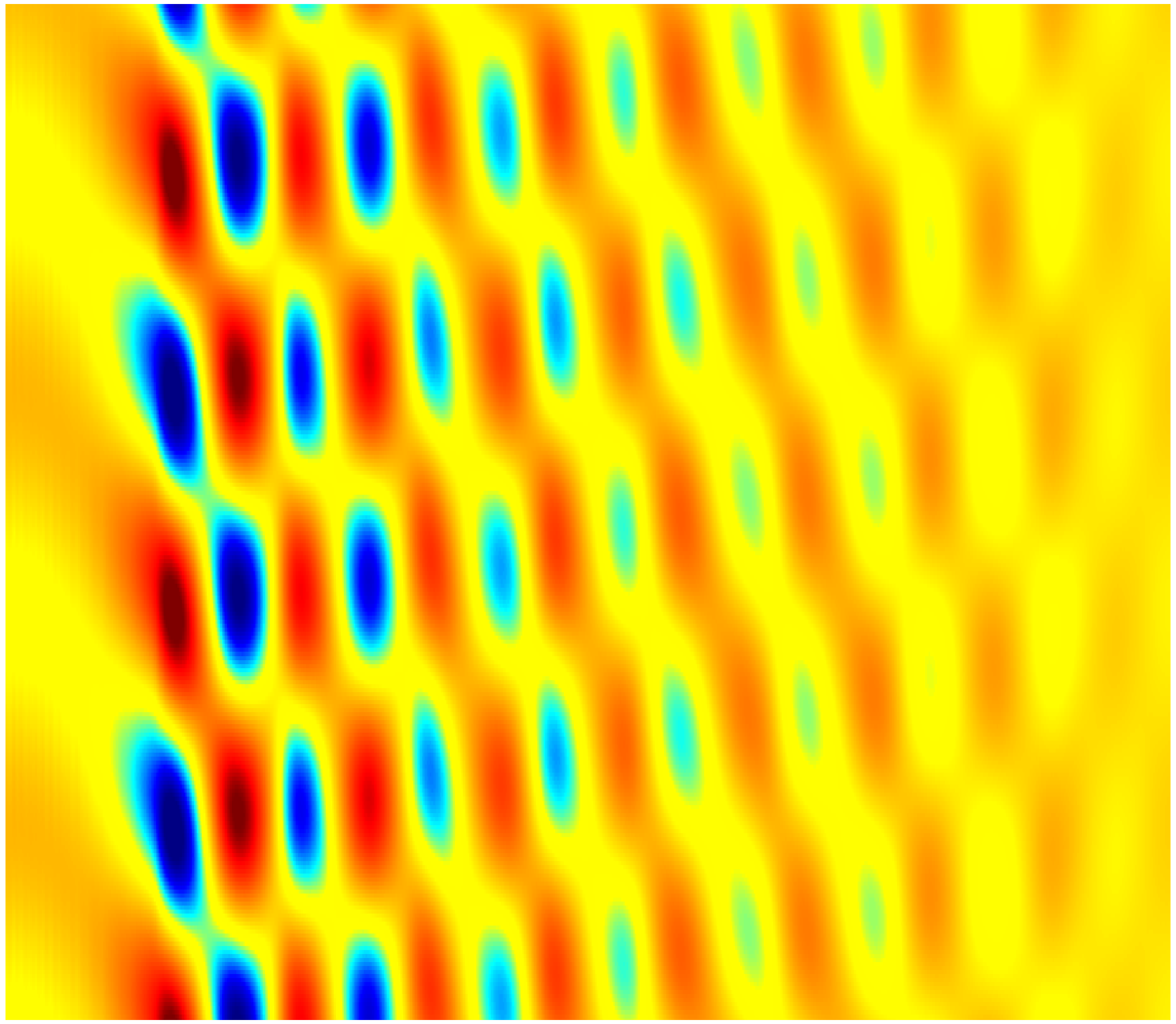
UBC

- Greg Lawrence
- Matt Penrice
- Ted Tedford
- Bill Unruh

Silke Weinfurtner

MARIE CURIE ACTIONS

SISSA



General idea behind my line of research

General idea is...

to test various aspects of quantum gravity in table-top experiments

some aspects/ideas of/for quantum gravity that are otherwise hard to impossible to access observationally/experimentally

...using
* fluids and superfluids
* condensed matter systems
* quantum information

in **theoretical**, NUMERICAL & **experimental** studies.

semi-classical & quantum gravity

classical and quantum field theory in curved spacetimes

- super-radiant scattering from rotating black holes
  ongoing experiment at SISSA
- **black-hole radiation**
  experiment carried out at UBC
- cosmological particle production
  ongoing theoretical studies
  future experiments...

discrete gravity & effective field theories

- emergence of a smooth geometry as an ensemble average over discrete geometries (analogue CDT)
  ongoing theoretical studies

...and to apply quantum gravity studies to other branches of physics

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Semi-classical gravity ➤ (Q)FT in curved spaces

Gravitational field is classical and **back-reaction** of the quantum processes onto the classical gravitational field are **negligible**.

Simple example:

(i) waves propagating on **flat** spacetime (massless minimally coupled Klein-Gordon scalar field):

$$\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\psi = \nabla^2\psi \quad \text{equivalently to} \quad \partial_a\left(\sqrt{-\eta}\,\eta^{ab}\partial_b\,\psi\right) = 0 \quad \text{where} \quad \eta_{ab} = \begin{bmatrix} -c^2 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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$$\downarrow$$

(ii) "minimal substitution" **curved** spacetime :

$$\partial_a\left(\sqrt{-g}\,g^{ab}\partial_b\,\psi\right) = 0 \quad \text{where} \quad g_{ab} = \begin{bmatrix} g_{00}(\mathbf{x},t) & g_{01}(\mathbf{x},t) & g_{02}(\mathbf{x},t) & g_{03}(\mathbf{x},t) \\ g_{01}(\mathbf{x},t) & g_{11}(\mathbf{x},t) & g_{12}(\mathbf{x},t) & g_{13}(\mathbf{x},t) \\ g_{02}(\mathbf{x},t) & g_{12}(\mathbf{x},t) & g_{22}(\mathbf{x},t) & g_{23}(\mathbf{x},t) \\ g_{03}(\mathbf{x},t) & g_{13}(\mathbf{x},t) & g_{23}(\mathbf{x},t) & g_{33}(\mathbf{x},t) \end{bmatrix}$$

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(iii) quantized Klein-Gordon scalar on generally curved-spacetime:

$$\partial_a\left(\sqrt{-g}\,g^{ab}\partial_b\,\hat{\psi}\right) = 0 \quad \text{where} \quad G_{ab}(g_{ab},\Lambda) \cancel{=} 8\pi G_{\mathrm{N}}\,\langle\hat{T}_{ab}\rangle$$

QFT in CS ➤ Analogue/Effective Gravity

Analogue gravity systems:
The <u>equations of motion for linear perturbations</u> in an analogue/effective/emergent gravity system can be simplified to

$$\frac{1}{\sqrt{-g}}\,\partial_a\left(\sqrt{-g}\,g^{ab}\partial_b\psi\right)=0$$

defining an effective/acoustic/emergent metric tensor:

$$g_{ab}\propto\begin{bmatrix} -\left(c^2(\mathbf{x},t)-v^2(\mathbf{x},t)\right) & -\vec{v}^{\,T}(\mathbf{x},t)\\ -\vec{v}(\mathbf{x},t) & \mathbf{I}_{d\times d}\end{bmatrix}$$

<u>Where do we expect such a behavior?</u>

Broad class of systems with various dynamical equations, e.g. electromagnetic waveguide, fluids, ulatra-cold gas of Bosons and Fermions.

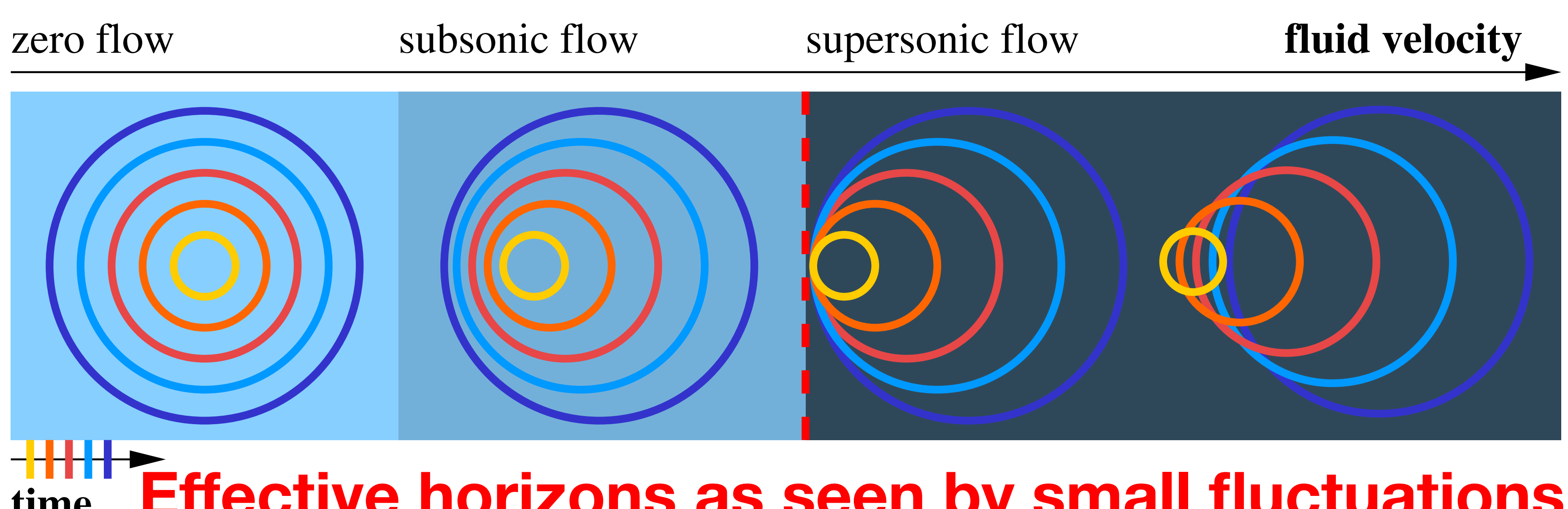
In example below: Fluid dynamics derived from conservation laws:

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho\,\mathbf{v})=0 \qquad \textit{Continuity equation}$$

$$\rho\frac{D\mathbf{v}}{Dt}=-\nabla p \qquad \textit{Euler equation}$$

<u>Simple example:</u>

Small fluctuations in **inviscid**, **irrotational**, **incompressible** fluid flow



Effective horizons as seen by small fluctuations

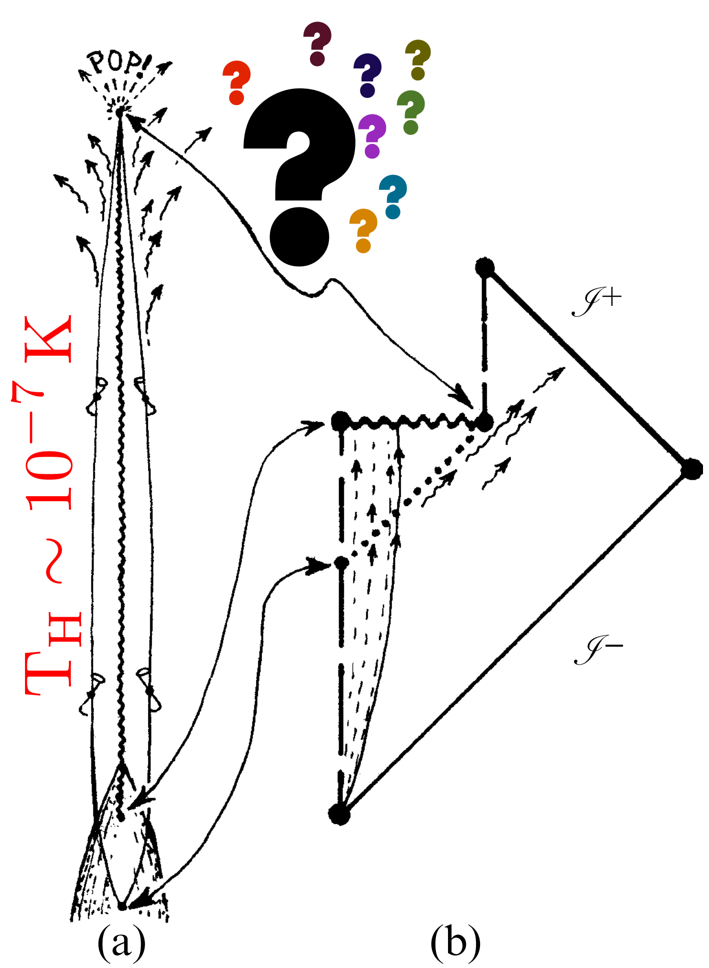
Analogue Gravity ➤ Applications

Let us first put aside the issue of classical versus quantum field theory in curved spacetimes...

1981: **Experimental black hole evaporation?** W.G. Unruh

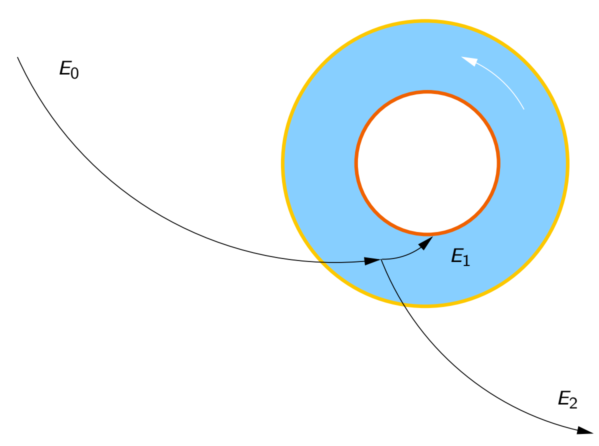
Possibility for experimental verification of the <u>generality</u> (UV-independence) of effects predicted within quantum field theory in curved spacetimes!

Analogy Gravity: Strong model dependent deviations and eventual break-down at 'small' scales expected!



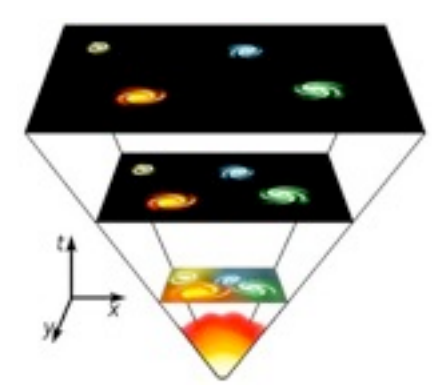
Example 1:

Experimental Black Hole Evaporation



Example 2:

Superradiant scattering from rotating black holes

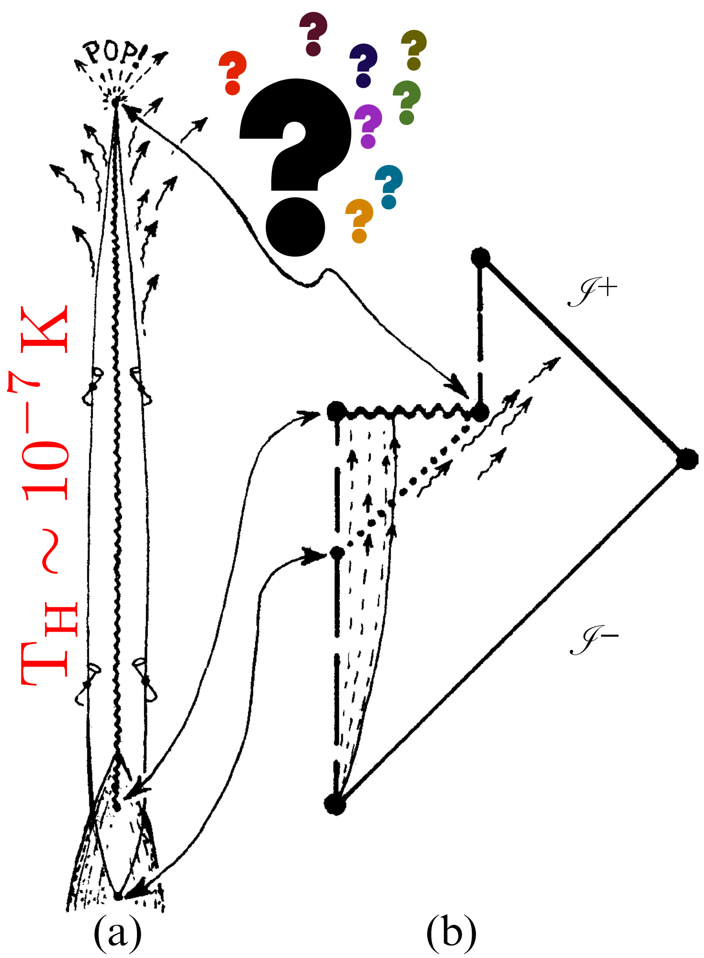


Example 3:

Cosmological particle production

Experimental Black Hole Evaporation [**Example 1**]

How do black holes lose their mass..?



Example 1:

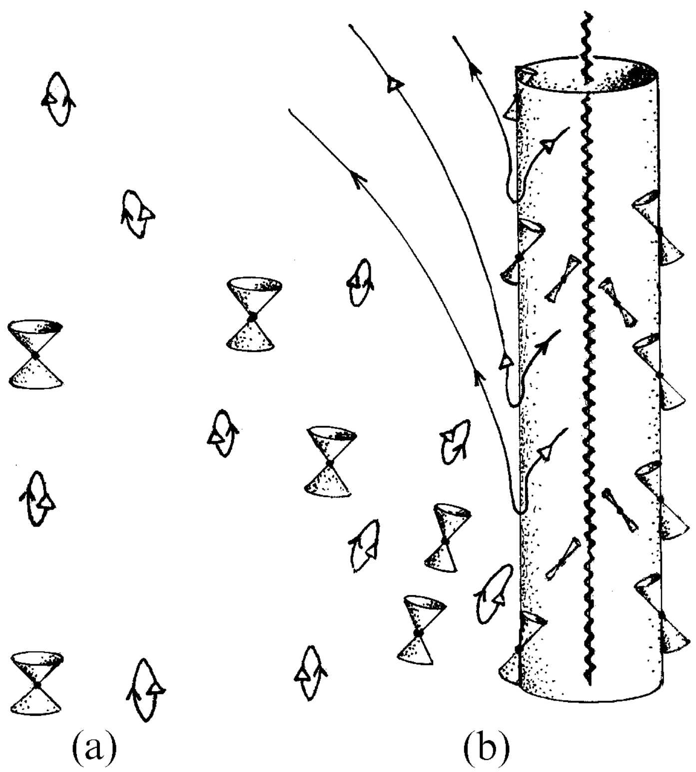
Experimental Black Hole Evaporation

(1) What is Hawking radiation?

(2) Is there a reason why we should at all doubt that black holes evaporate..?

(3) How can we set up a table-top experiment that “conclusively” tests Hawking/Unruh’s prediction?

BHE process ➤ What is Hawking radiation?

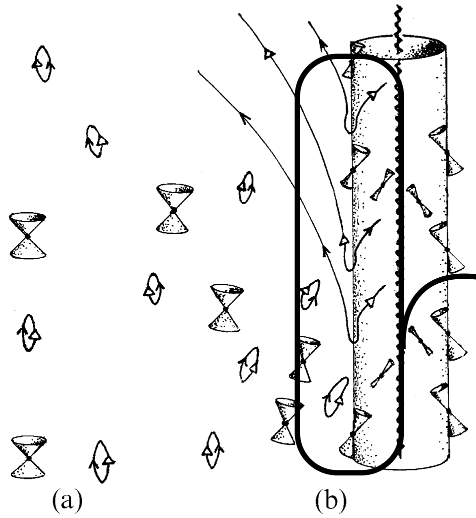


Pair-creation:
Separation of particle-anti-particle pairs from the quantum vacuum;
Negative norm modes absorbed by black hole;
[Particle Creation by Black Holes, by Stephen Hawking, in 1974]

$$\phi_\omega^{\mathbf{in}} = \alpha_+^{\mathbf{out}} + \beta_-^{\mathbf{out}}$$

Let's try to understand Hawking radiation as a simple scattering process...

BHE process ➤ What is Hawking radiation?



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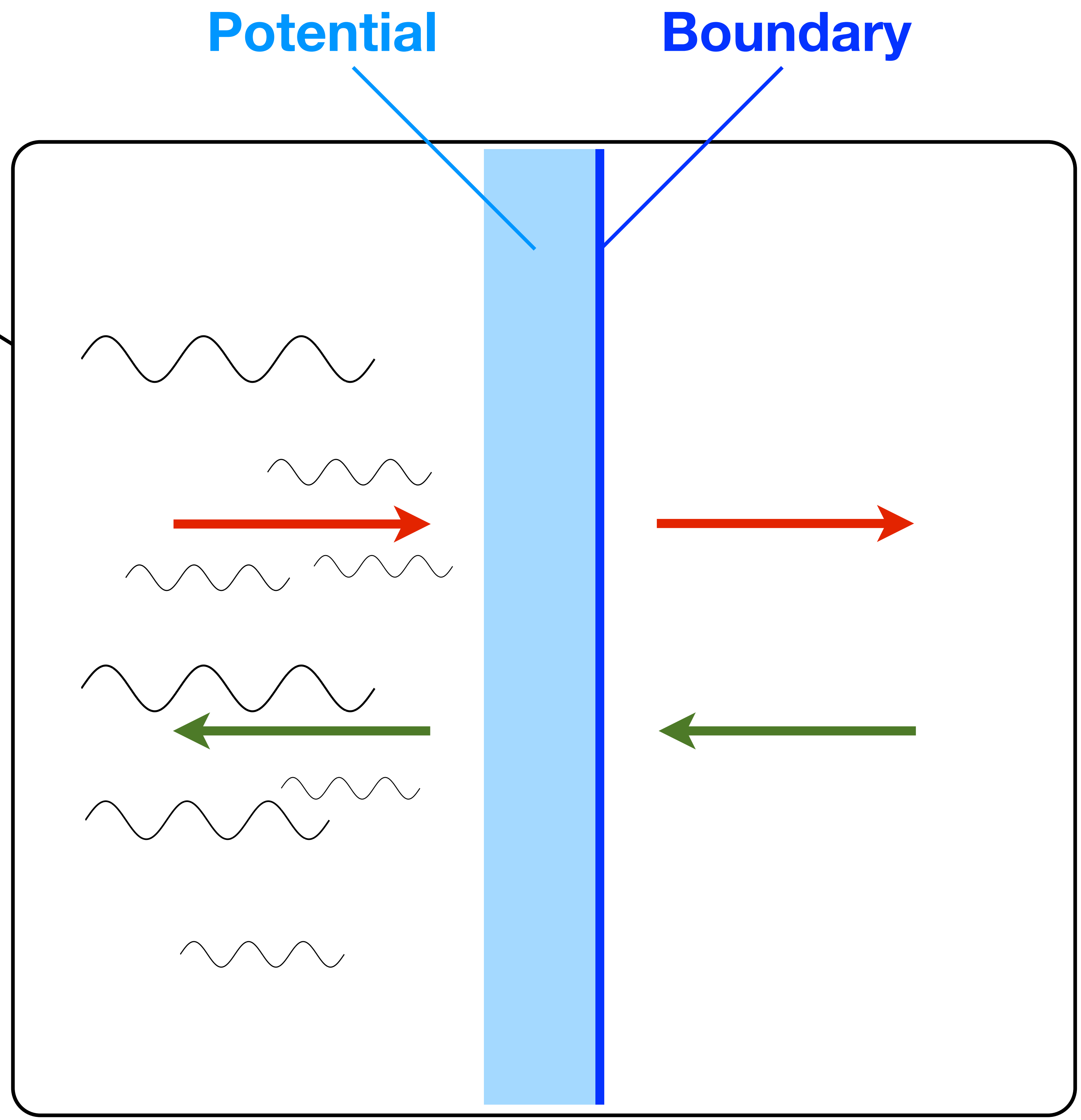
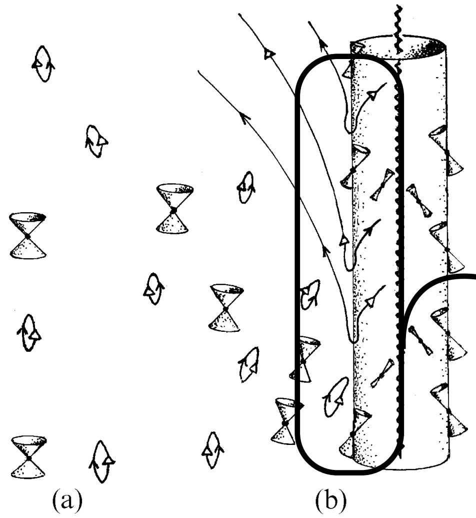


Right moving modes

Left moving modes

BHE process ➤ What is Hawking radiation?



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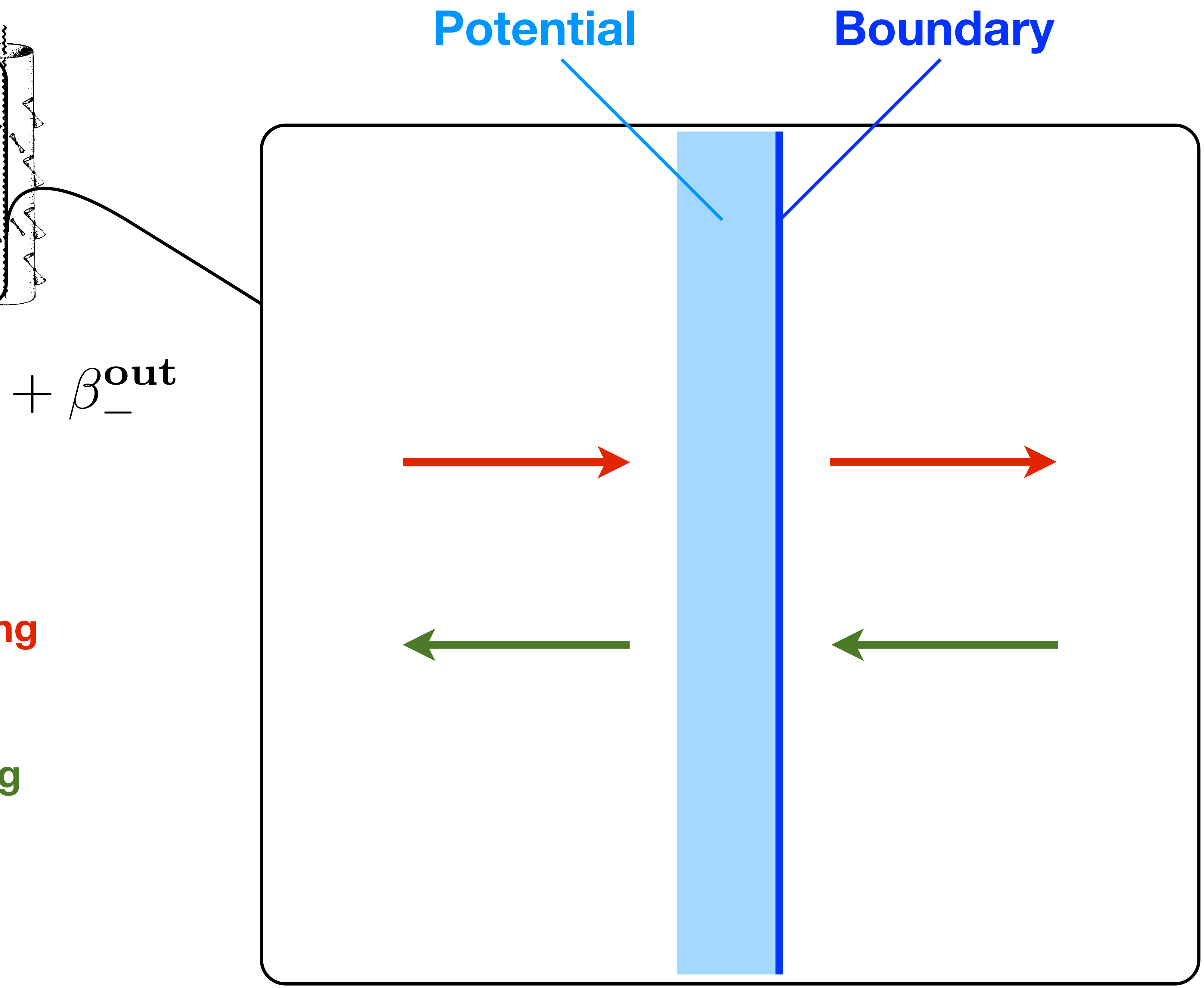

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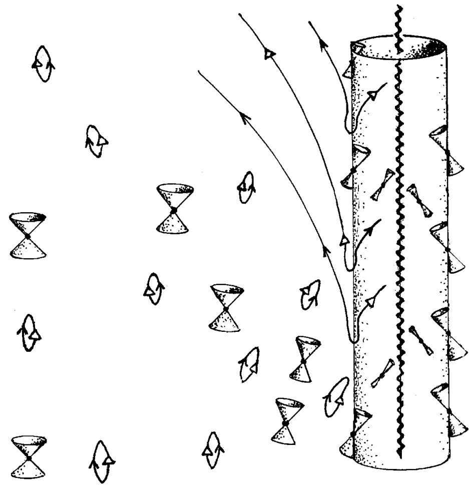

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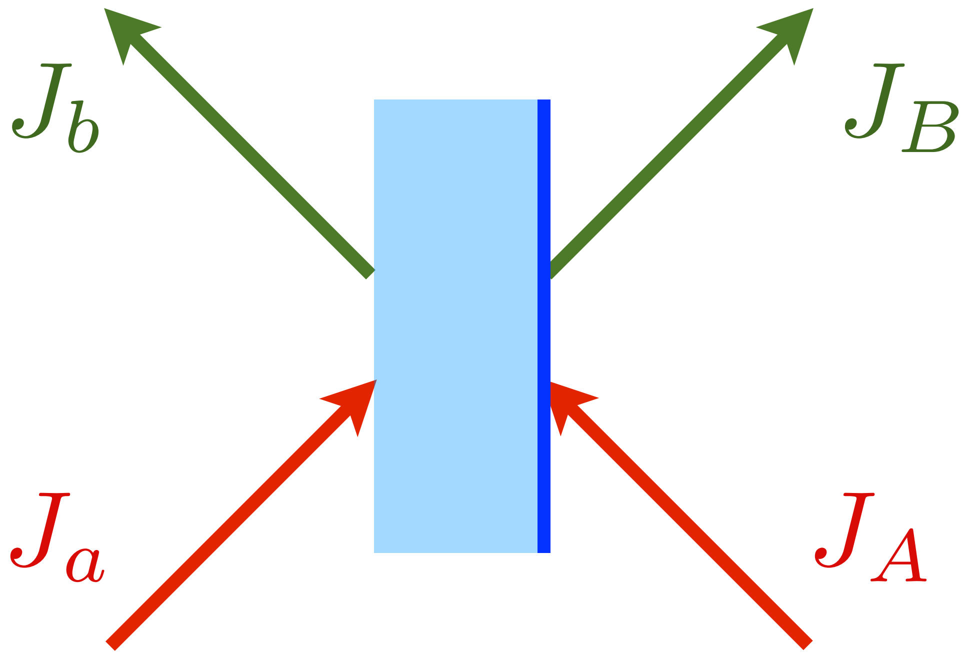
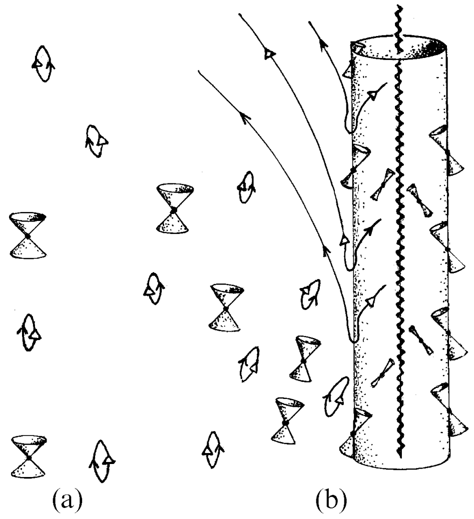
Modes moving into potential

Modes moving out of potential



$$J_a + J_A = J_b + J_B$$

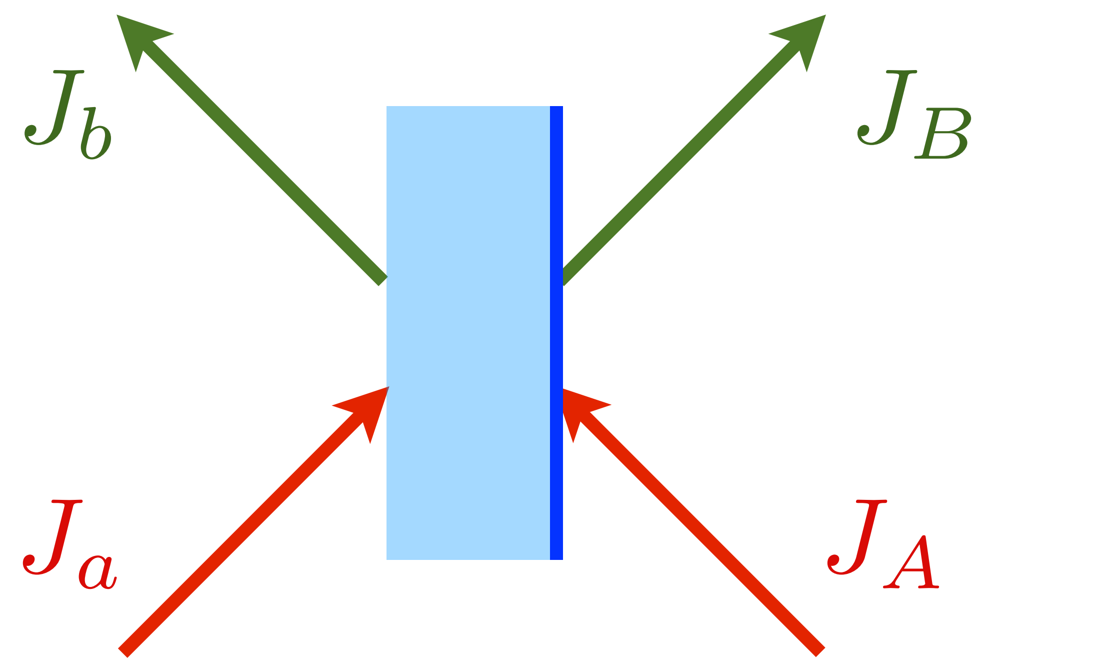
BHE process ➤ What is Hawking radiation?



$$\phi_\omega^{\mathbf{in}} = \alpha_+^{\mathbf{out}} + \beta_-^{\mathbf{out}}$$

Conserved quantity: Particle current:

$$J_n := |A_n|^2 \left.\Omega\right|_{\pm\infty} \left.\frac{d\omega}{dk}\right|_{k_n}$$



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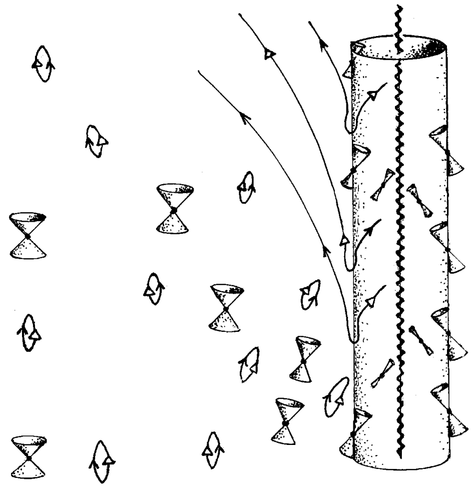
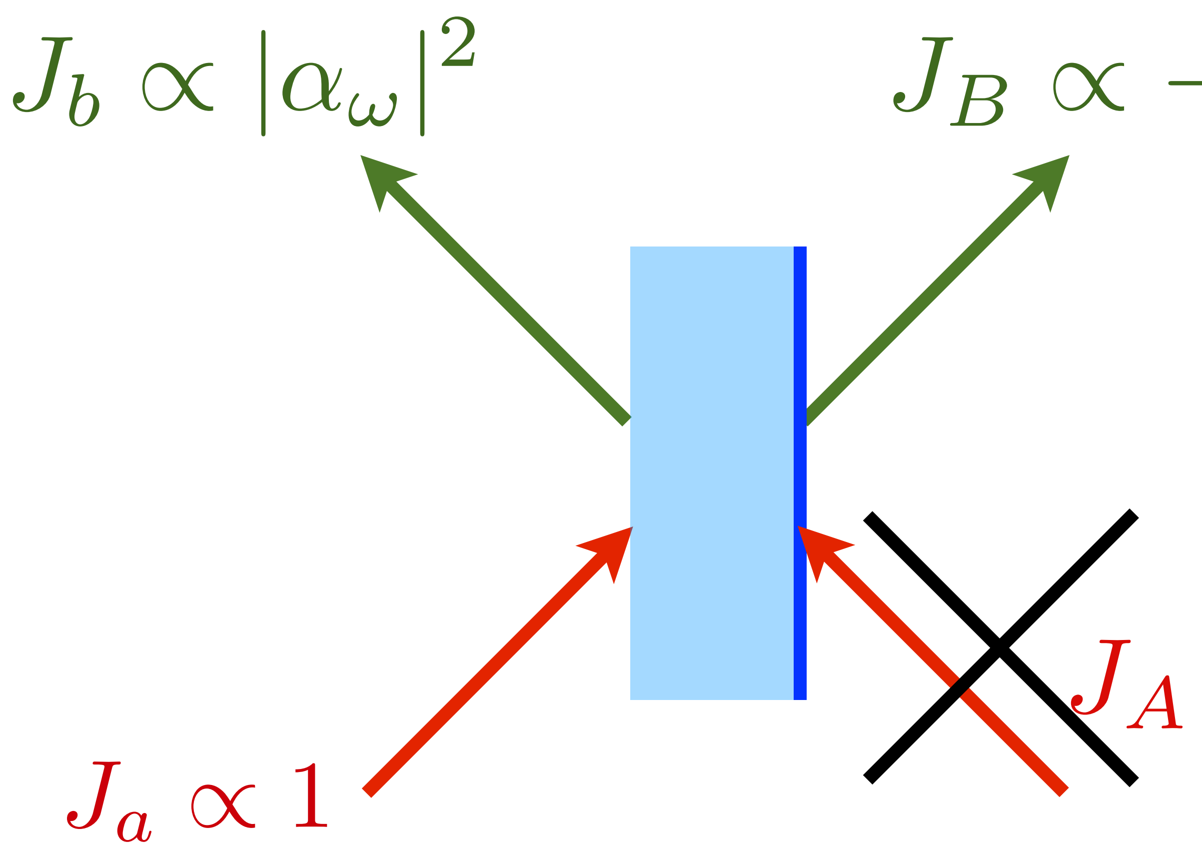
BHE process ➤ What is Hawking radiation?



(a) (b)

$$\phi_\omega^{\mathbf{in}} = \alpha_+^{\mathbf{out}} + \beta_-^{\mathbf{out}}$$

Particle current: $J_n := |A_n|^2 \, \Omega|_{\pm\infty} \left.\frac{d\omega}{dk}\right|_{k_n}$



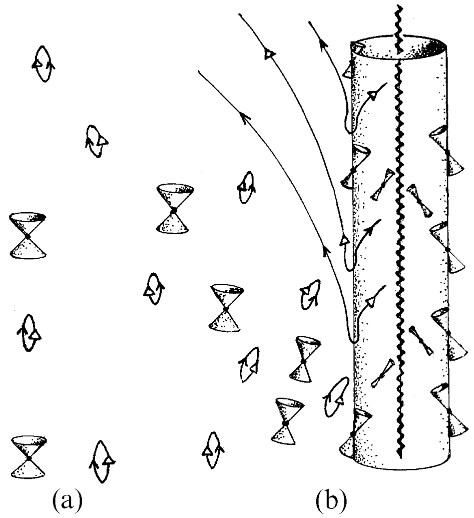
$$1 \quad + \quad 0 \qquad = |\alpha_\omega|^2 + -|\beta_\omega|^2$$

$$\boxed{\frac{|\beta_\omega|^2}{|\alpha_\omega|^2} = e^{-\frac{2\pi\omega}{g_{\mathrm{H}}}} = e^{-\frac{\hbar\,\omega}{k_B \mathbf{T}}}}$$

$$|\alpha_\omega|^2 - |\beta_\omega|^2 = 1$$

Black holes: Linear Classical and Quantum Field Amplifier!

BHE process ➤ What is Hawking radiation?



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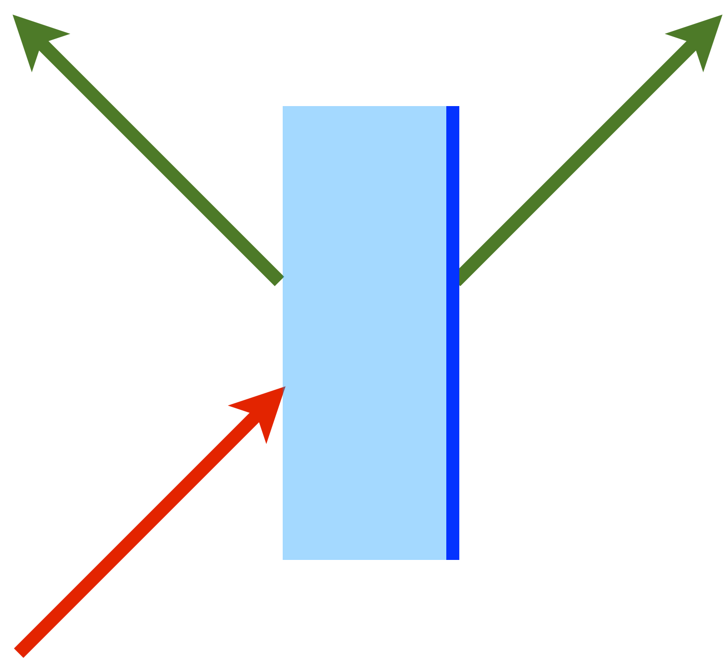
$$\phi_\omega^{\mathbf{in}} = \alpha_+^{\mathbf{out}} + \beta_-^{\mathbf{out}}$$

$$J_b \propto |\alpha_\omega|^2 \qquad J_B \propto -|\beta_\omega|^2$$



$$J_a \propto 1$$

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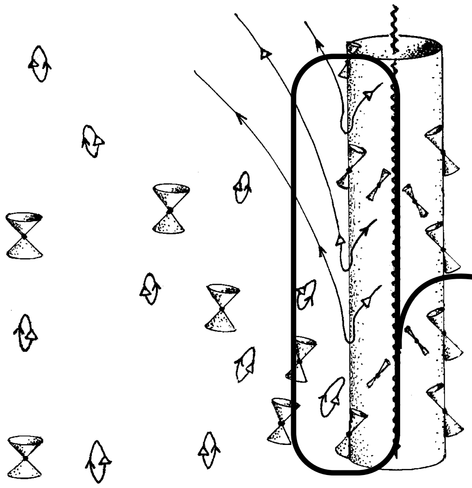
Black holes: Linear Classical and Quantum Field Amplifier!

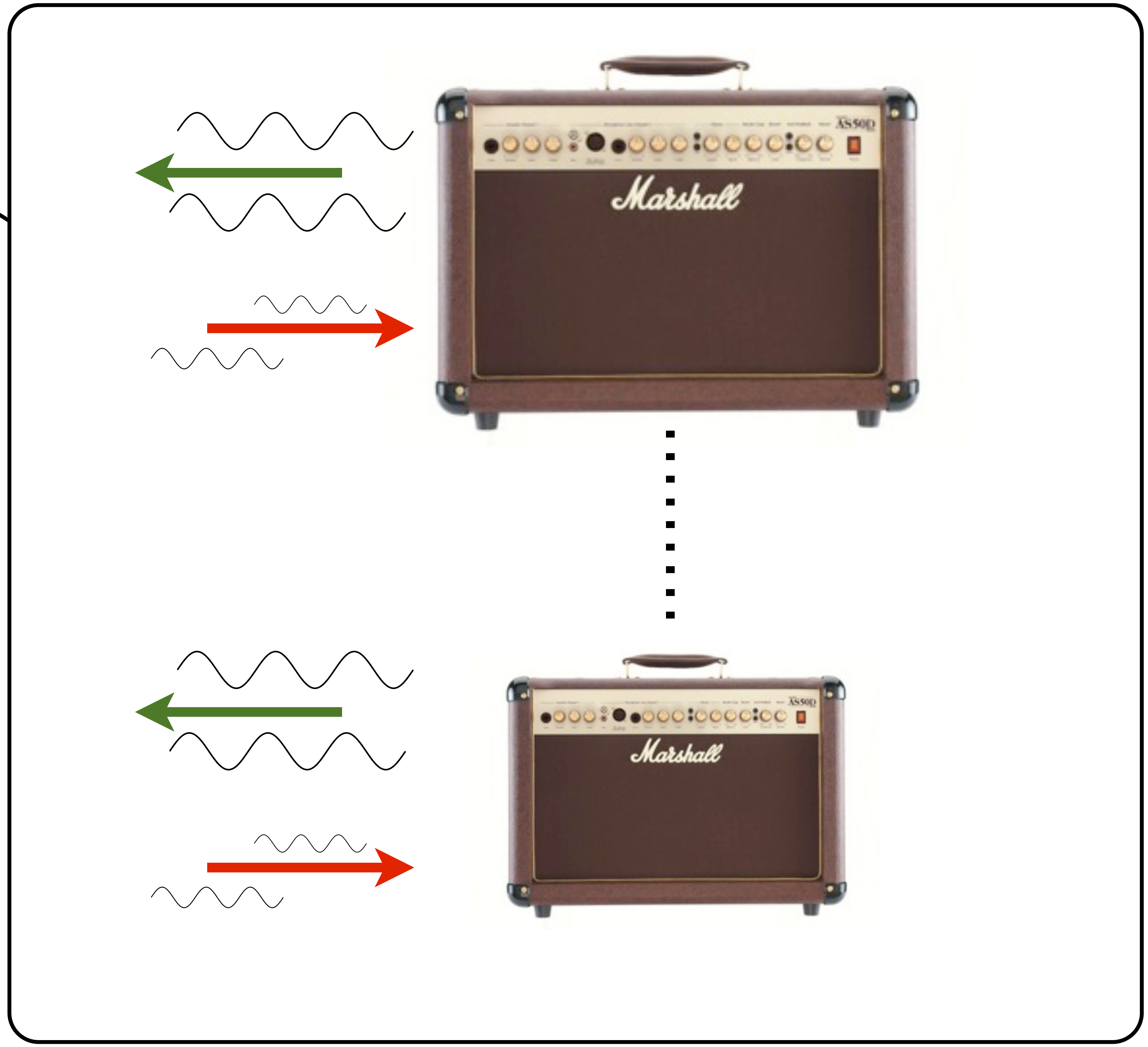
BHE process ➤ What is Hawking radiation?



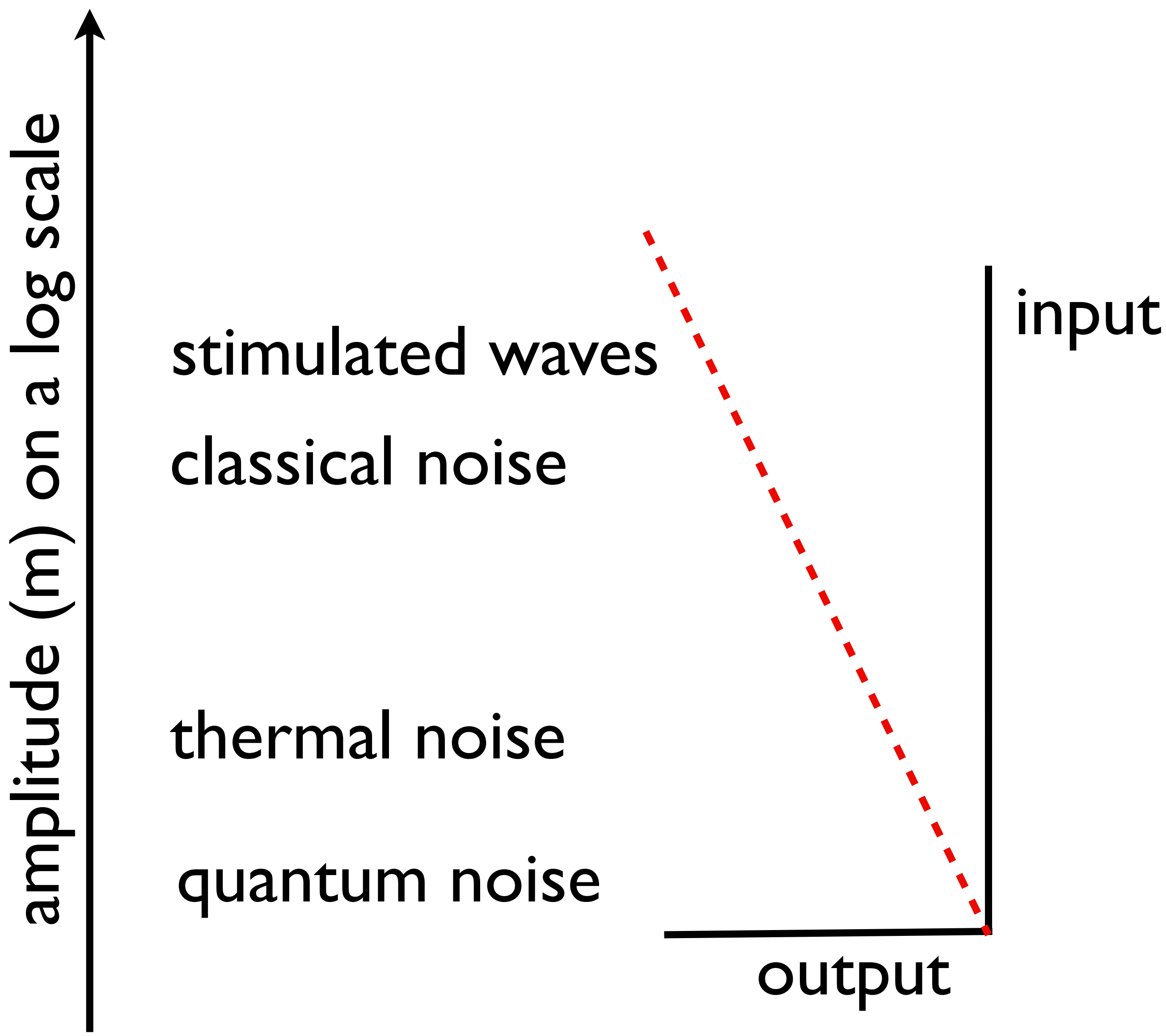
$$\phi^{\mathbf{in}}_{\omega} = \alpha^{\mathbf{out}}_{+} + \beta^{\mathbf{out}}_{-}$$

$$\frac{|\beta_\omega|^2}{|\alpha_\omega|^2} = e^{-\frac{2\pi\omega}{g_{\mathrm{H}}}}$$

- ✔ pair-creation process
- ✔ Boltzmann distribution
- ✔ surface gravity



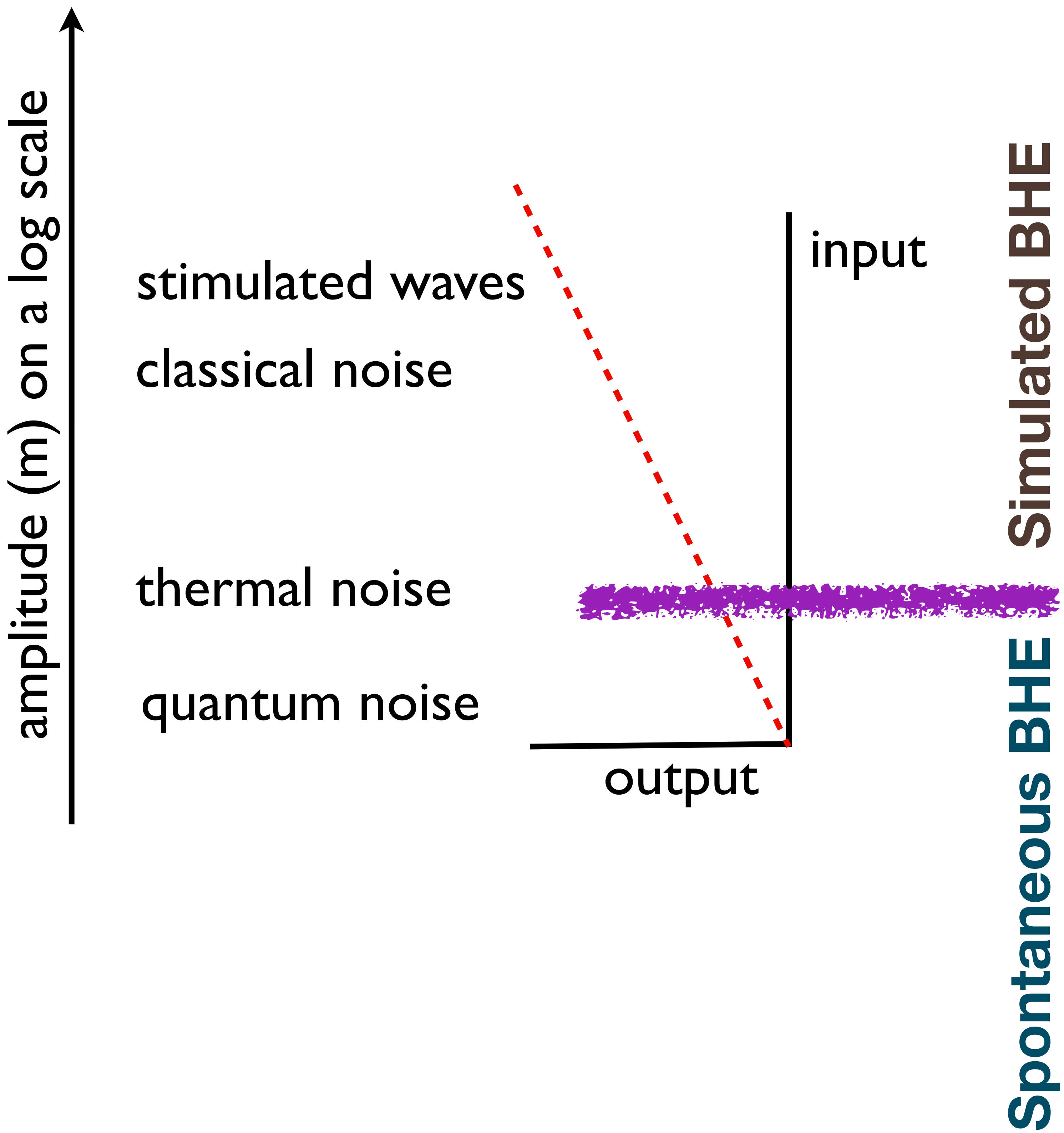
BHE process ➤ What is being amplified?



Assumption:
Linear amplifier over a huge range!

✔ pair-creation process (classical correlations)
✔ Boltzmann distribution
✔ surface gravity

BHE process ➤ What is being amplified?



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✔ quantum correlations

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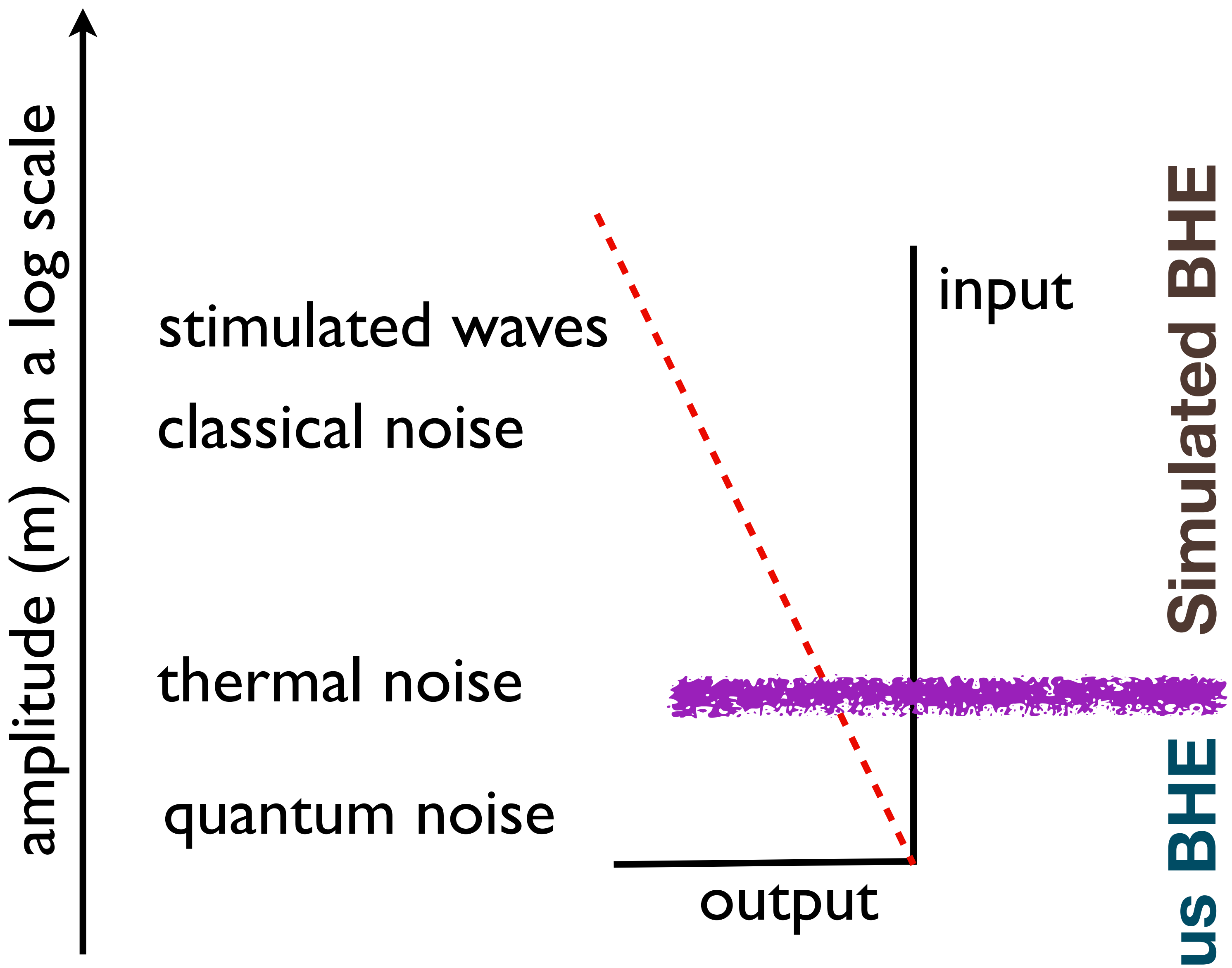


Simulated BHE

Spontaneous BHE

Assumption:
Linear amplifier over a huge range!

- ✔ pair-creation process (classical correlations)
- ✔ Boltzmann distribution
- ✔ surface gravity

- ✔ quantum correlations

why do we care: the UV-**problem**

BHE process ➤ the UV-**problem**

[Wave equation on effective curved spacetime]

Equation of motion for **linear** perturbations in analogue gravity systems:

$$\frac{1}{\sqrt{-g}}\,\partial_a\left(\sqrt{-g}\,g^{ab}\,\partial_b\phi_1\right) = 0$$

1981: Experimental black hole evaporation ? , by Bill Unruh; Vol 46, #21, PRL.

$T_H \sim 10^{-7}\,\mathrm{K}$

UV_problem?

Possibility to test **experimentally** the ***generality*** of the **Hawking process**!

insensitive to particular **'UV'-behaviour of linear perturbations**

robust against model-specific **dynamics**

Scientific goal ➤ conclusive detection of BHE

- Spontaneous versus stimulated emission: Black holes are phase insensitive linear amplifiers...
- Nature of Hawking process: Semi-classical quantum gravity effect, where the Einstein dynamics is not taken into consideration.
- Black versus white hole emission: White holes are the time-reversal of black holes, and the Hawking process applies to both.

Our experiment ➤ Principle idea

2002: Schutzhold & Unruh: Gravity wave analogs of black holes (Phys. Rev. D66 044019)

Our experiment in a nutshell

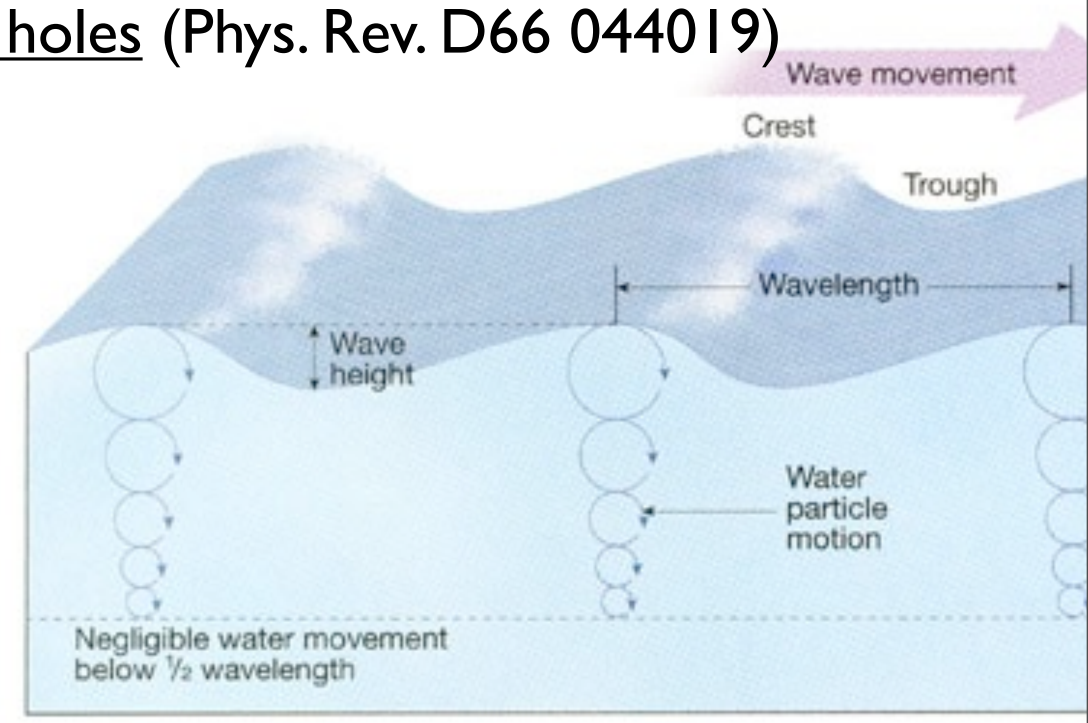


Figure 14.2 This diagram illustrates the basic parts of a wave as well as the m wave. Negligible water movement occurs below a depth equal to one-half the

Set-up: Surface waves on open channel flow with varying depth.

- stationary
- irrotational
- *incompressible*
- *inviscid*

$$v = v(x) = \frac{q}{h(x)} \propto \frac{1}{h(x)} \qquad c = c(x) \approx \sqrt{gh(x)} \propto \sqrt{h(x)}$$

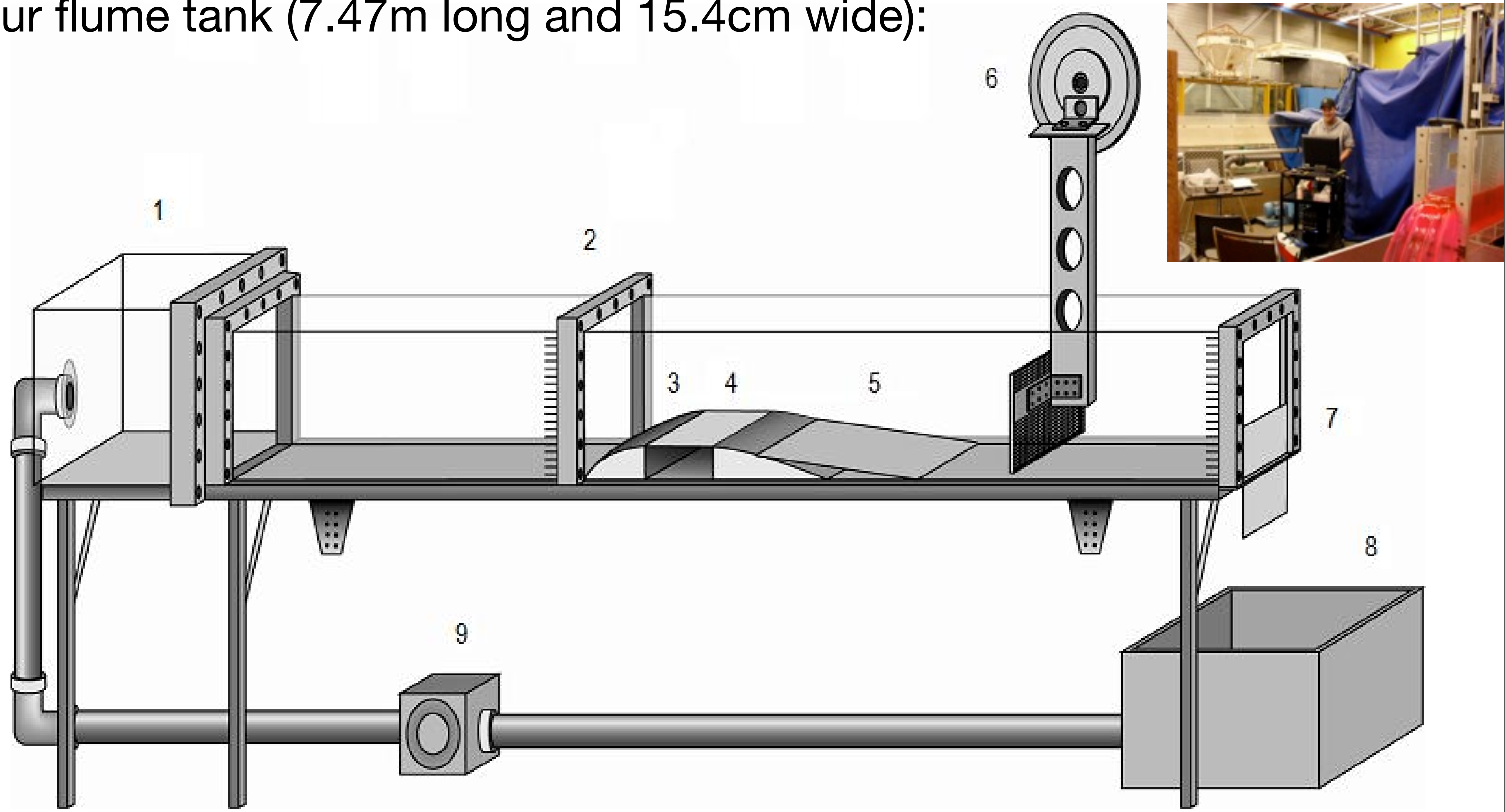
Let's recall the acoustic line-element:

$$g_{ab} \propto \begin{bmatrix} -\left(c^2 - v^2\right) & -\vec{v}^T \\ -\vec{v} & \mathbf{I}_{d\times d} \end{bmatrix}$$

Goal: Set up black and white horizon & detect stimulated conversion to pos. & neg. waves who's relative amplitudes obey Hawking's formula.

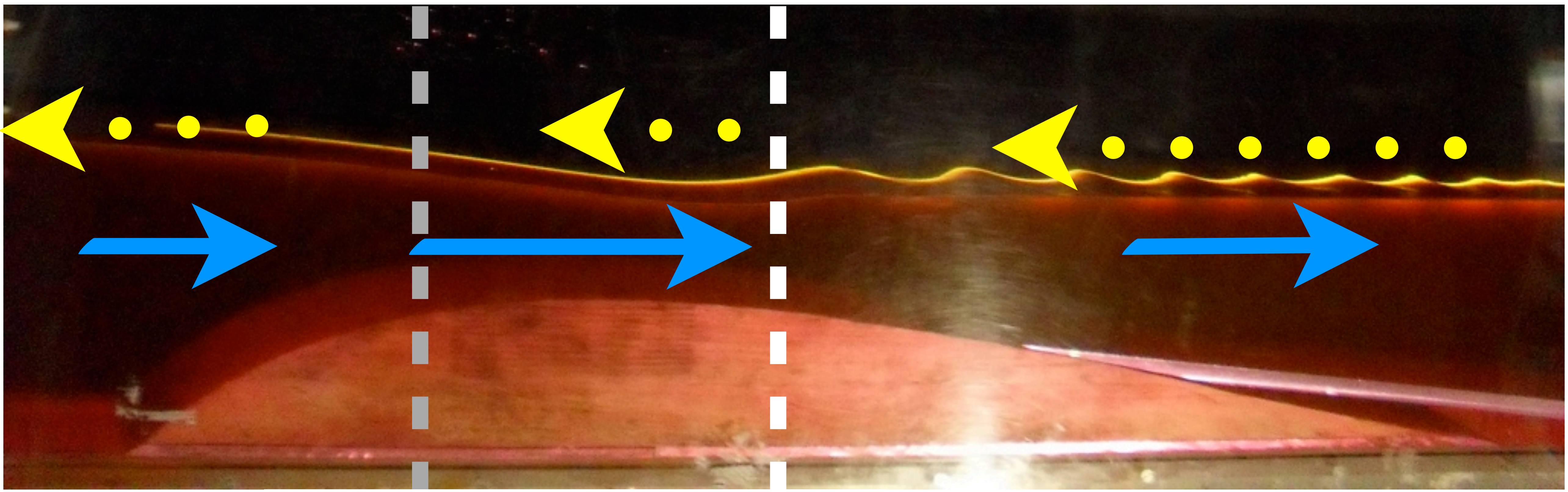
Our experiment ➤ Setup

Our flume tank (7.47m long and 15.4cm wide):



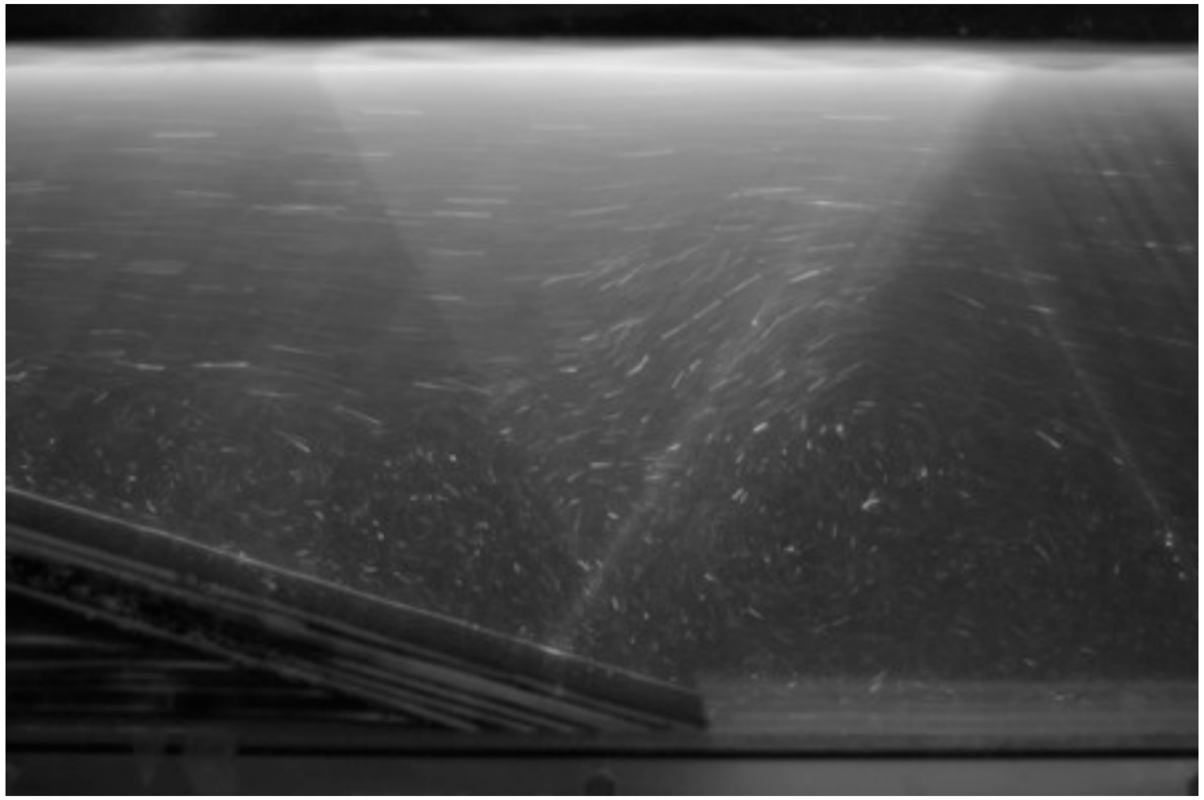
Our experiment ➤ Black & White hole horizons

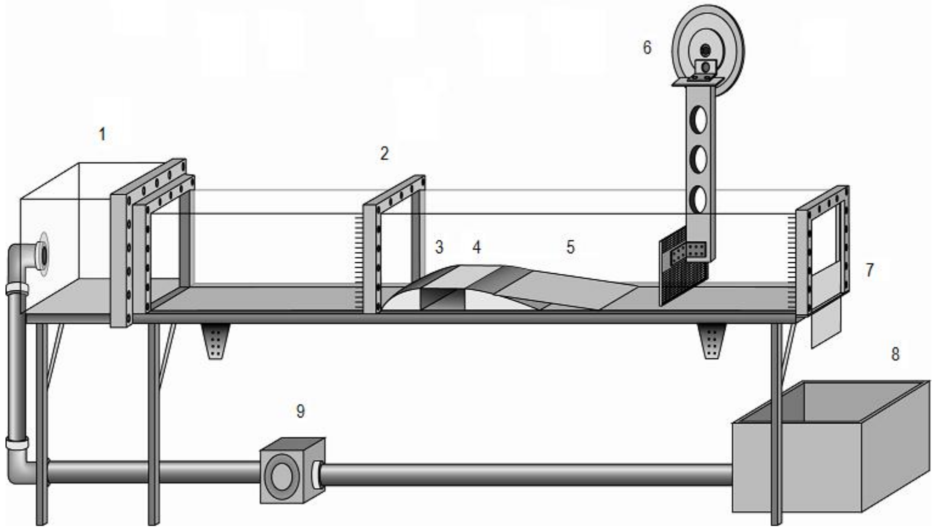
effective
white hole



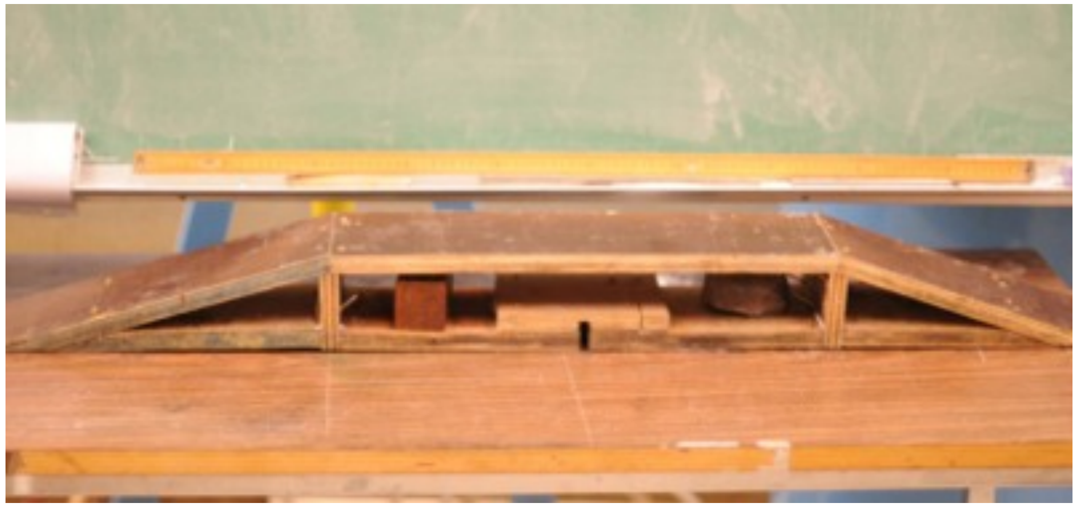
effective
black hole

Our experiment ➤ The design of our obstacle



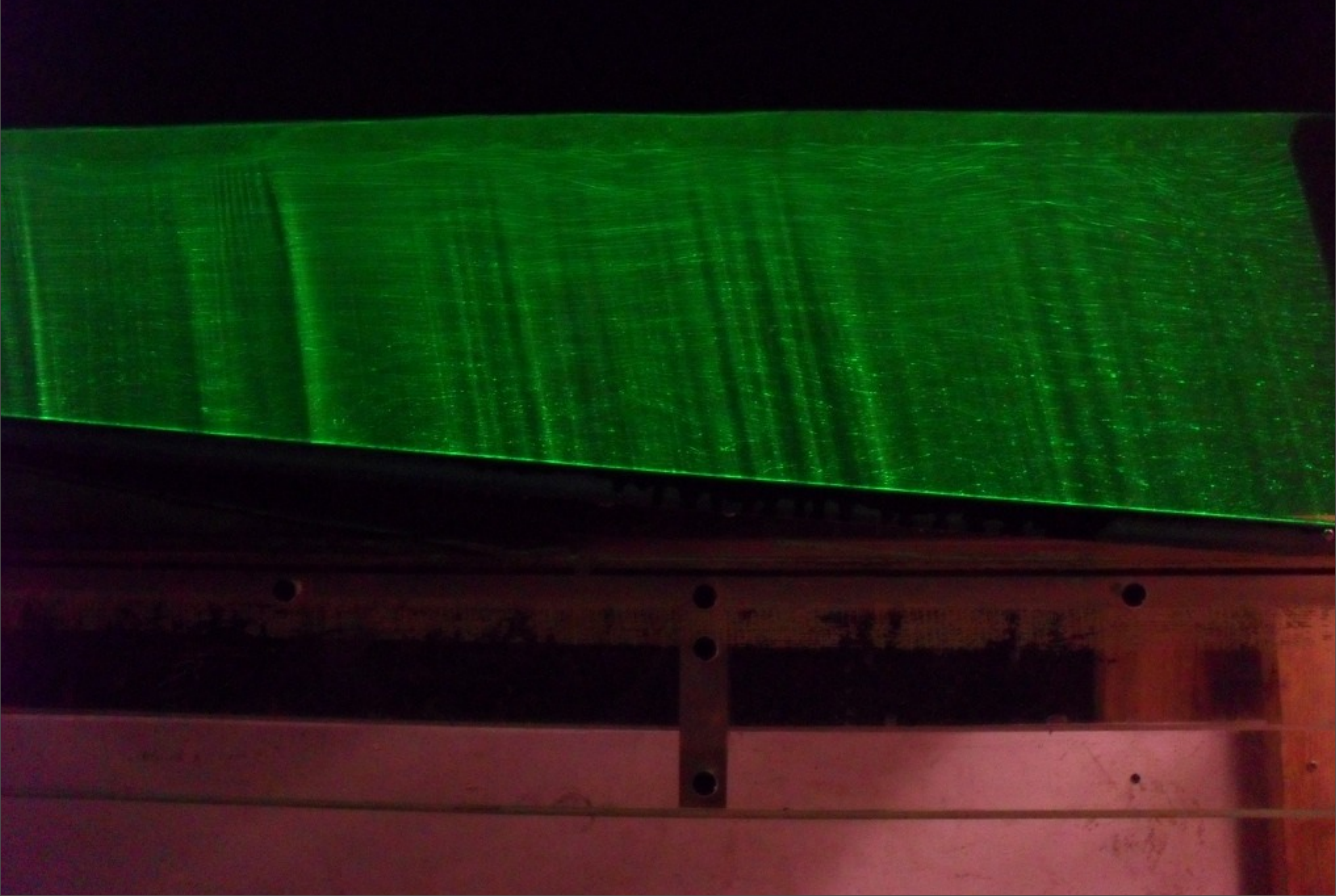


Initial design for our experiment

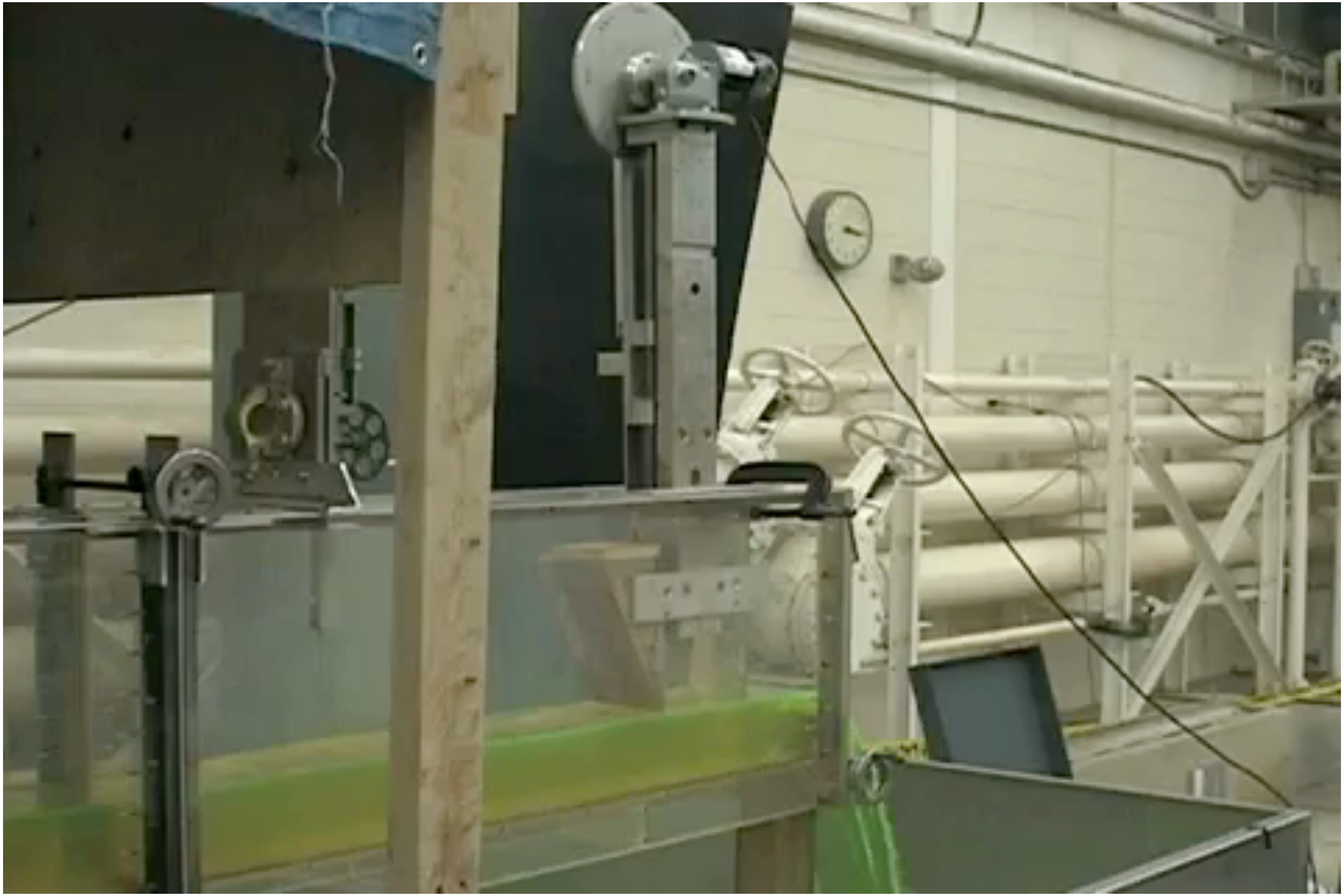


Down-scaled version of Germain
Rousseaux et al. obstacle.
[length: 14m to 1m]

Our experiment ➤ The design of our obstacle



Our experiment ➤ early experiment with bigger waves



Field theory ➤ physics of surface waves

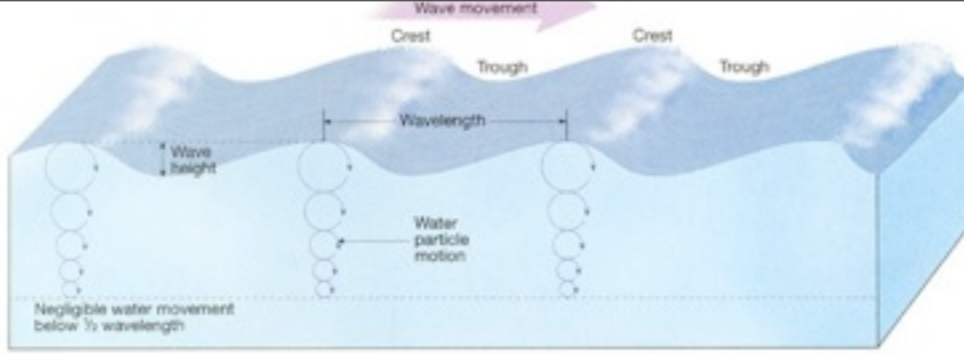
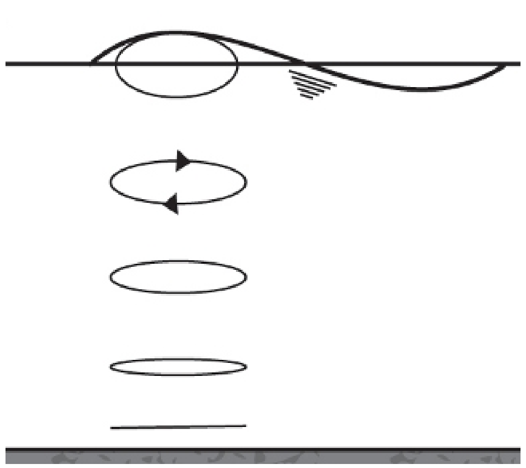
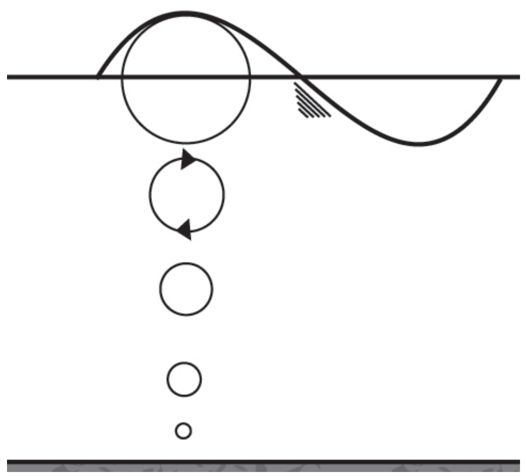


Figure 14.2 This diagram illustrates the basic parts of a wave as well as the movement of water particles with the passage of the wave. Negligible water movement occurs below a depth equal to one-half the wavelength (the level of the dashed line).

$$\Omega^2 = \left(g\,k + \frac{\sigma}{\rho} k^3 \right) \tanh(k\,h)$$



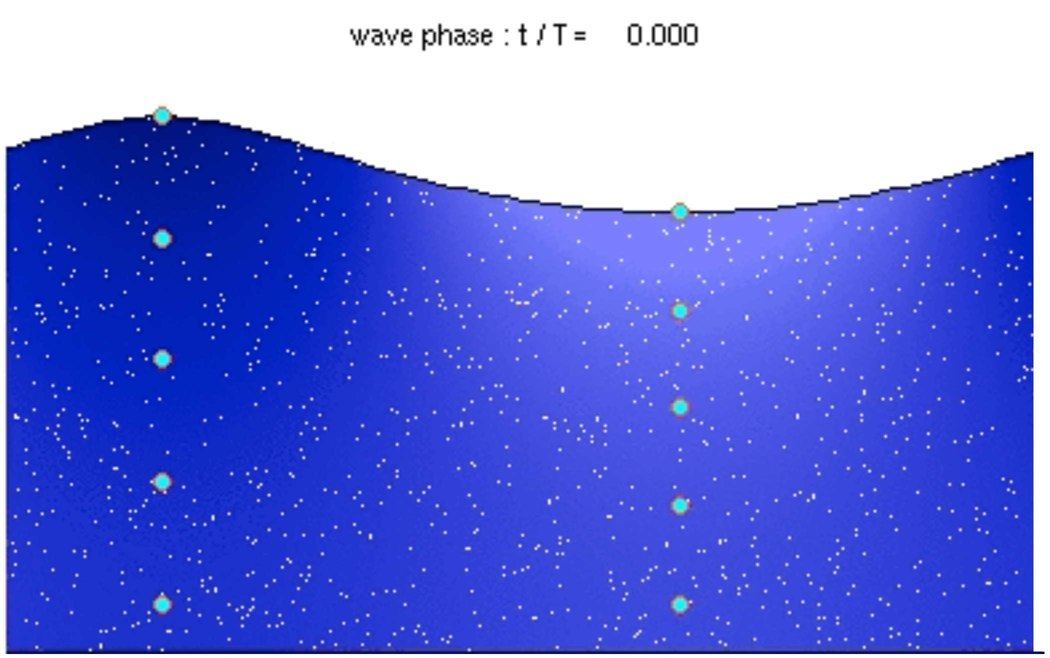


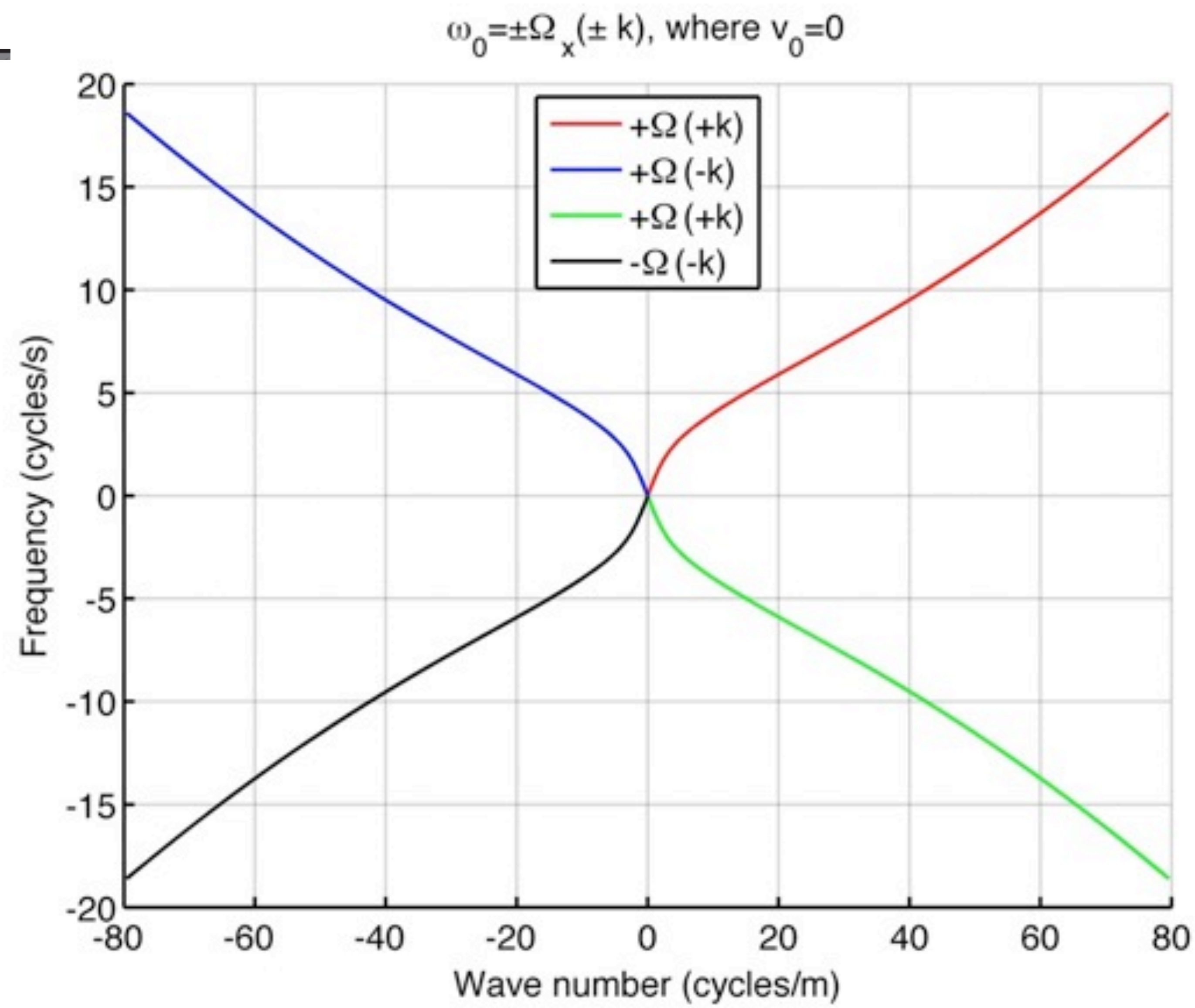
shallow:

$$\Omega = \sqrt{gh}\,k$$

deep:

$$\Omega = \sqrt{gk}$$





Field theory ➤ physics of surface waves

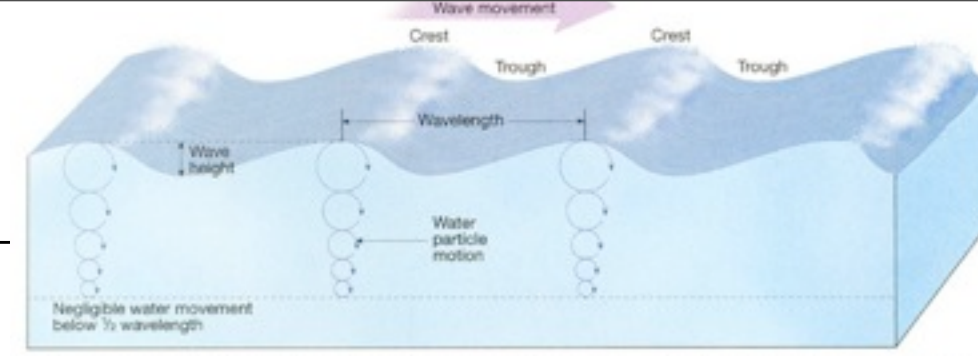
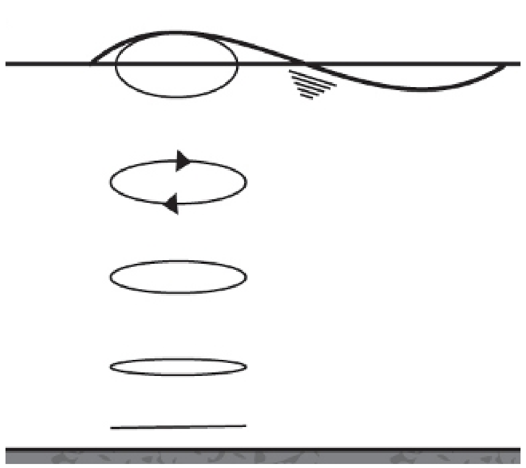
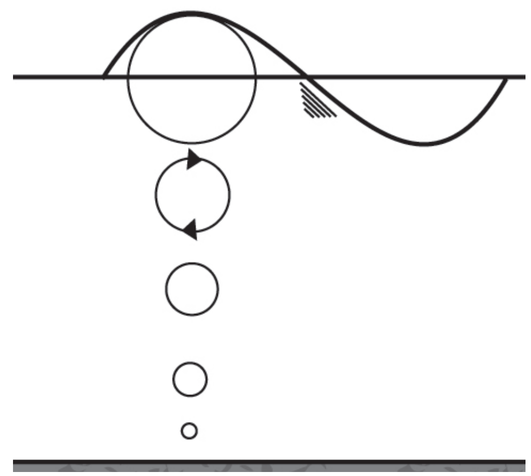


Figure 14.2 This diagram illustrates the basic parts of a wave as well as the movement of water particles with the passage of the wave. Negligible water movement occurs below a depth equal to one-half the wavelength (the level of the dashed line).





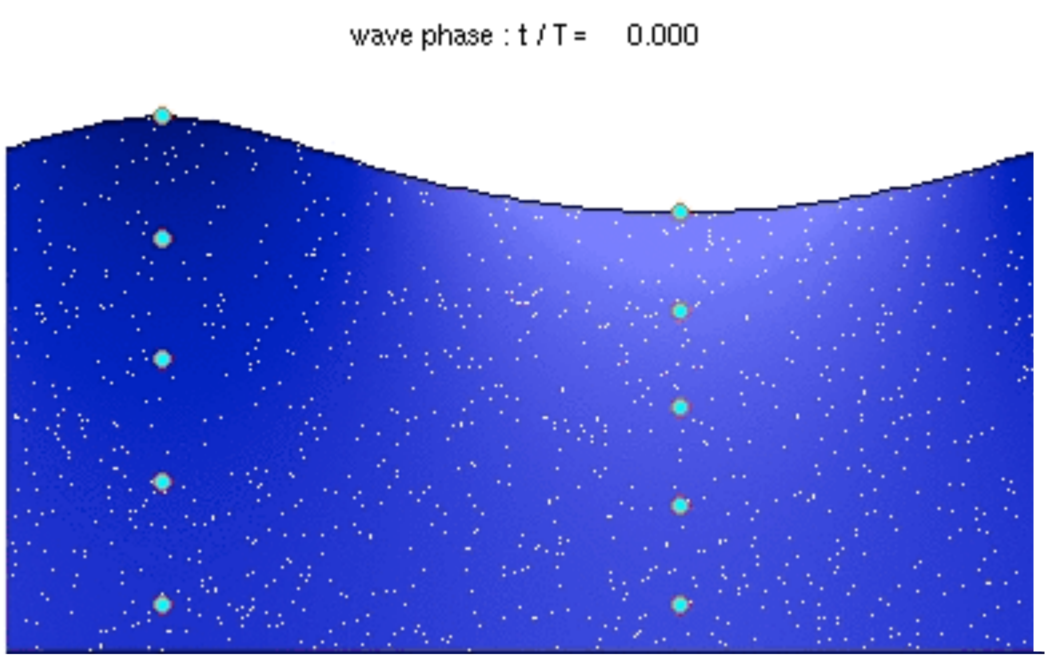
$$\Omega^2 = \left(g\,k + \frac{\sigma}{\rho} k^3 \right) \tanh(k\,h)$$

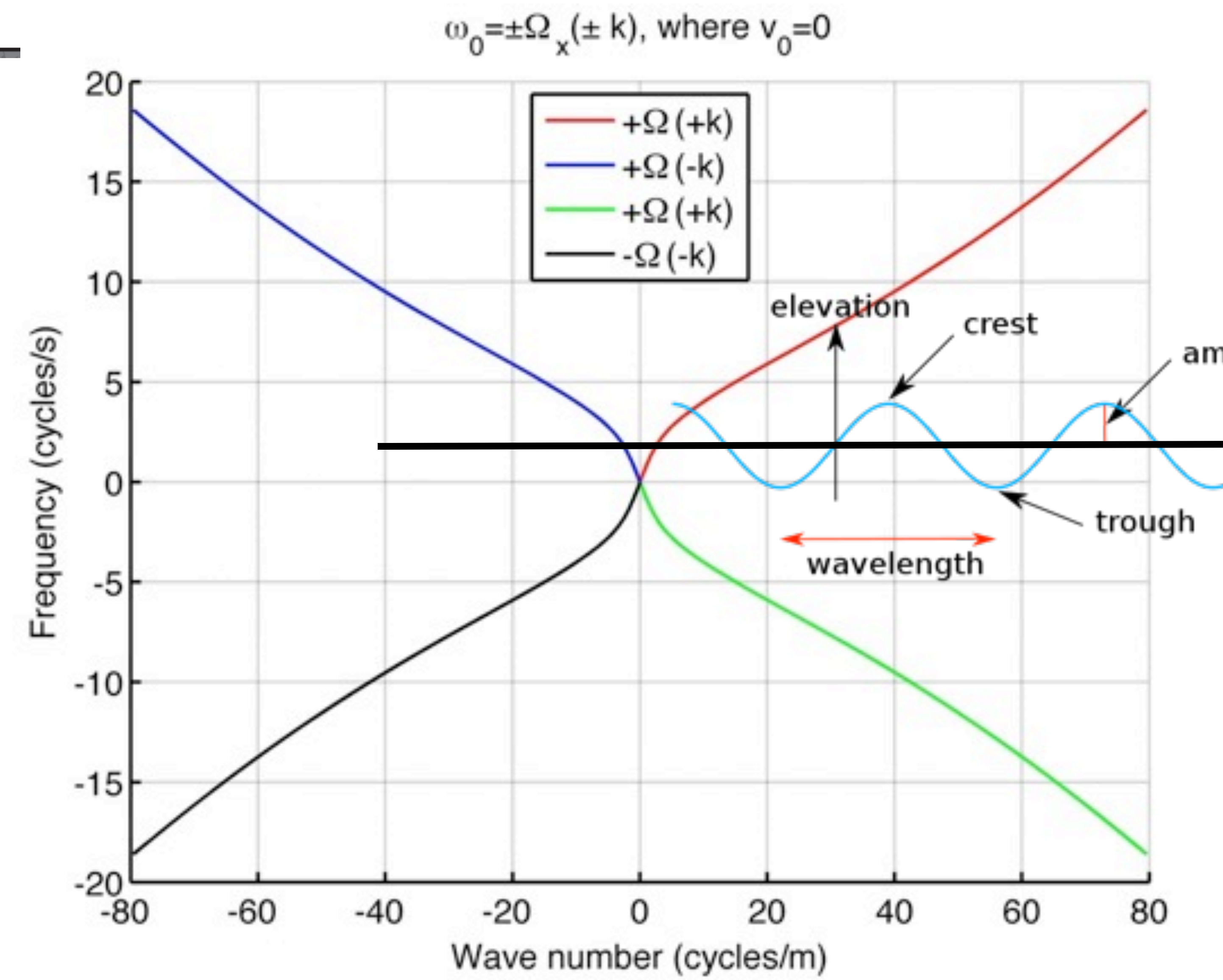
shallow:

$$\Omega = \sqrt{gh}\,k$$

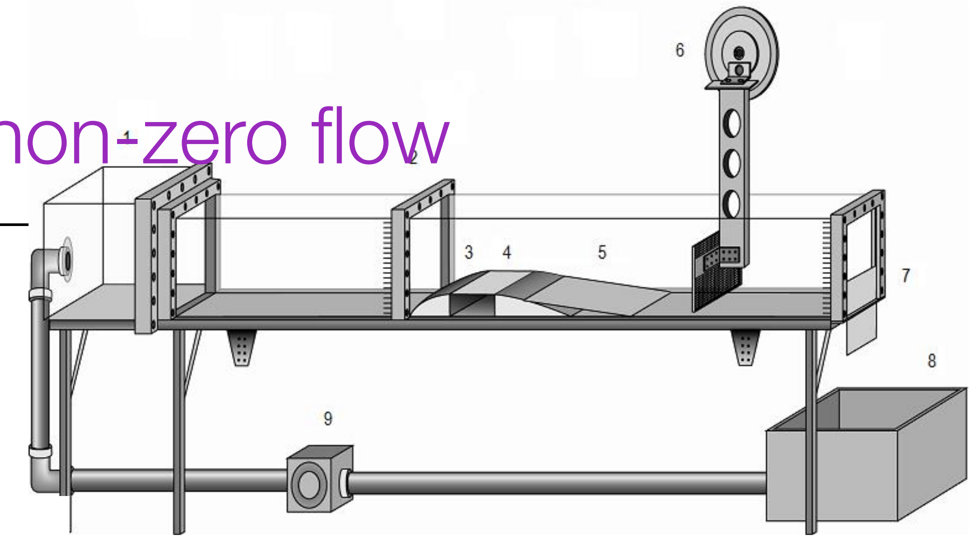
deep:

$$\Omega = \sqrt{gk}$$

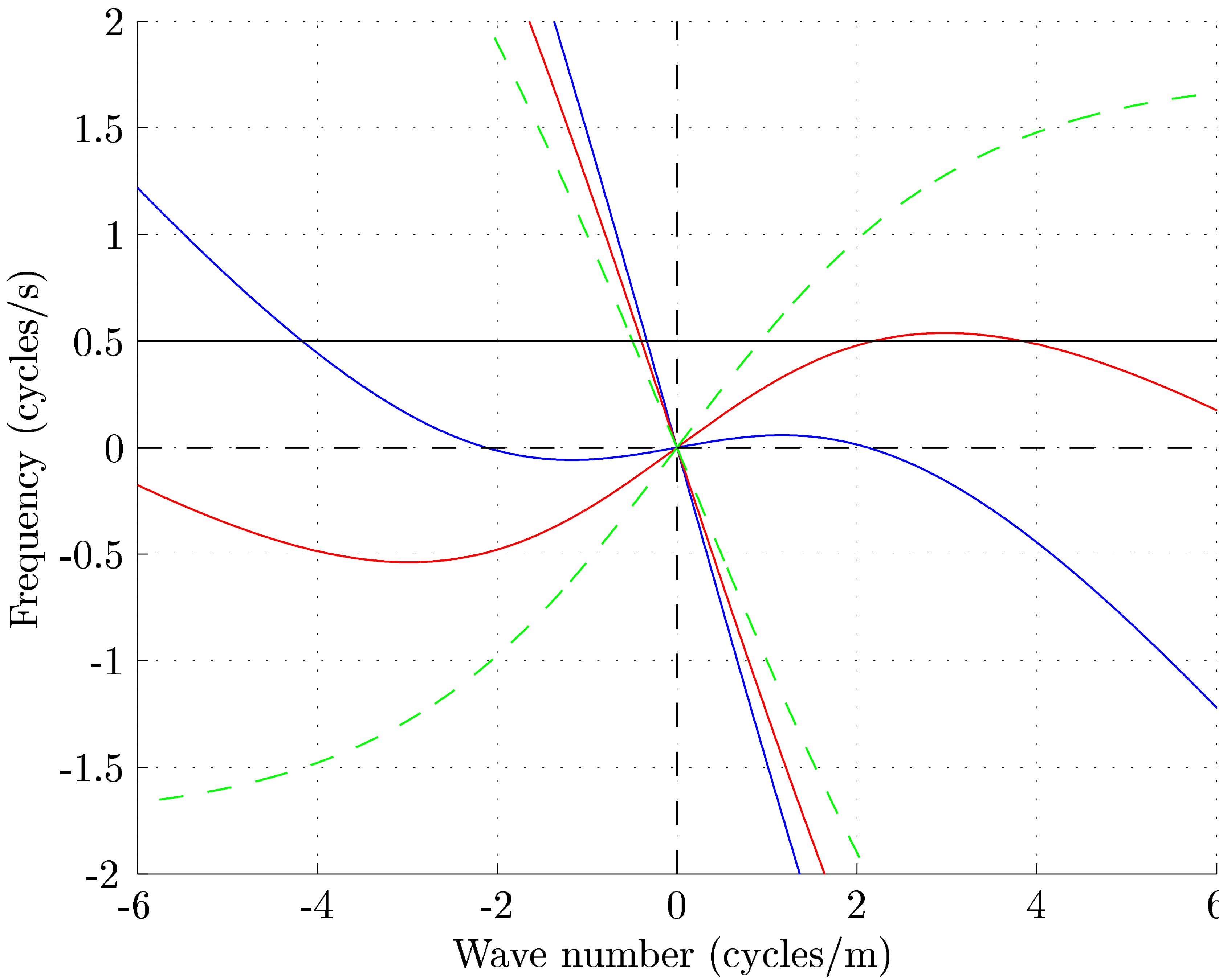




Field theory ➤ physics of surface waves non-zero flow



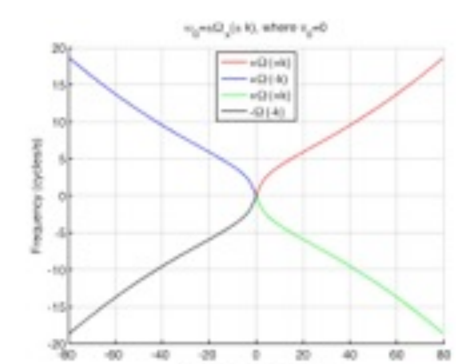
$$\Omega_{\mathrm{LAB}} = \Omega_{\mathrm{WATER}} \pm v\,k$$



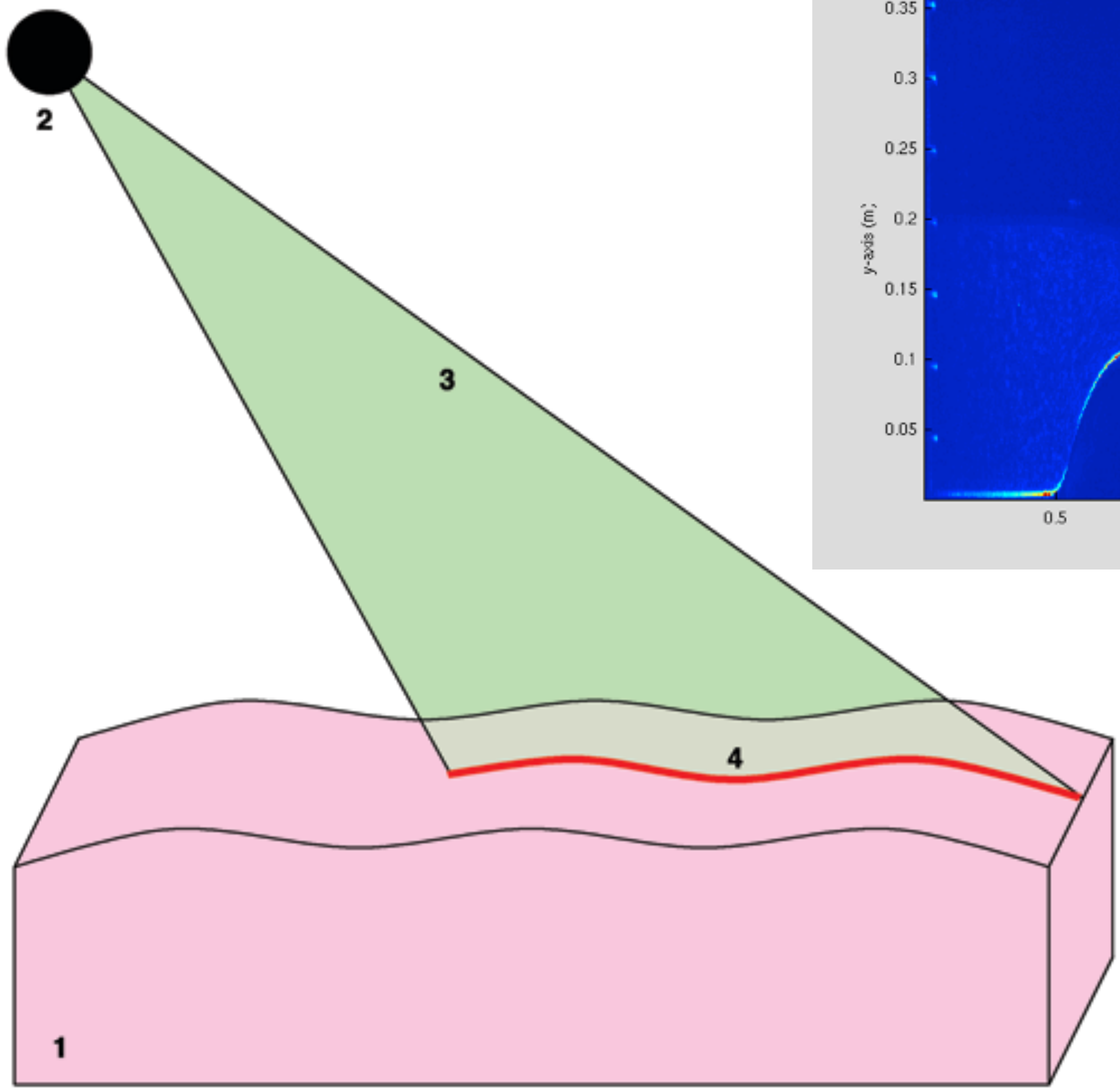
Dispersion relation for
maximum height
conversion point
minimum height

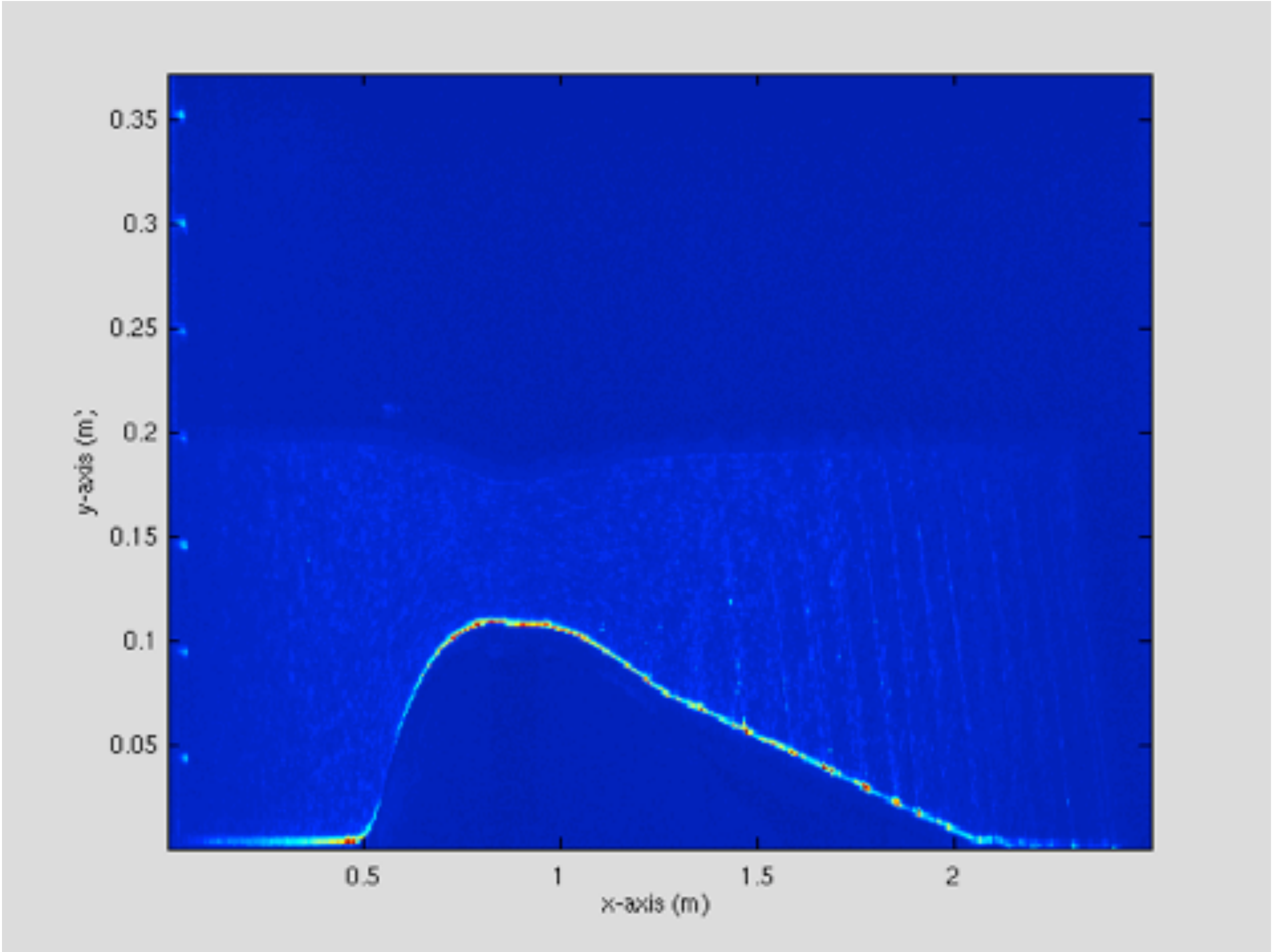
shallow: $\Omega = \sqrt{gh}\,k$

deep: $\Omega = \sqrt{gk}$

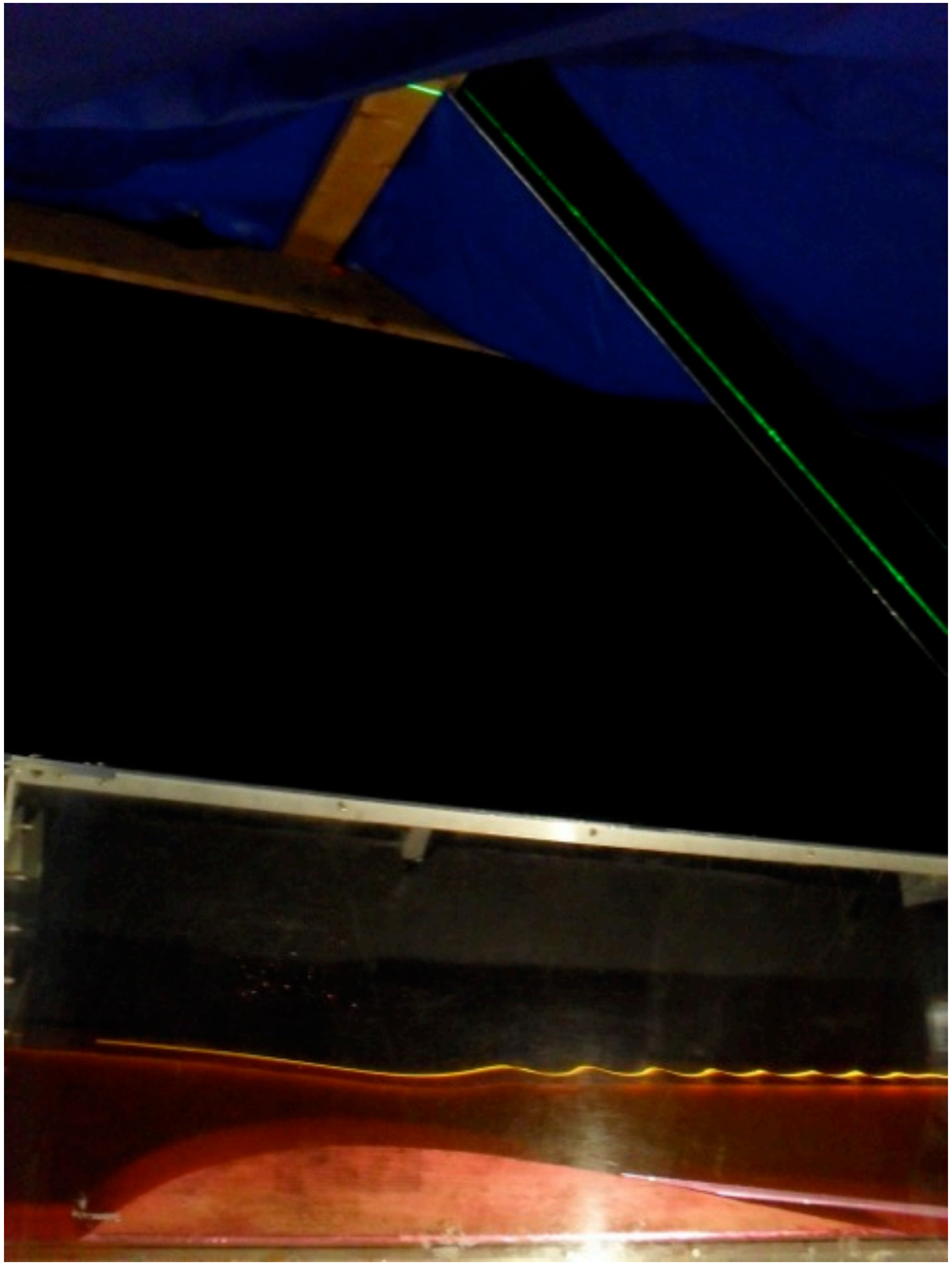


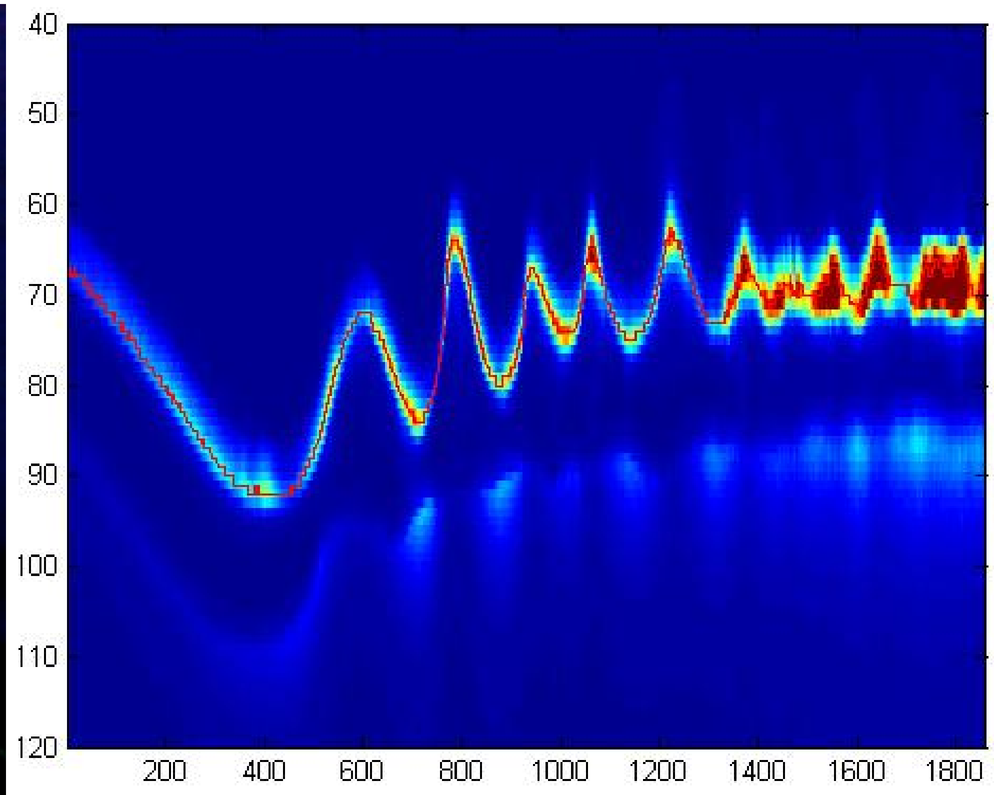
Our experiment ➤ Observable

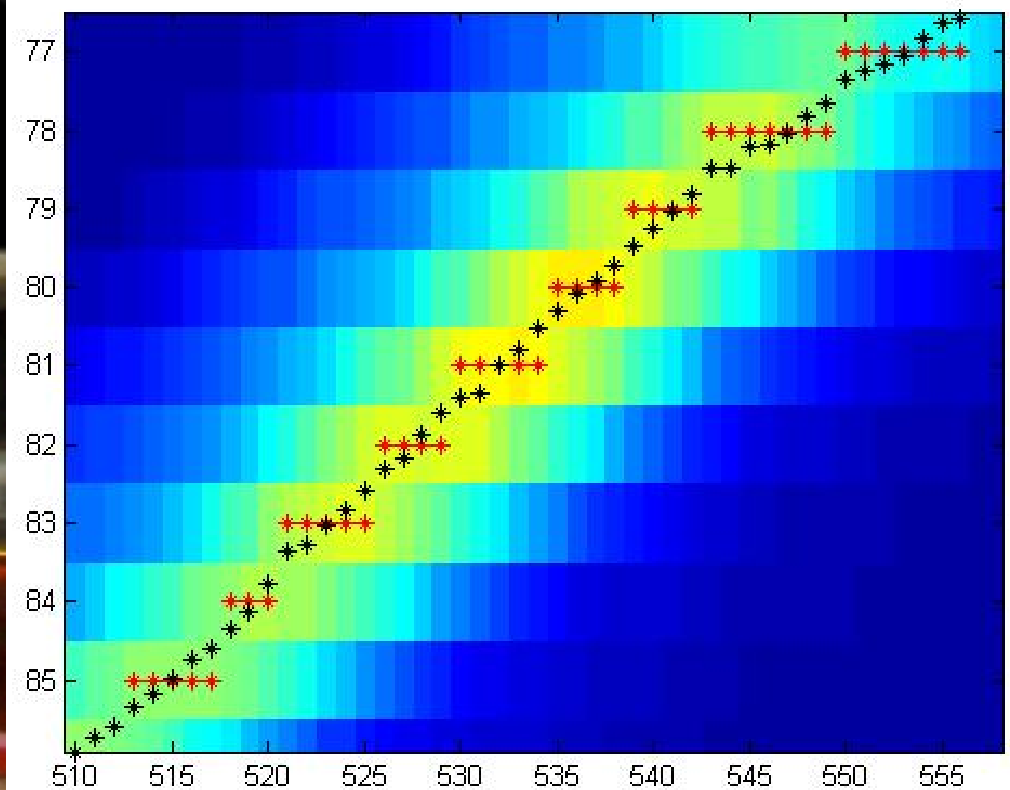


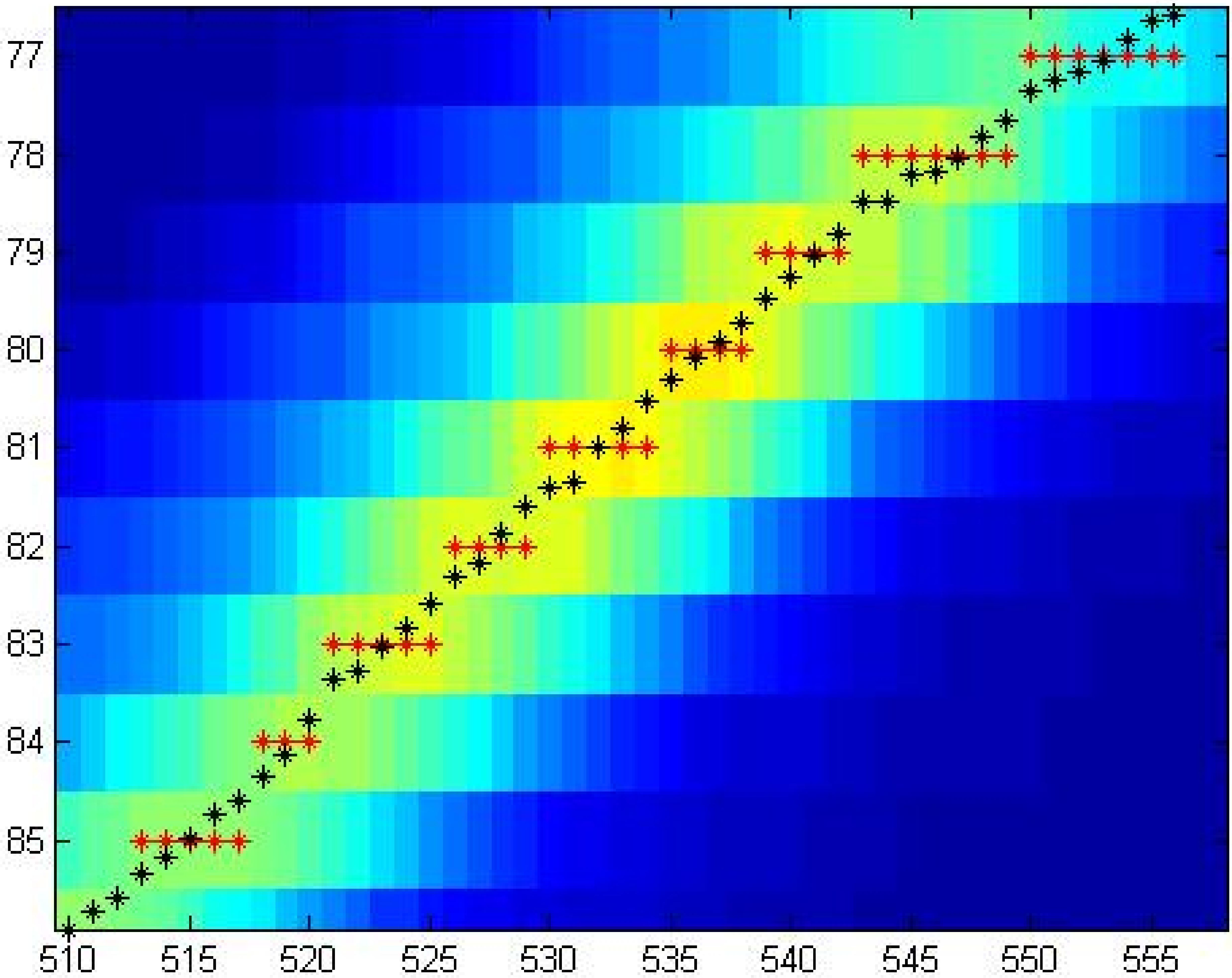


Our experiment ➤ Data analysis









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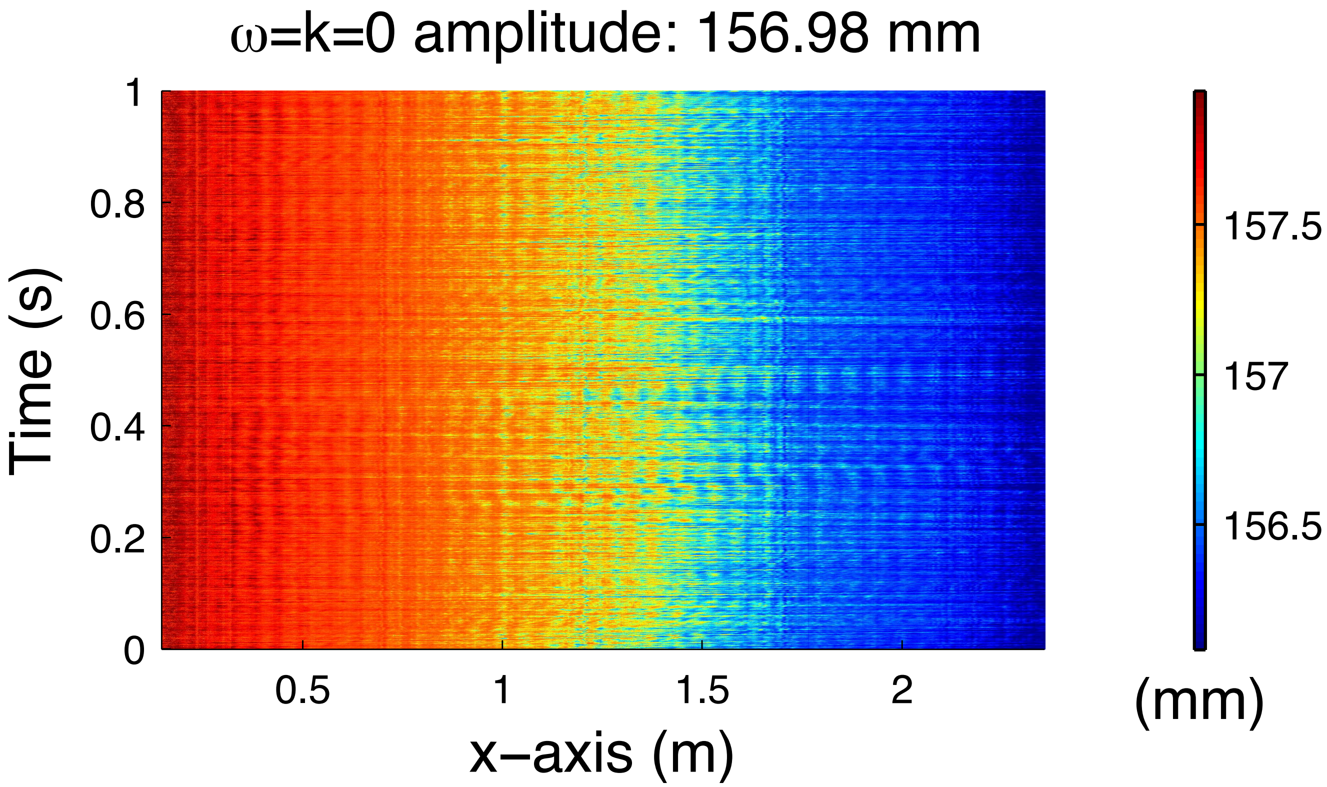
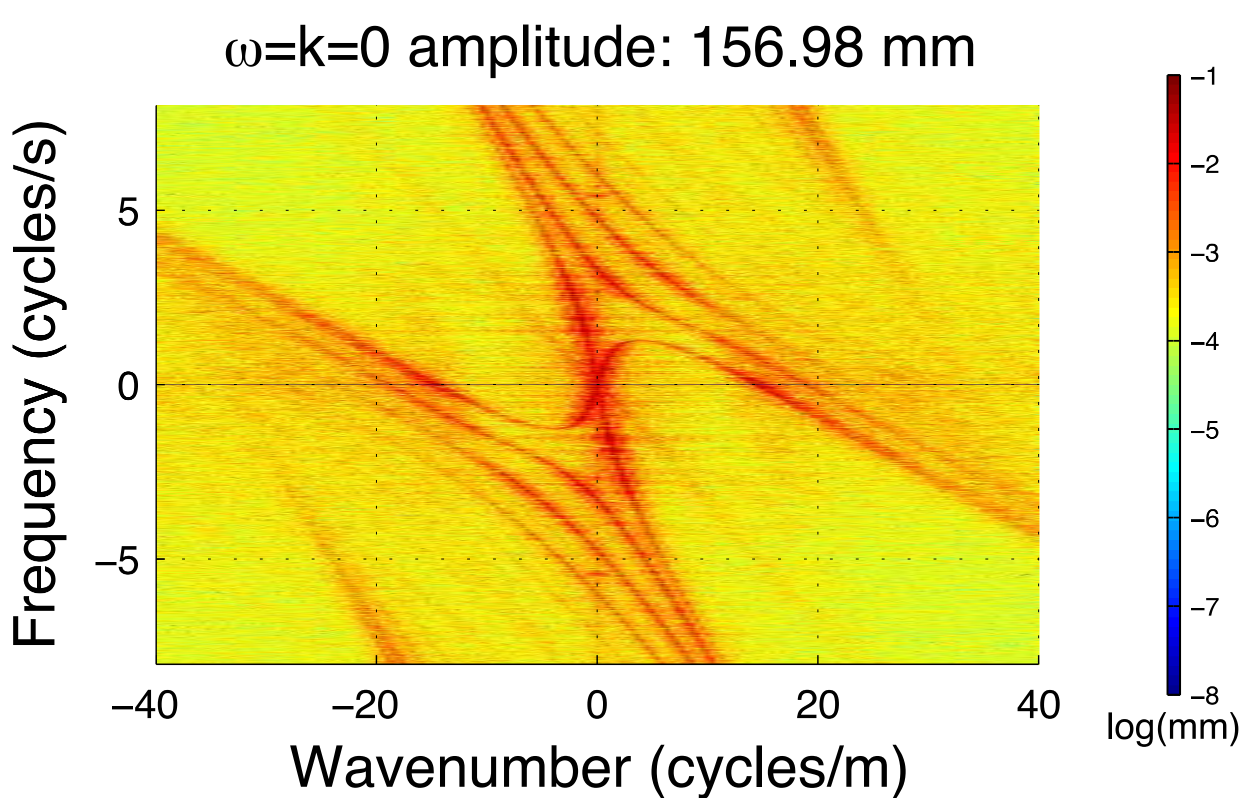
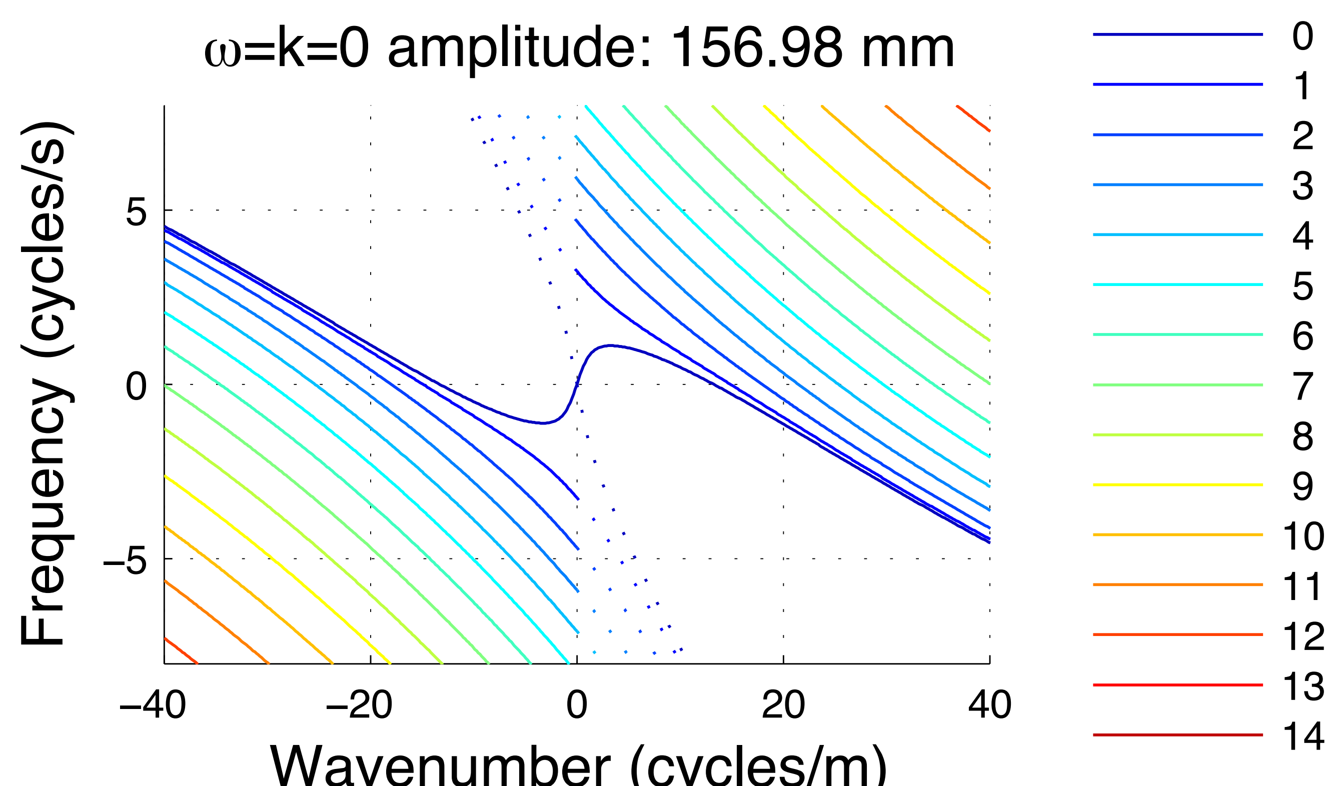
Data analysis ➤ from wave characteristic to dispersion rel.



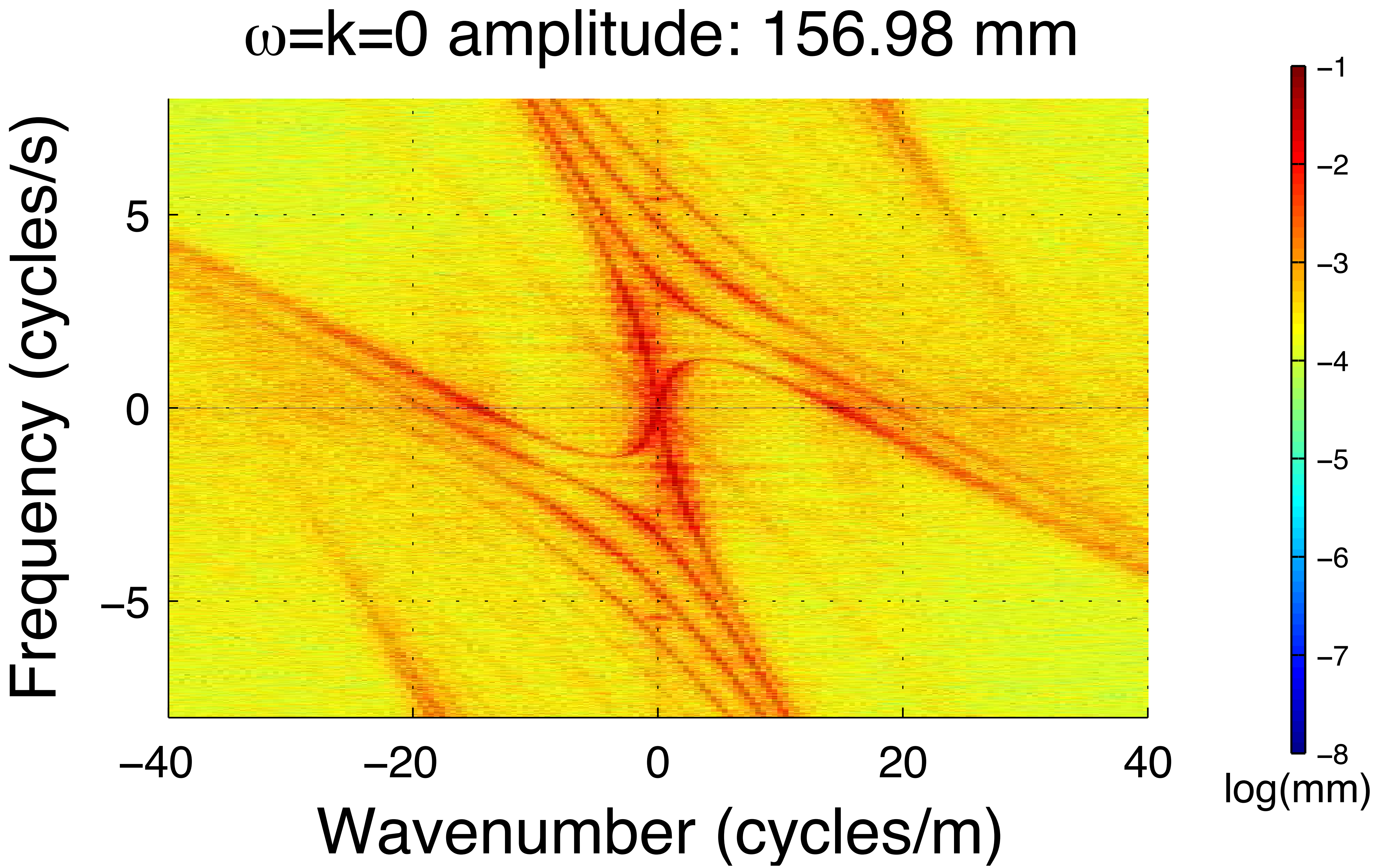
$$(f + \tilde{v}\,k)^2 = \left(\frac{g\,k}{2\,\pi}\right) \cdot \tanh(2\,\pi\,k\,h)$$

$$k = \sqrt{k_{||}^2 + k_{\perp}^2} = \sqrt{(1/\lambda)^2 + (n/l_w).^2};$$

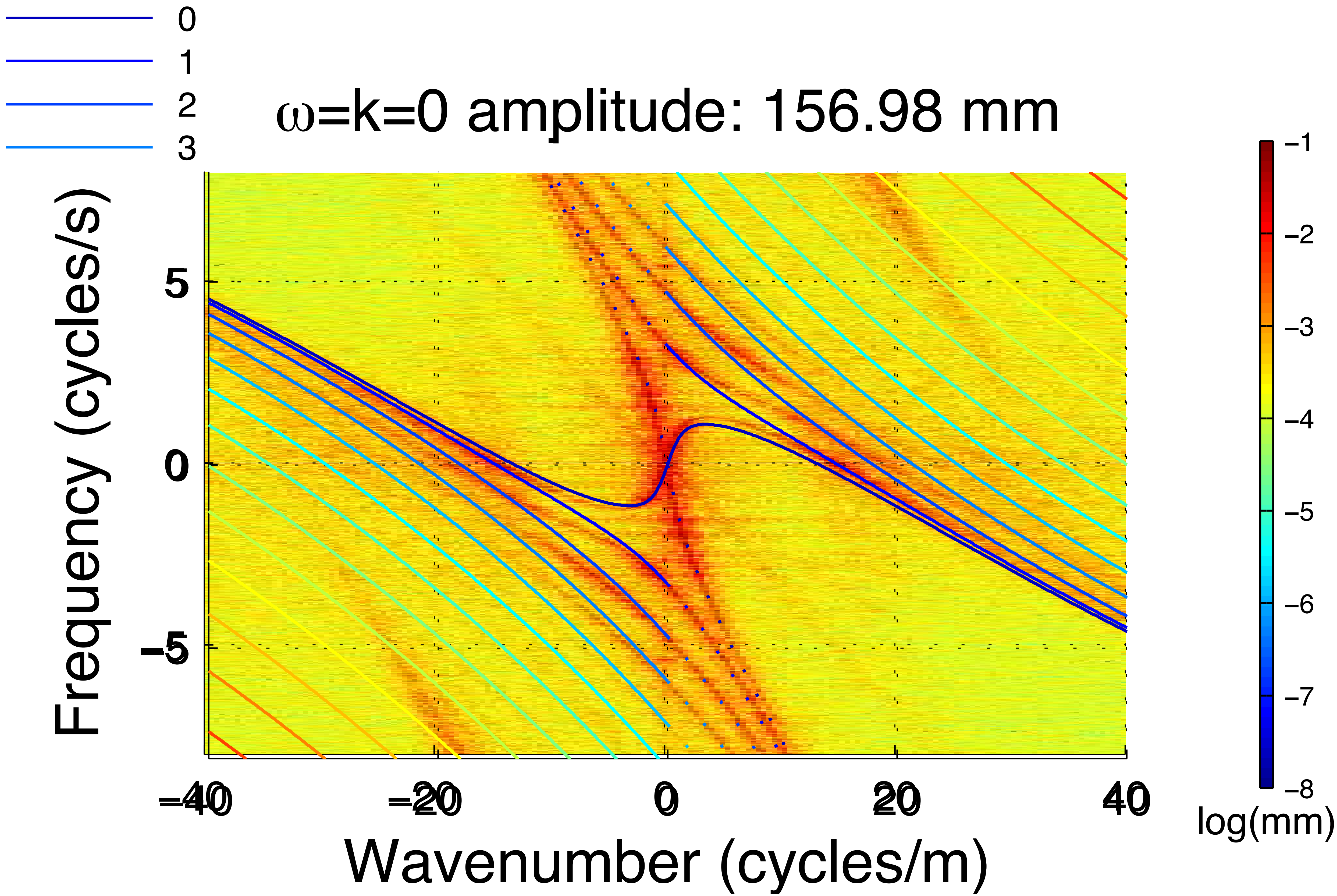




Data analysis ➤ from wave characteristic to dispersion rel.



Data analysis ➤ from wave characteristic to dispersion rel.



Data analysis ➤ from wave characteristic to dispersion rel.

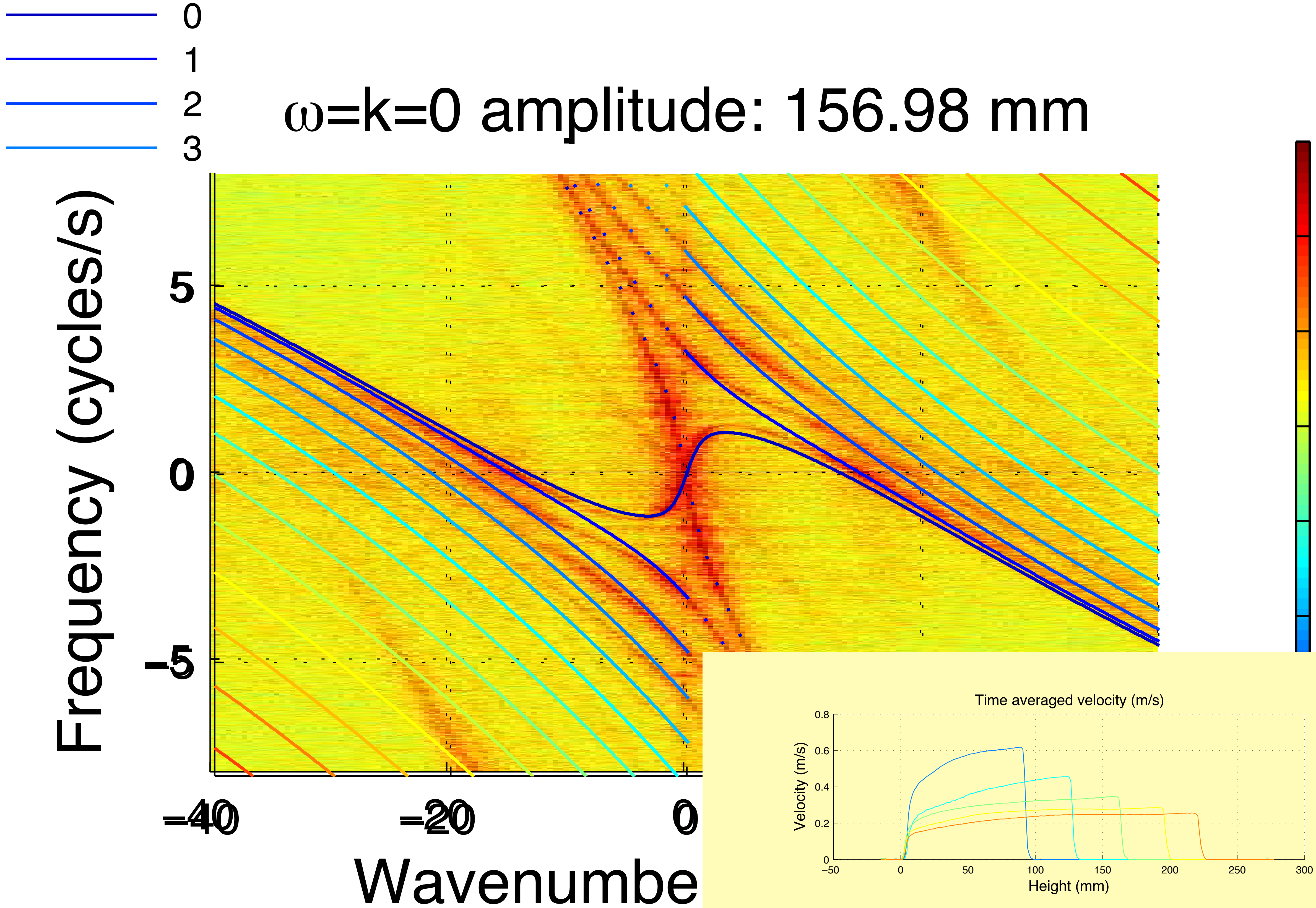
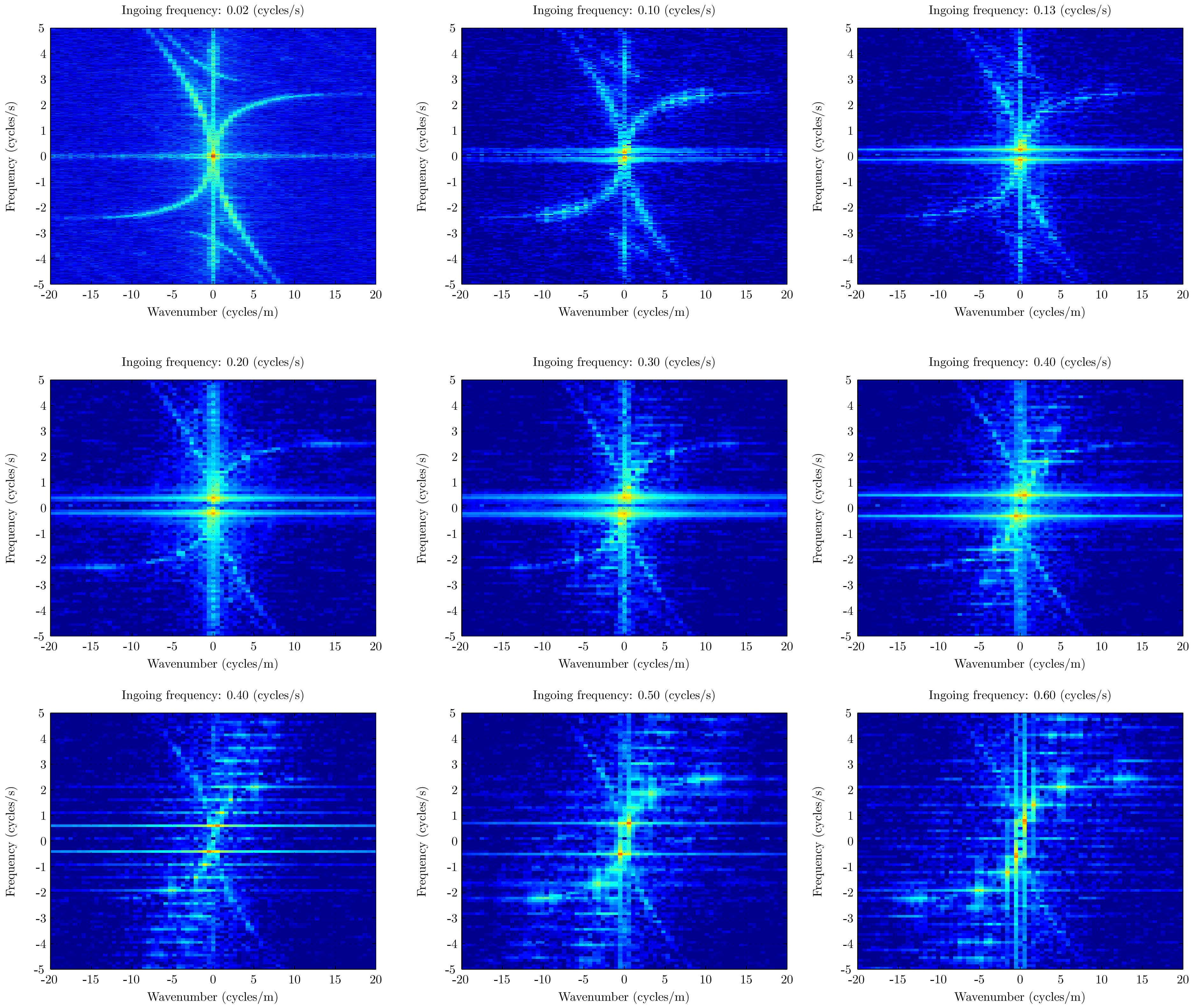
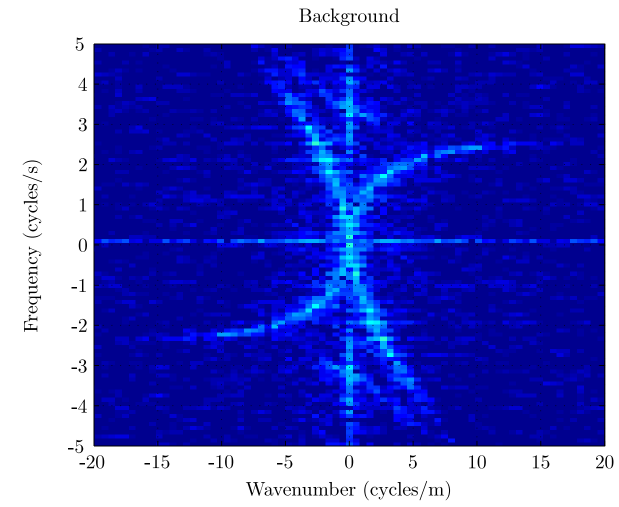


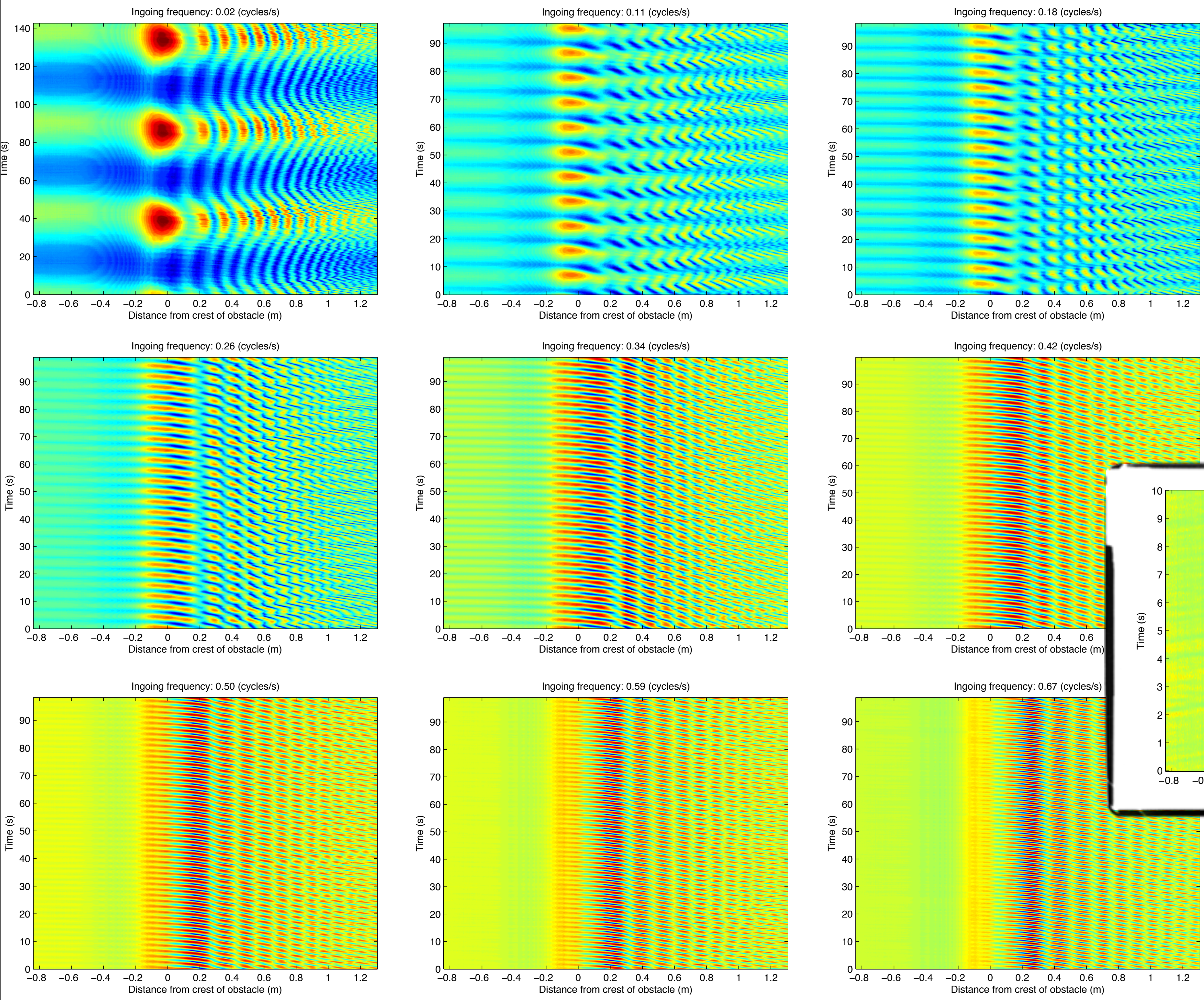
FIG. 16: (Colors online only.) Flow profiles from the PIV measurements.

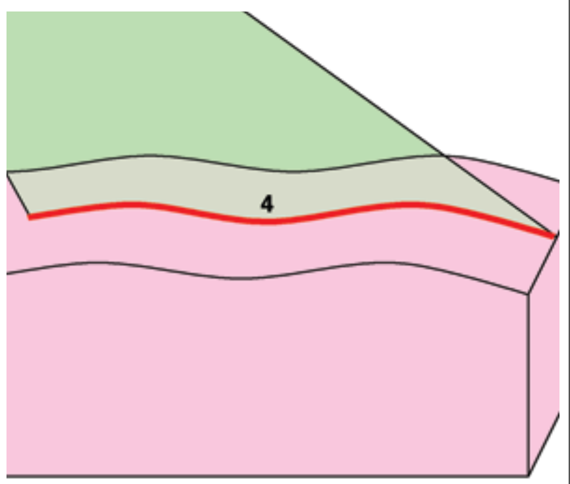
Our experiment ➤ Exciting classical field modes

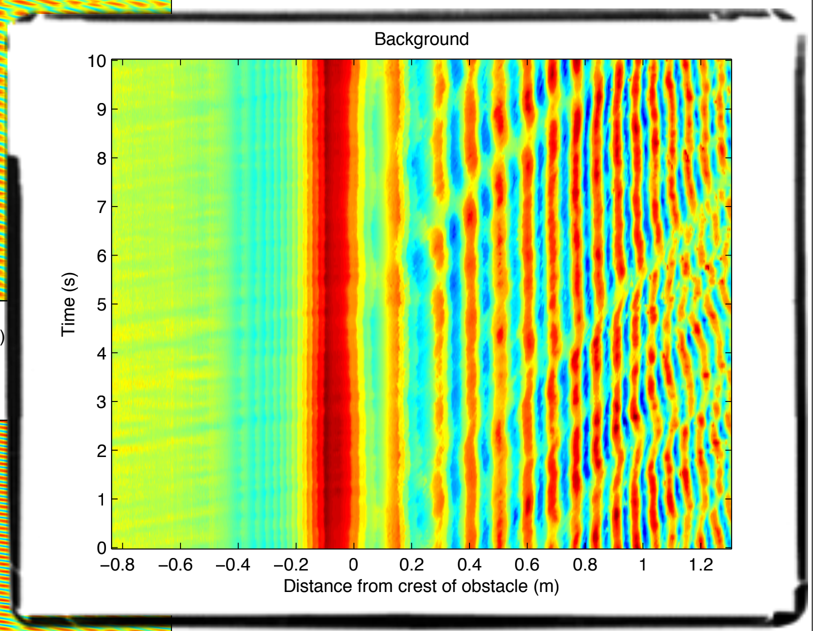




Our experiment ➤ Experimental procedure

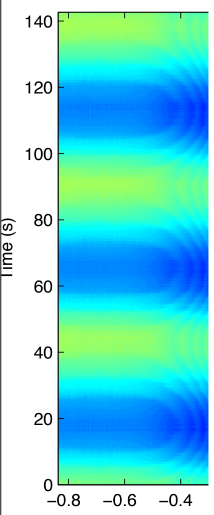


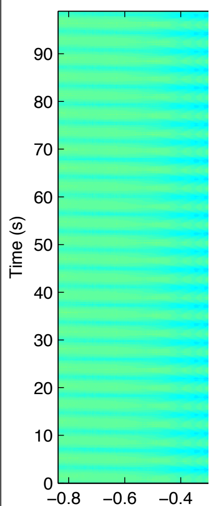


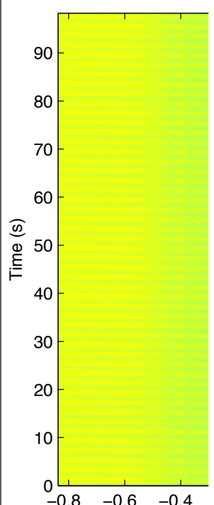


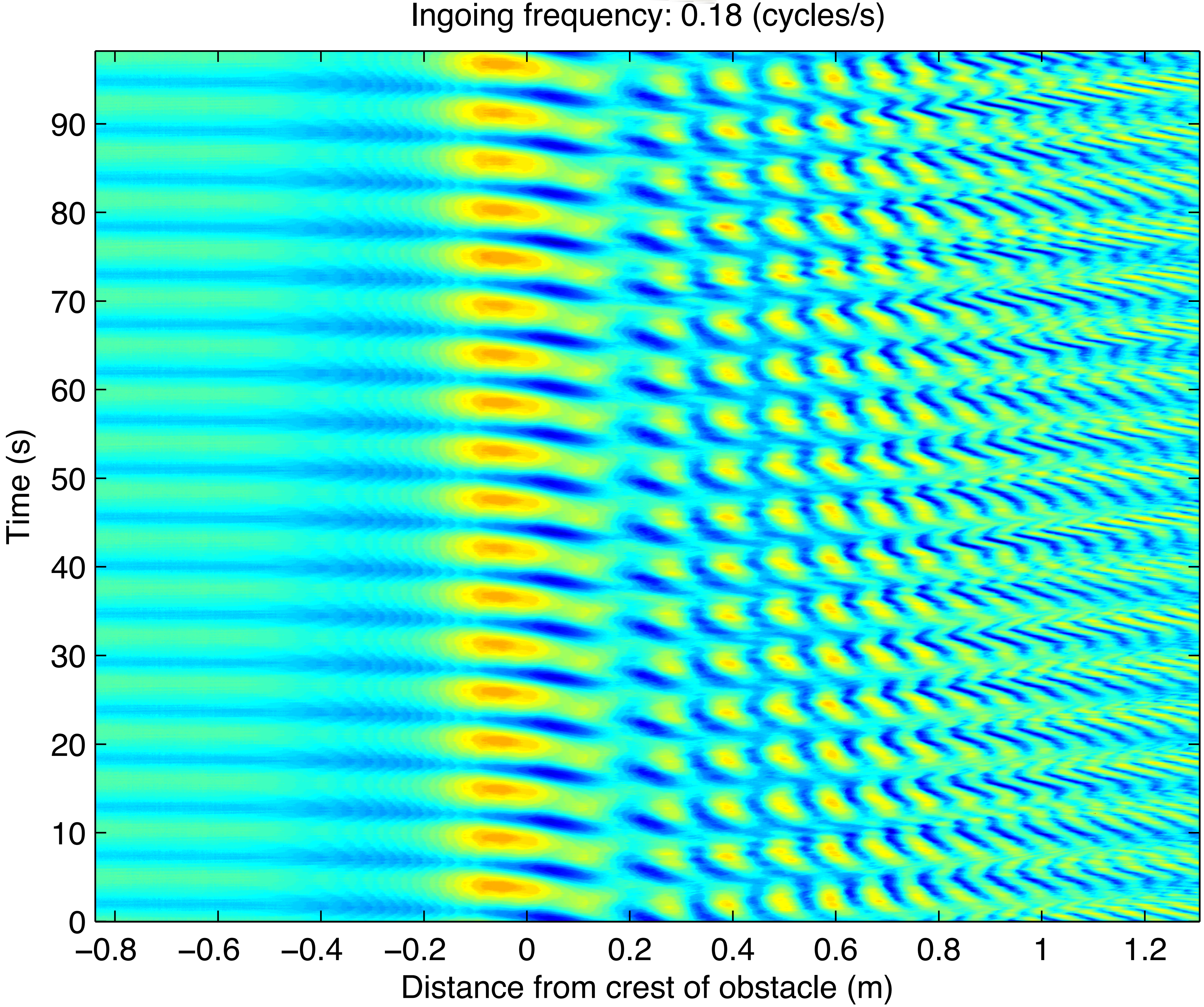
Standing wave: the undulation?

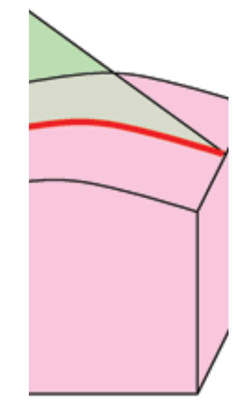
Our experiment ➤ Experimental procedure

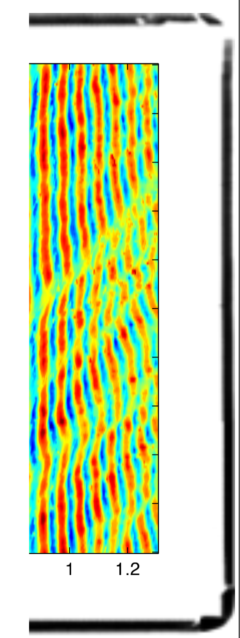








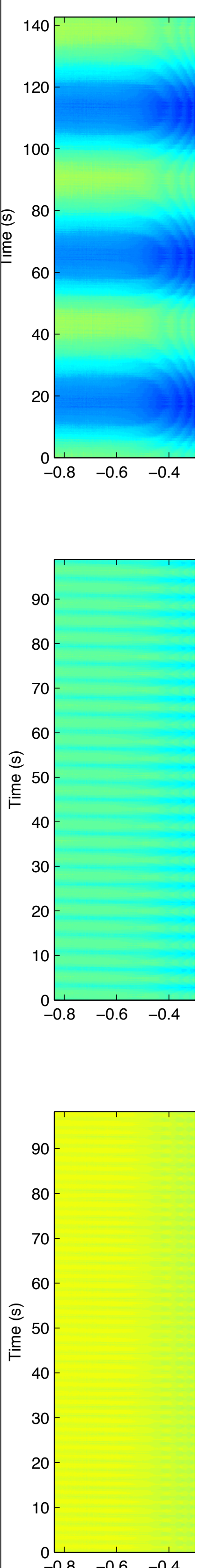


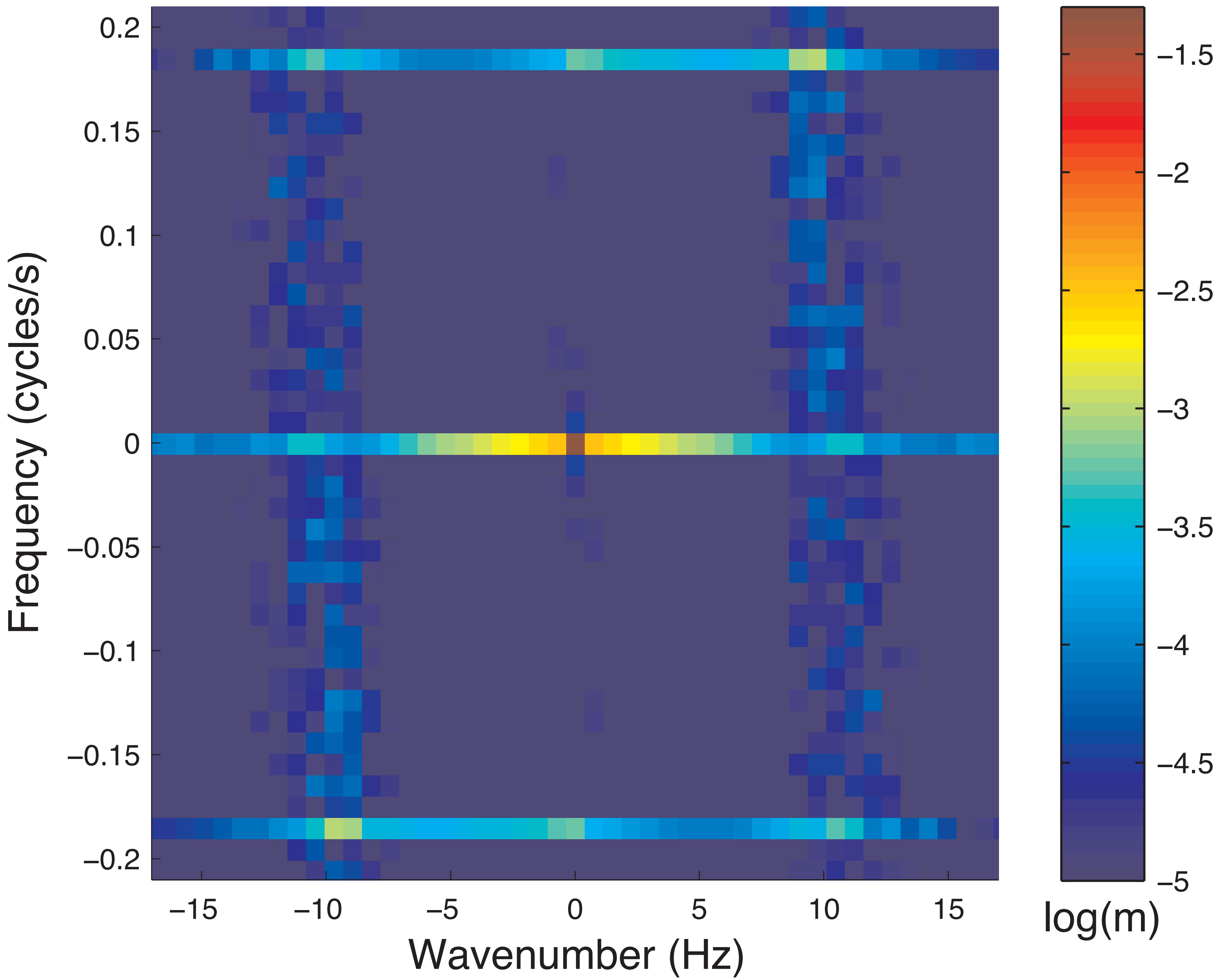


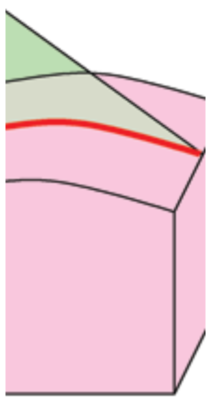
vave:

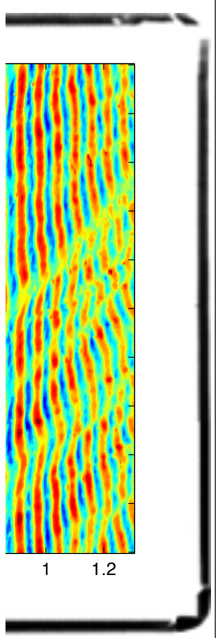
tion?

Our experiment ➤ Experimental procedure





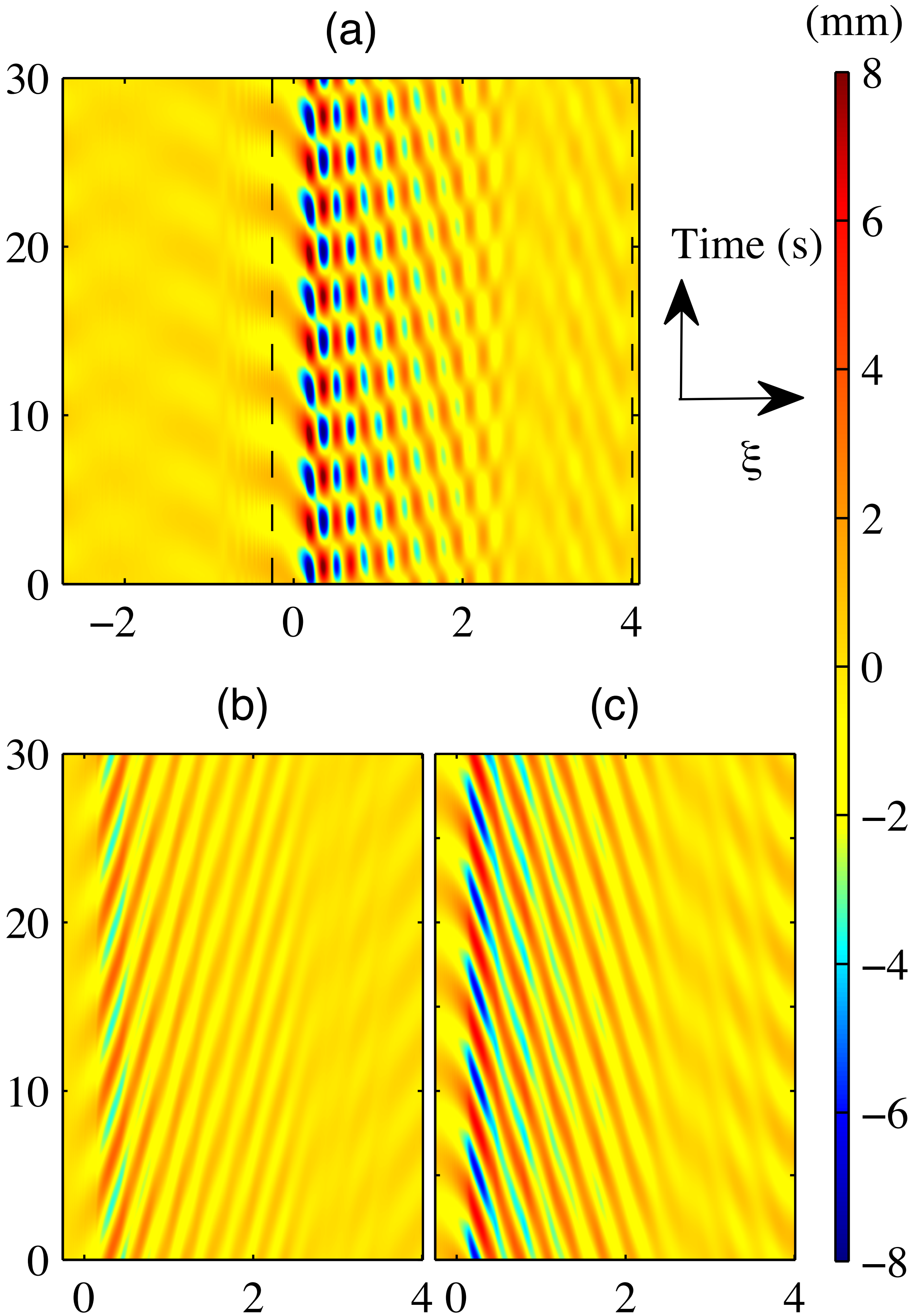


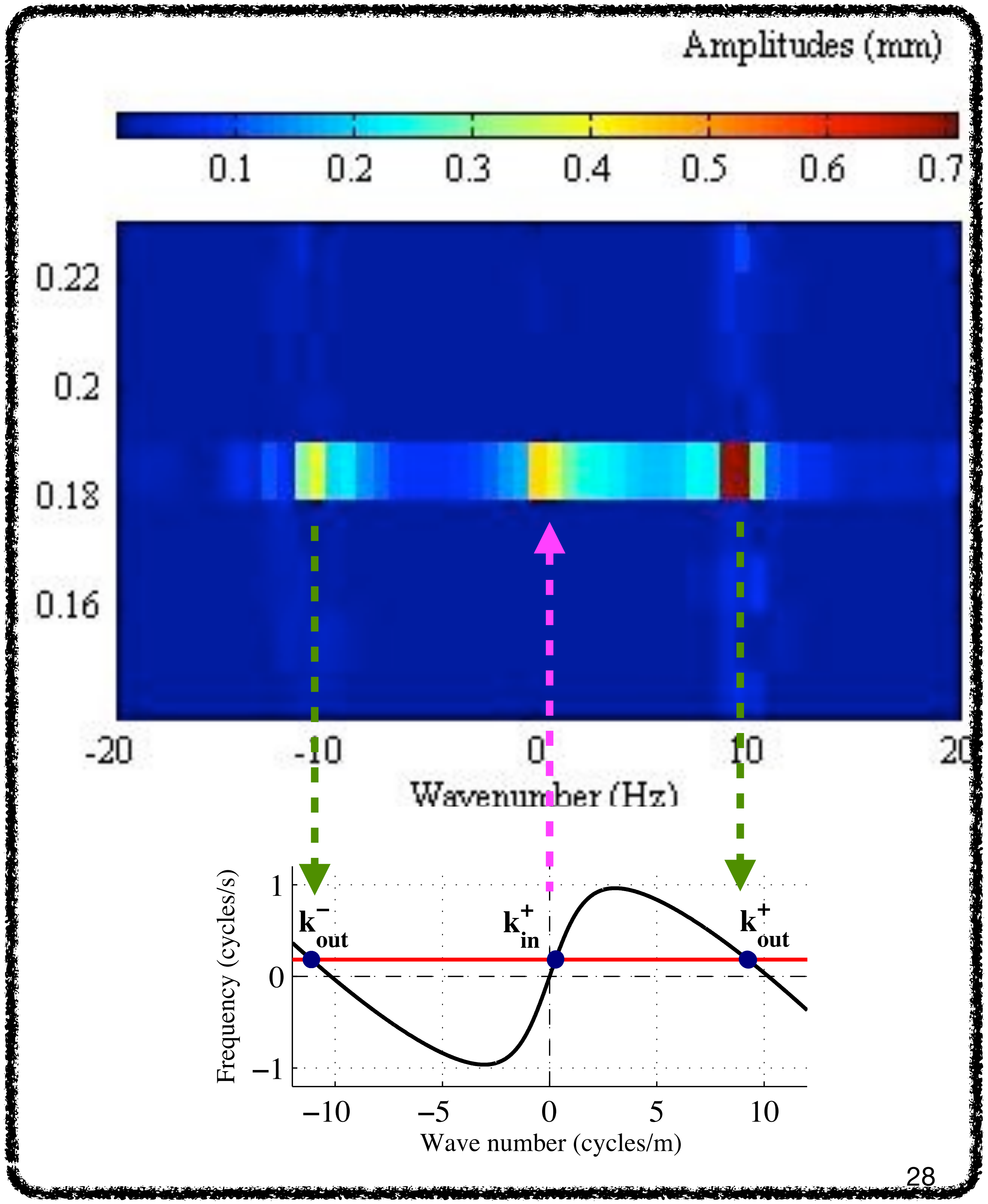


vave:

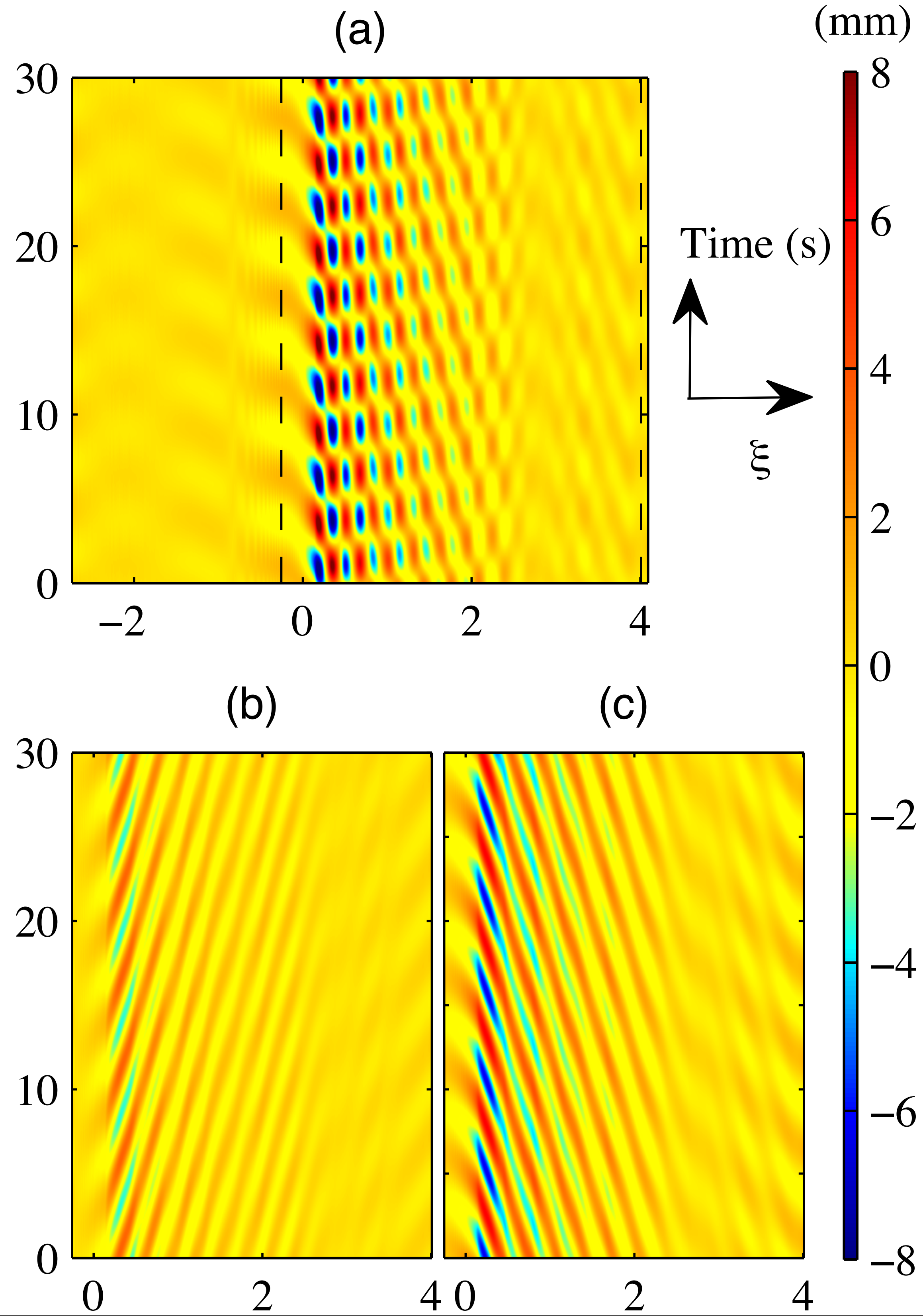
tion?

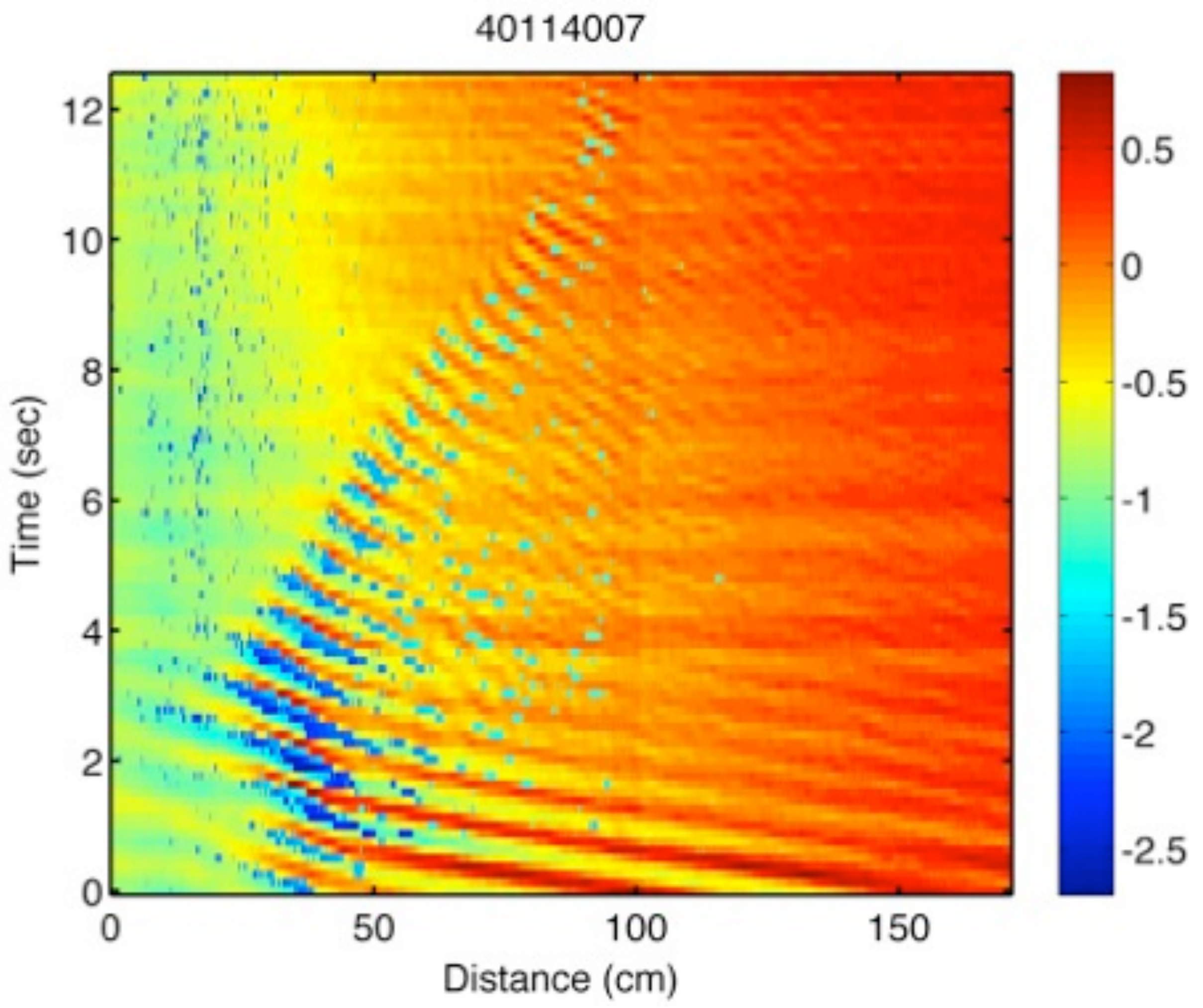
Our experiment ➤ Pair-creation process





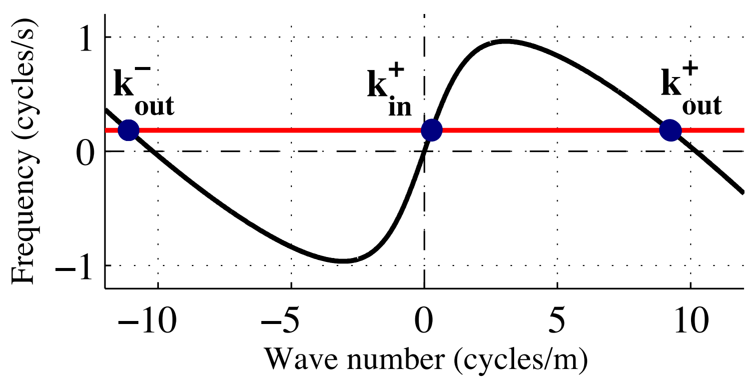
Our experiment ➤ Group versus phase velocity horizon



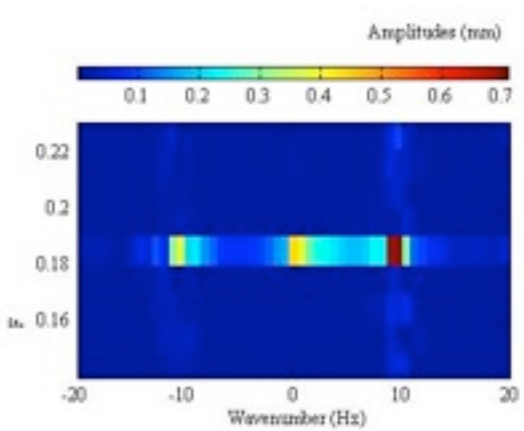


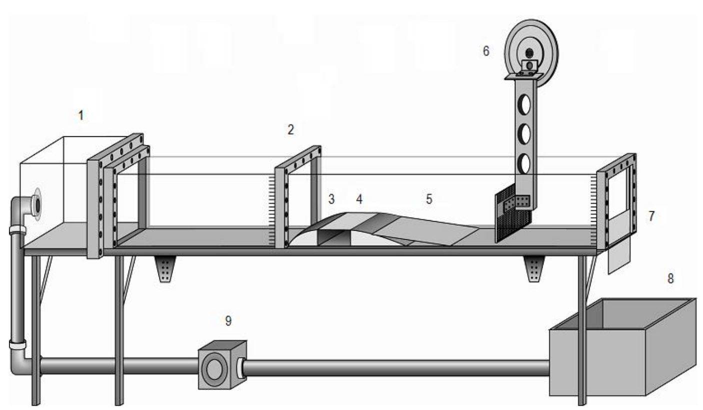
Our experiment ➤ Boltzmann distribution

(i) Amplitudes of converted waves depending on ingoing frequency:



(ii) what is a wave (particle) nearbythe white hole horizon..?

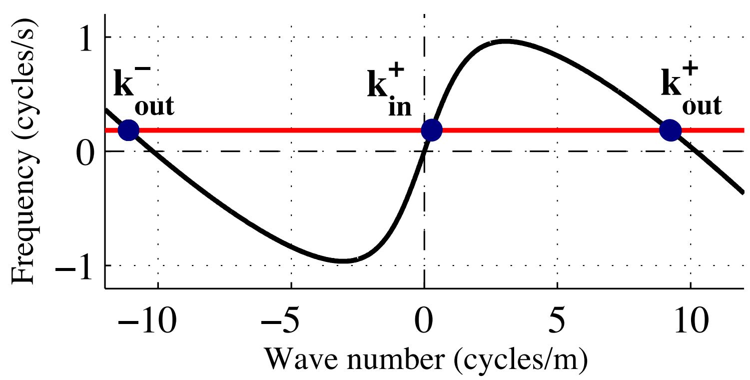


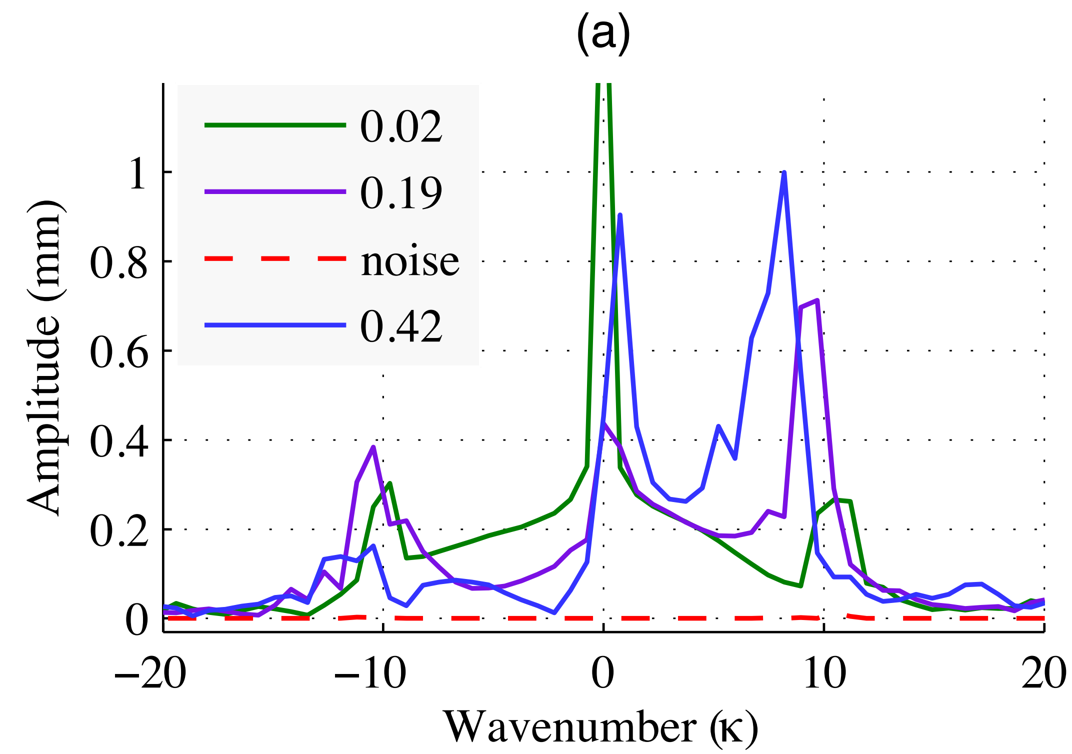


(ii) Norm is conserved: $$\int \frac{|A(f,\kappa)|^2}{f+\kappa} d\kappa$$

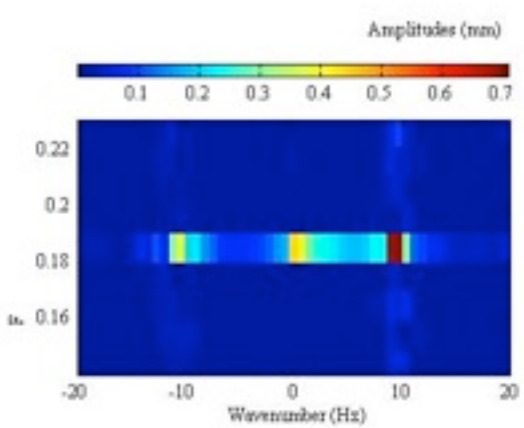
Our experiment ➤ Boltzmann distribution

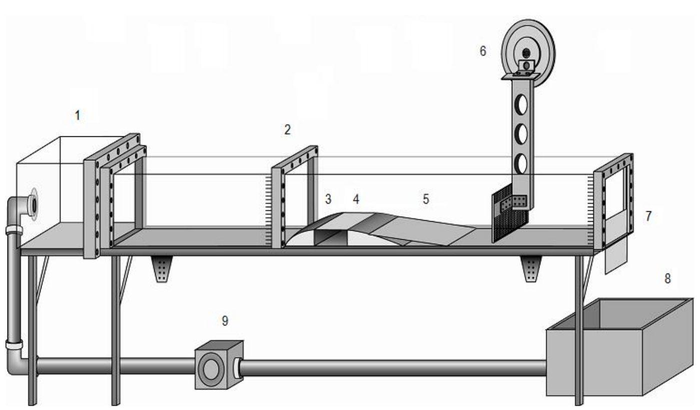
(i) Amplitudes of converted waves depending on ingoing frequency:





(ii) what is a wave (particle) nearbythe white hole horizon..?

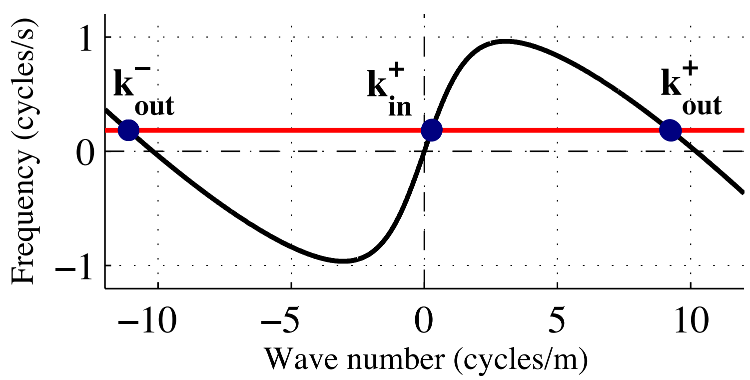




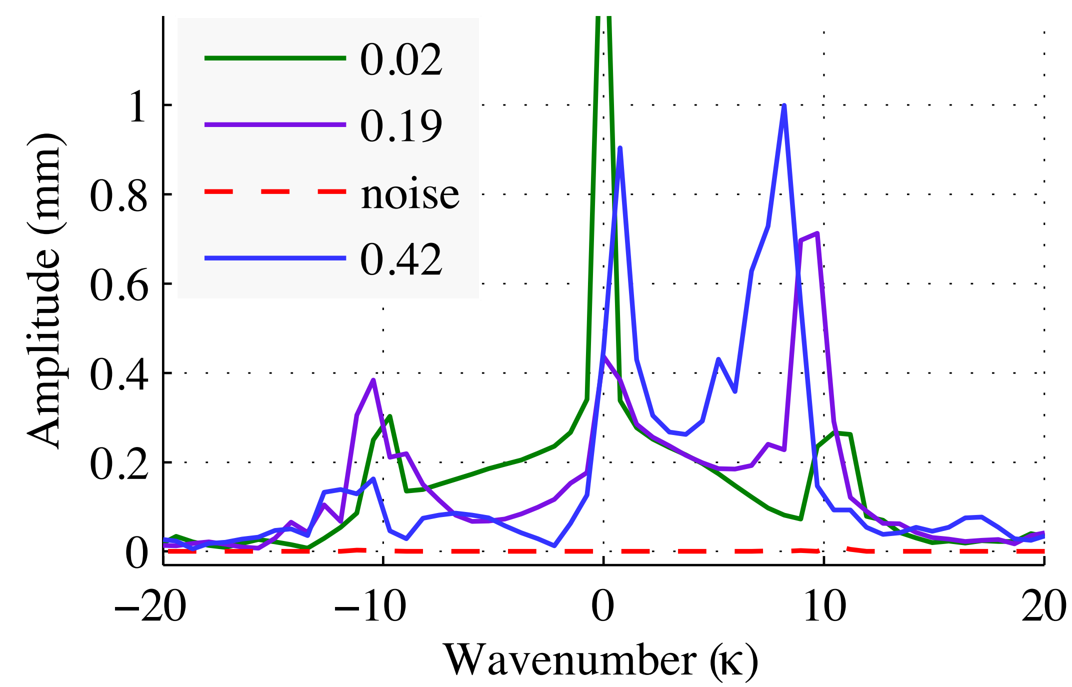
(ii) Norm is conserved: $$\int \frac{|A(f,\kappa)|^2}{f+\kappa} d\kappa$$

Our experiment ➤ Boltzmann distribution

(i) Amplitudes of converted waves depending on ingoing frequency:

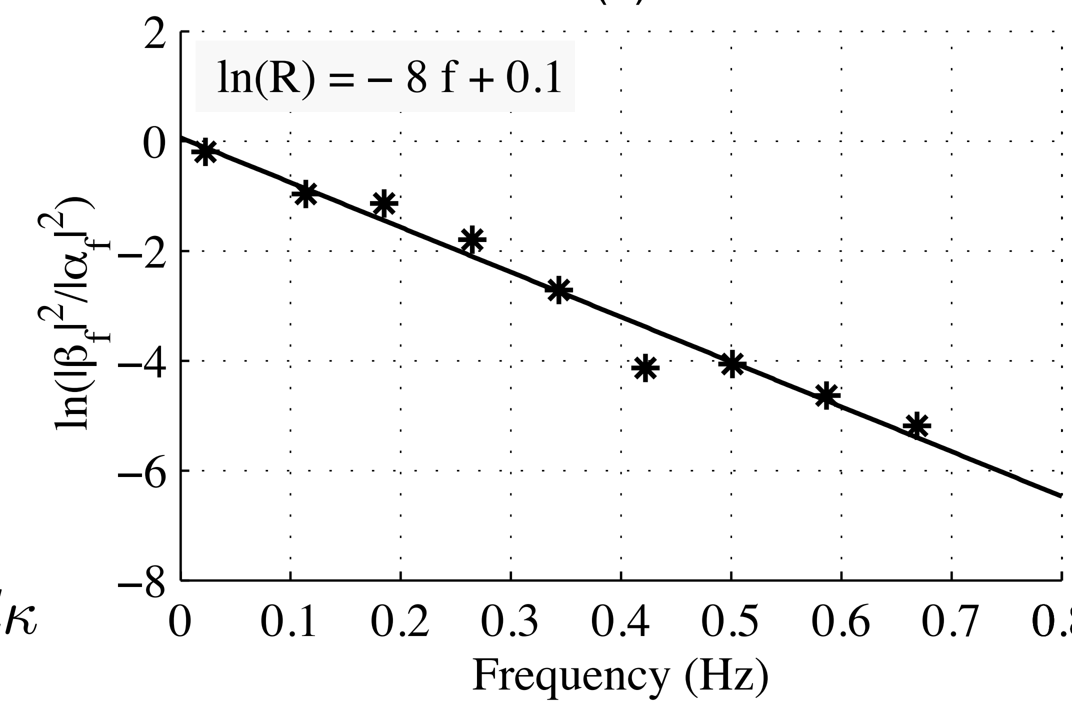


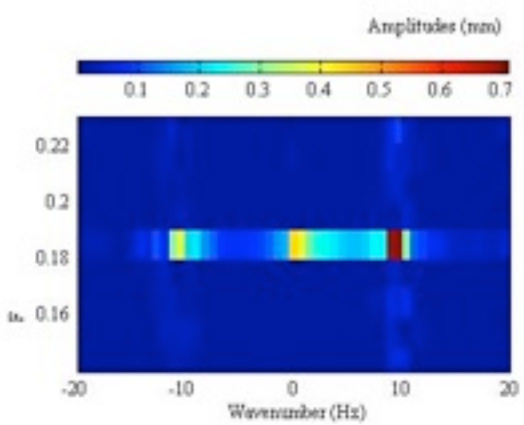
(a)

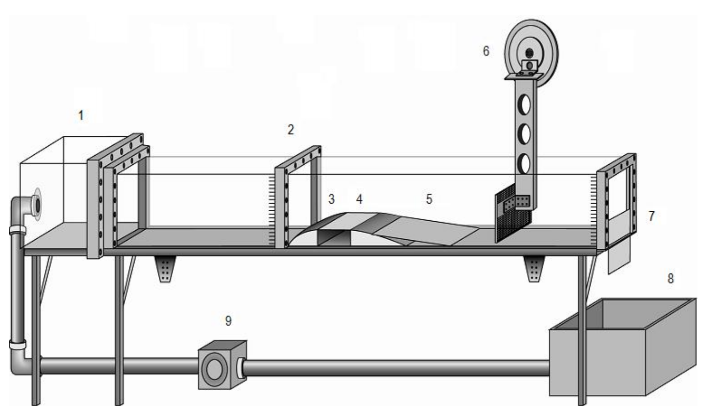


(ii) what is a wave (particle) nearbythe white hole horizon..?

(b)







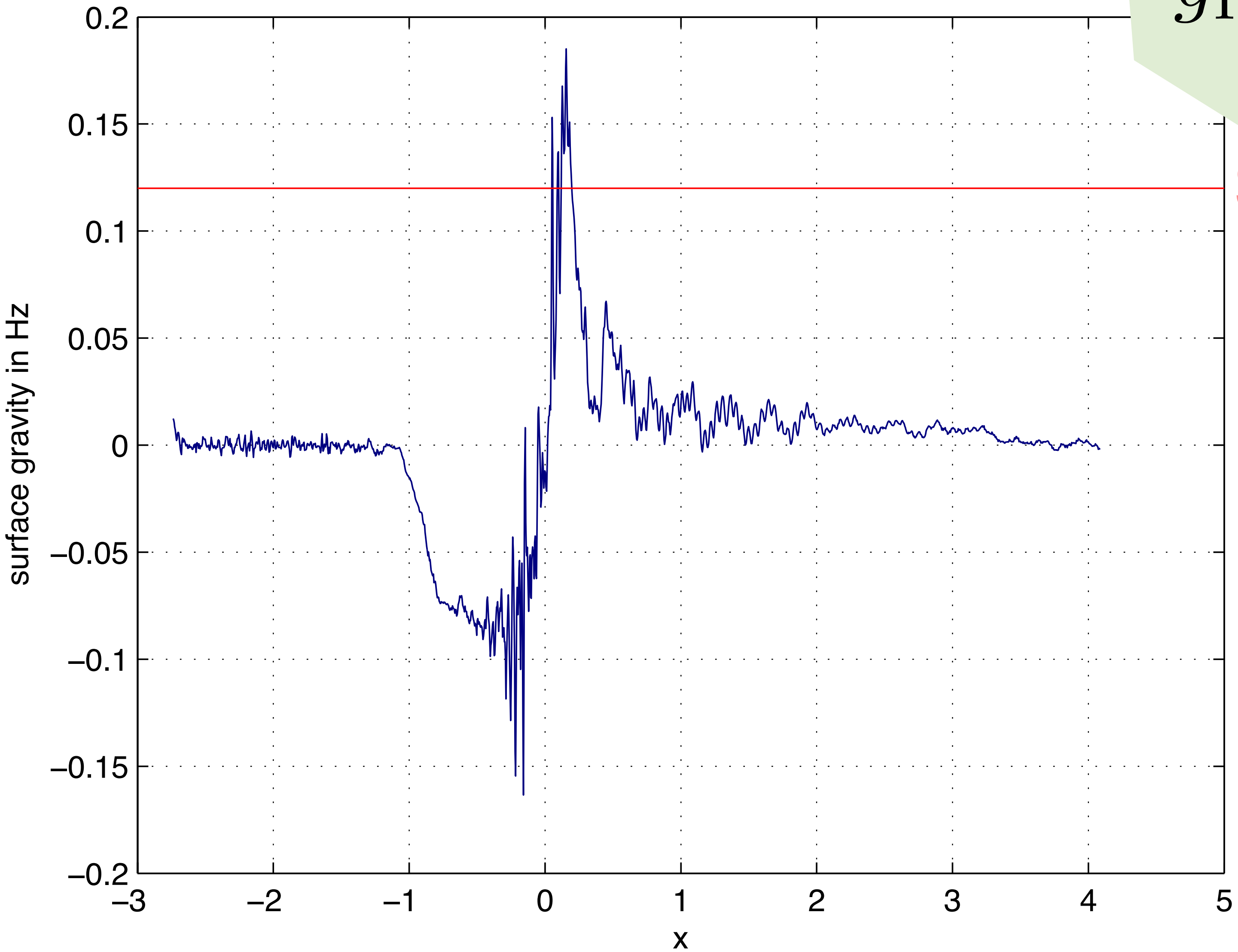
(ii) Norm is conserved:

$$\int \frac{|A(f,\kappa)|^2}{f+\kappa} d\kappa$$

Our experiment ➤ Surface gravity

- BH evaporation: $$|\beta_\omega|^2 = e^{-\frac{2\pi\omega}{g_\mathbf{H}}}|\alpha_\omega|^2$$

$$g_\mathrm{H} = \frac{1}{2}\frac{\partial(c^2 - v^2)}{\partial n}$$

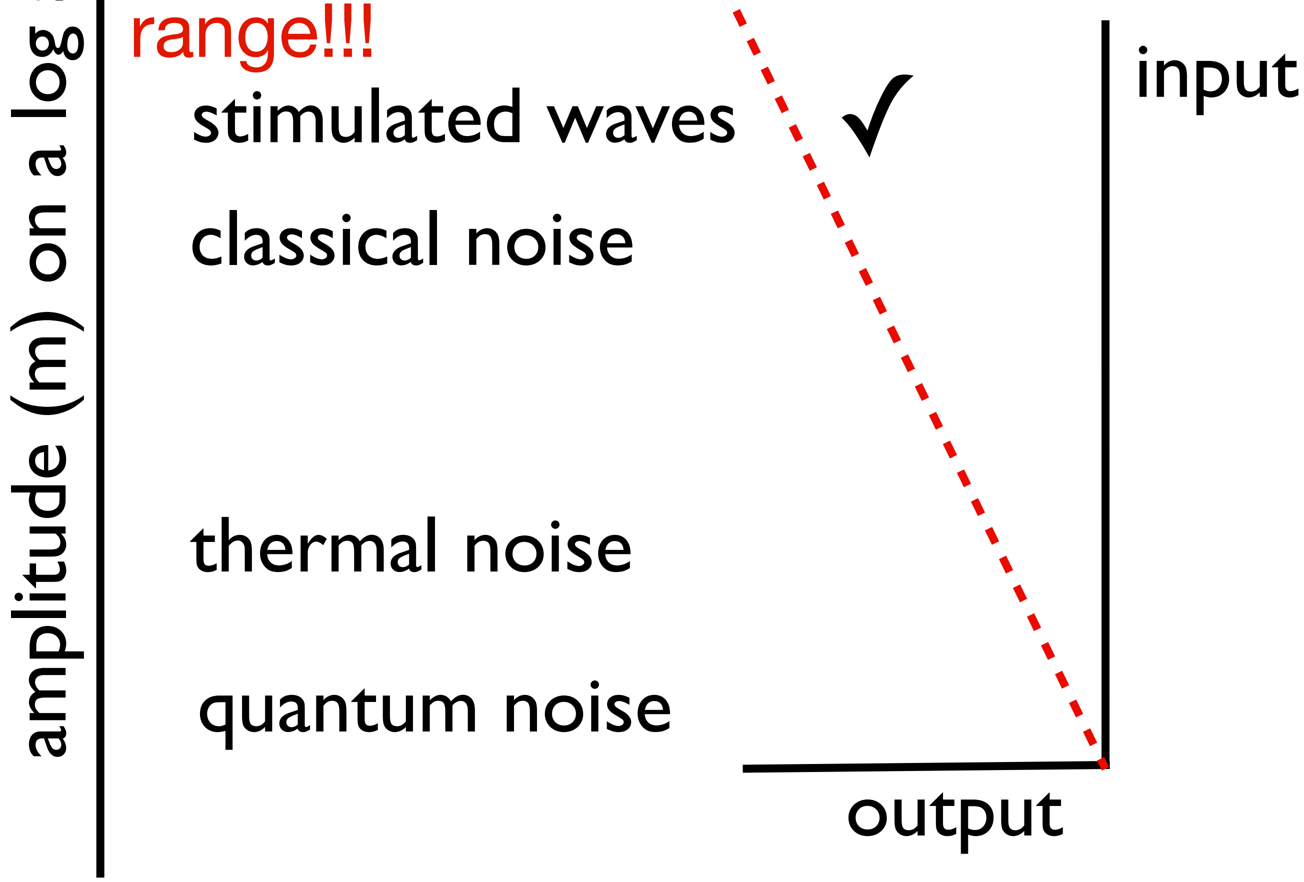


surface gravity (Hz) via **excitations:** **0.12 HZ**

surface gravity (Hz) via **background:** **0.08-0.18 Hz**

Our experiment ➤ Summary

Lesson: The thermal emission is a universal phenomenon, surviving fluid-dynamic deviations (viscosity, vorticity) and vastly altered dispersion relations, and linear over an amazing input range!!!



Assumption:

Linear amplifier over a huge range!

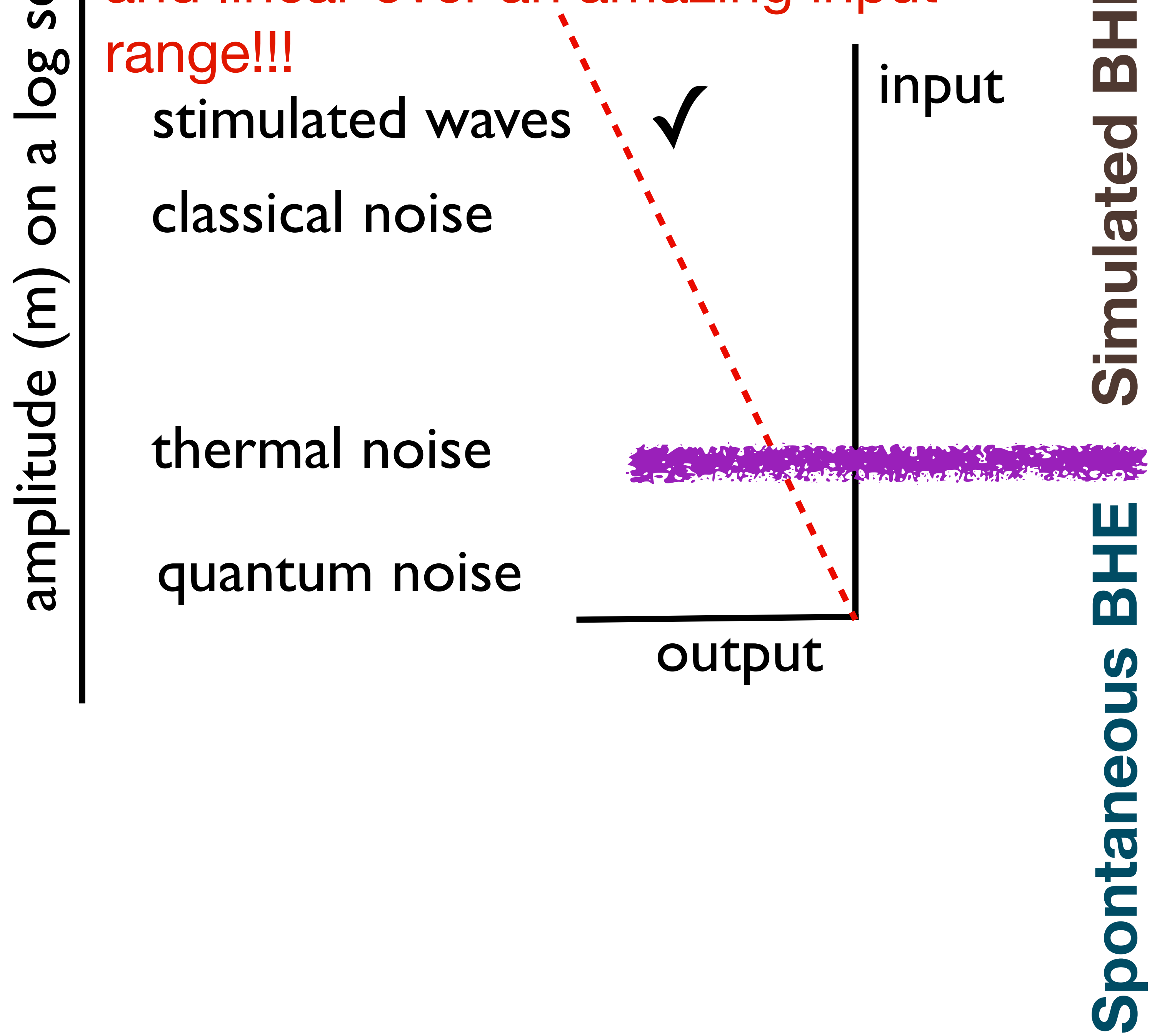
✔ pair-creation process (classical correlations)

✔ Boltzmann distribution

✔ surface gravity

Our experiment ➤ Summary

Lesson: The thermal emission is a universal phenomenon, surviving fluid-dynamic deviations (viscosity, vorticity) and vastly altered dispersion relations, and linear over an amazing input range!!!



Assumption:

Linear amplifier over a huge range!

✔ pair-creation process (classical correlations)

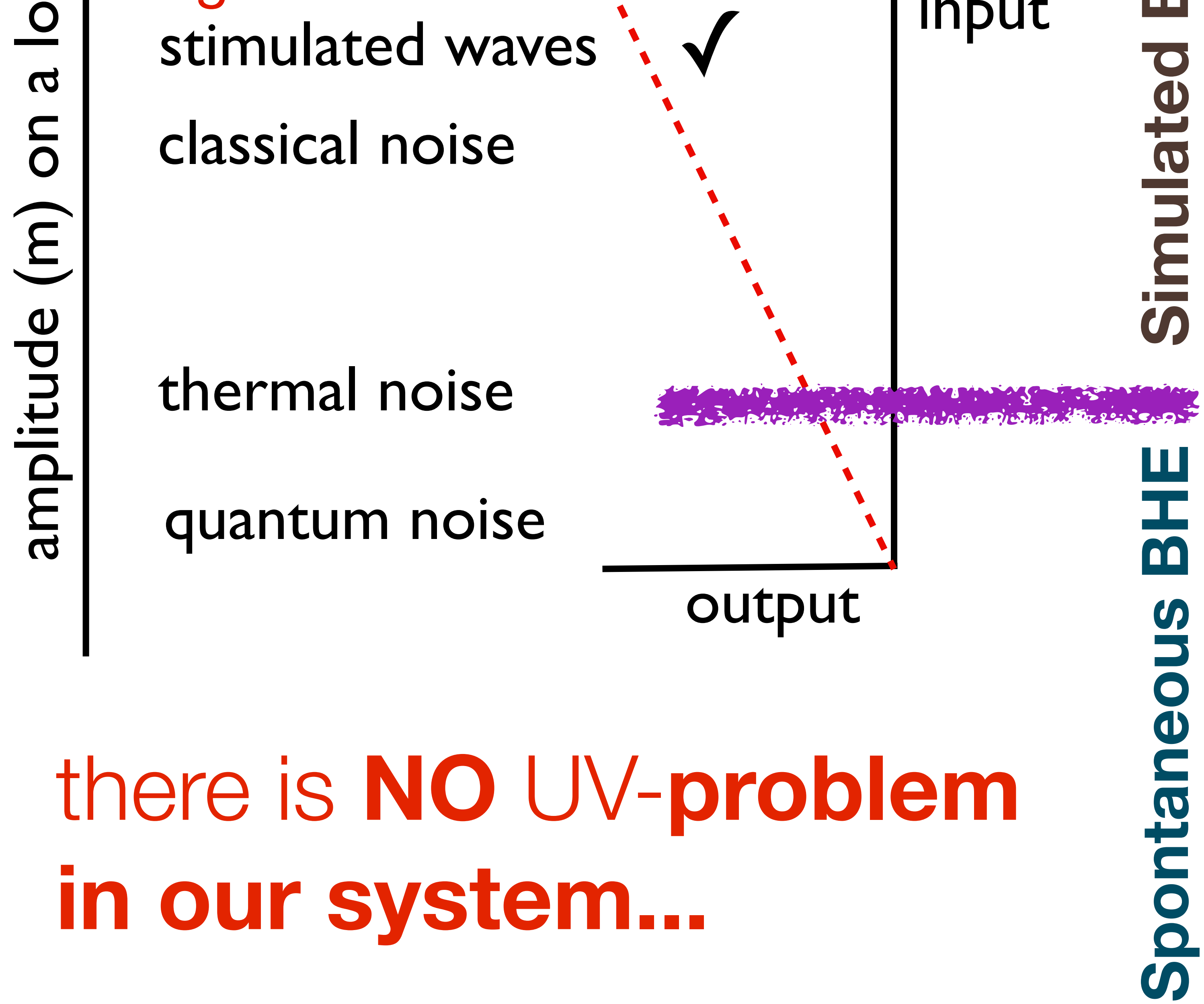
✔ Boltzmann distribution

✔ surface gravity

✔ quantum correlations

Our experiment ➤ Summary

Lesson: The thermal emission is a universal phenomenon, surviving fluid-dynamic deviations (viscosity, vorticity) and vastly altered dispersion relations, and linear over an amazing input range!!!



there is **NO** UV-**problem**
in our system...

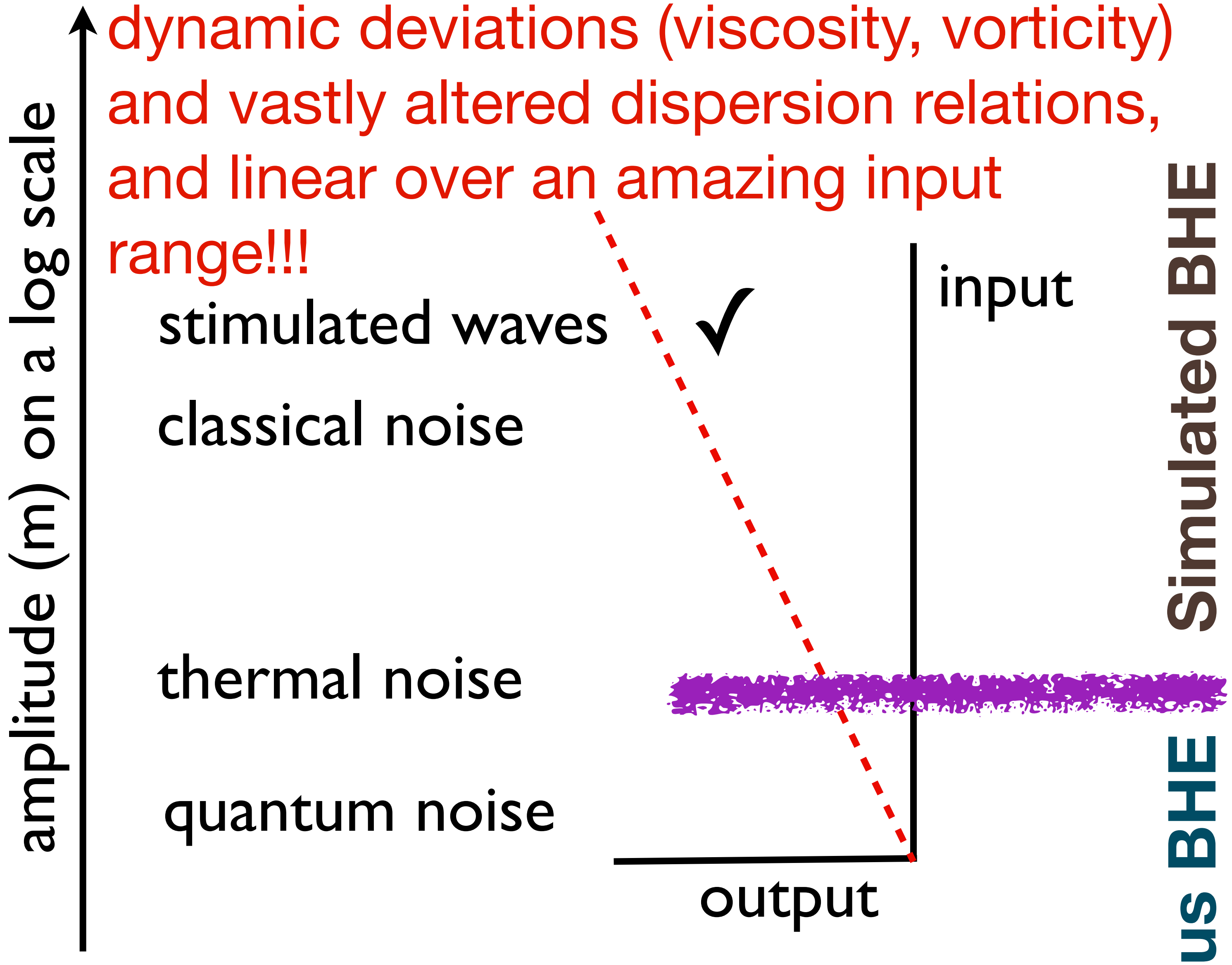
Assumption:
Linear amplifier over a huge range!

✔ pair-creation process (classical correlations)
✔ Boltzmann distribution
✔ surface gravity

✔ quantum correlations

Our experiment ➤ Summary

Lesson: The thermal emission is a universal phenomenon, surviving fluid-dynamic deviations (viscosity, vorticity) and vastly altered dispersion relations, and linear over an amazing input range!!!



Simulated BHE

Spontaneous BHE

there is **NO** UV-**problem**
in our system...

Assumption:
Linear amplifier over a huge range!

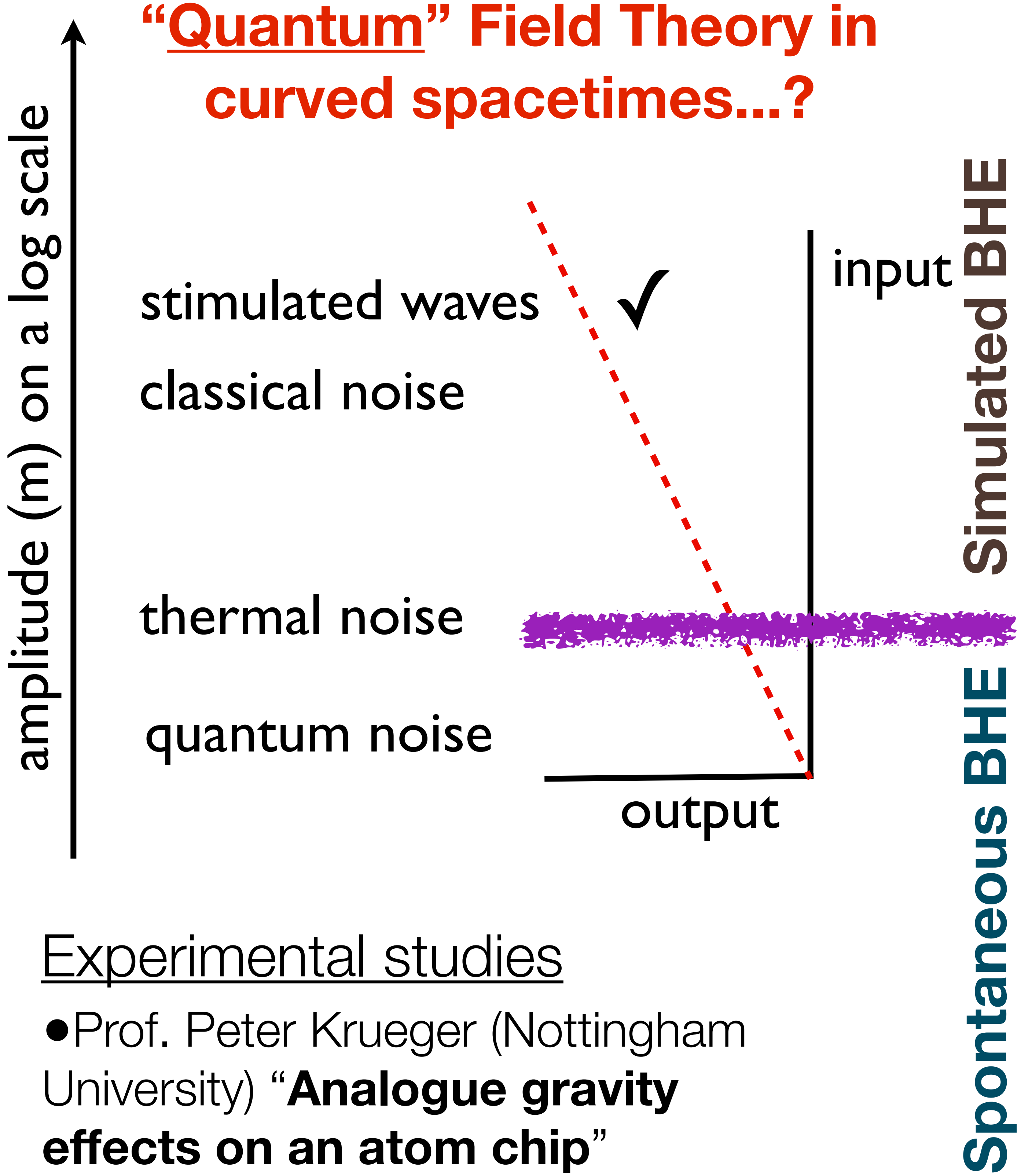
✔ pair-creation process (classical correlations)
✔ Boltzmann distribution
✔ surface gravity

However: Spontaneous emission straightforward, but un- detectable (**6x10^-12 K**); superfluid experiments necessary...

✔ quantum correlations

Future experiments ➤ “Quantum” field theory in

“Quantum” Field Theory in curved spacetimes...?

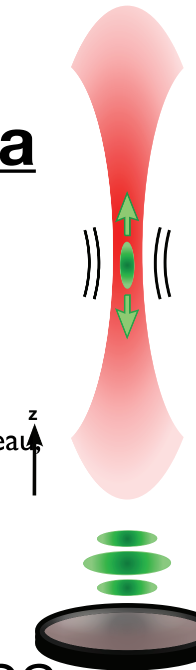


Experimental studies

- Prof. Peter Krueger (Nottingham University) “**Analogue gravity effects on an atom chip**”

An acoustic analog to the dynamical Casimir effect in a Bose--Einstein condensate: Classical or quantum correlations?

Jean-Christophe Jaskula, Guthrie B. Partridge, Marie Bonneau, Raphael Lopes, Josselin Ruaudel, Denis Boiron, Christoph I Westbrook

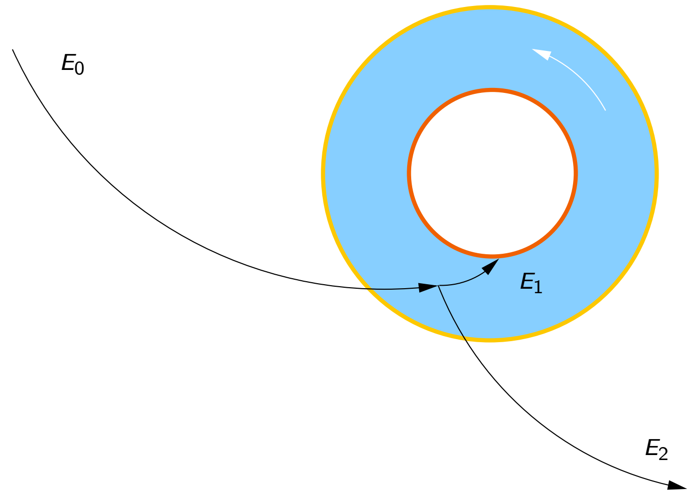


Theoretical studies in progress

- “**On the robustness of entanglement in analogue gravity systems**” in collaboration with Ivette Fuentes, Nicolai Friis, David Bruschi.
- “**Entanglement measures in parametrically excited Bose-Einstein condensates**” in collaboration with Piyush Jain.
- “**Analogue relativistic quantum information**” in collaboration with Ivette Fuentes and Piyush Jain.

New experiment - ongoing experiments at SISSA/ICTP/Elettra

Description: Experimental studies of effective rotating black holes, to detect:
- superradiant wave-scattering
- stimulated black-hole emission



Surface waves on stationary draining water / bathtub vortex / analogue rotating black hole...

...superfluid bathtub vortex flows

Theoretical studies:

* Vortex geometry for the equatorial slice of the Kerr black hole (M. Visser, S.W.);
* **In preparation:** Generalized superradiant scattering (M. Richartz, S.W., A.J. Penner, W.G. Unruh);
* **ArXiv:** Dispersive superradiant scattering (A. Prain, M. Richartz, S.W., S. Liberati)

Numerical studies:

* In preparation: Experimental superradiant scattering (M. Richartz, J. Penner, A. Prain, J. Niemela, S.W.)

Experiment studies:

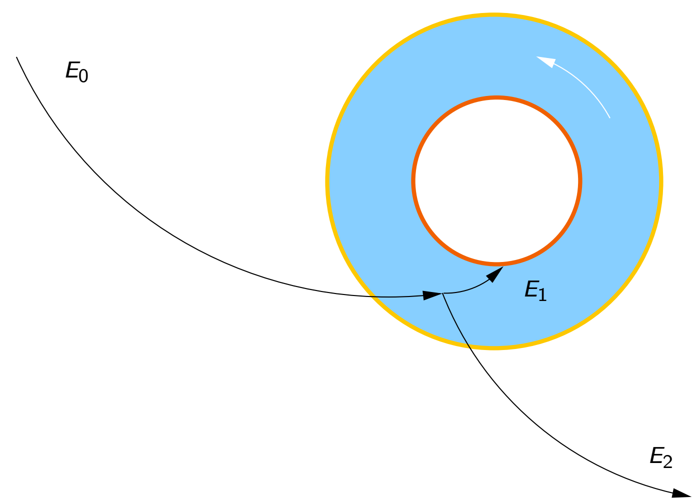
* surface wave detection
* design for water flume
* prototype ready for experiments
* big water flume (3 x 1.5 x 0.5 meter) under construction

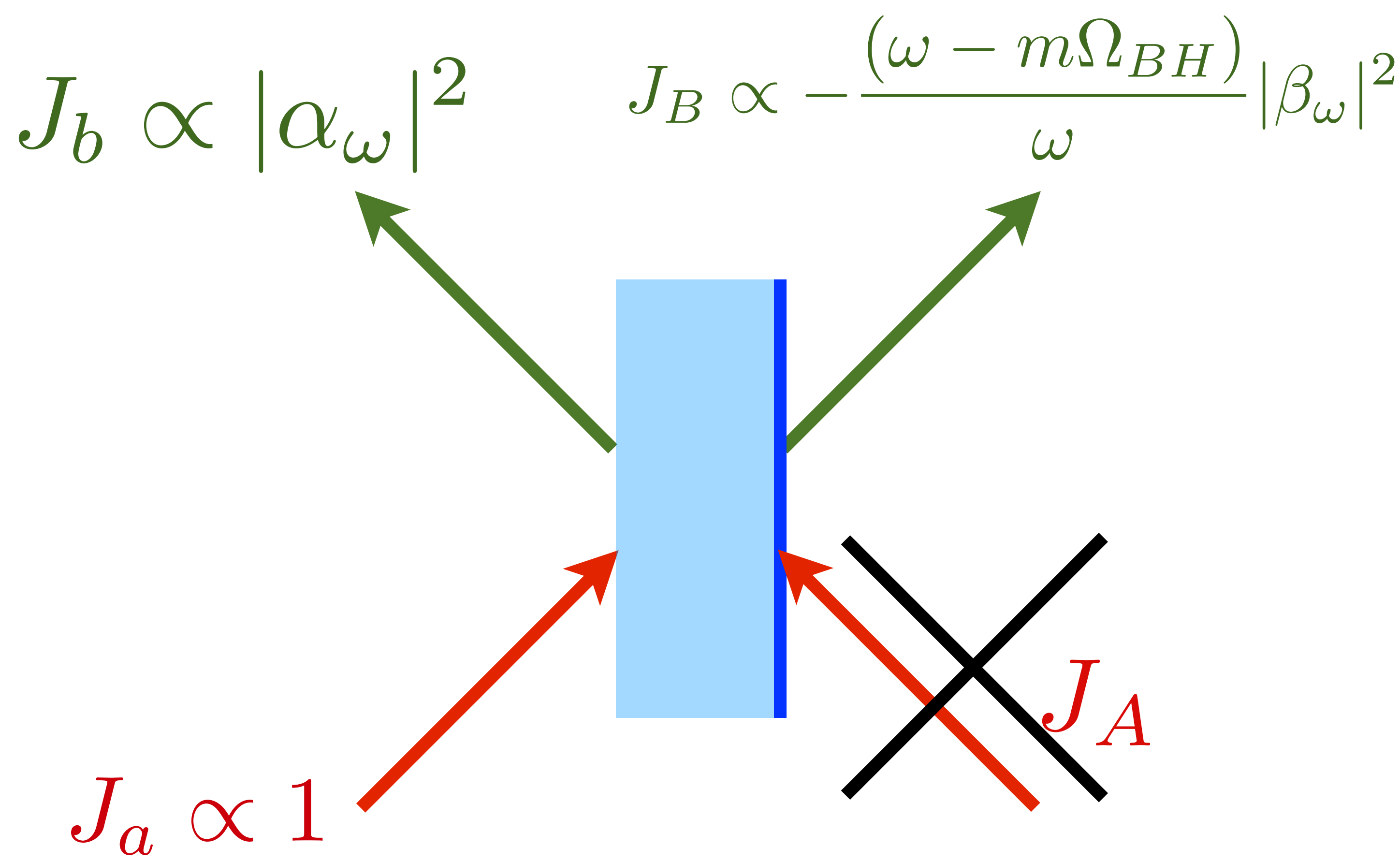
The team:

* *Prof. J. Niemela* (ICTP), Matt Penrice and Ted Tedford
* Prof. S. Liberati (SISSA), Dr. M. Richartz (Brasil), Dr. J. Penner (France), Dr. M. Danailov, A. Prain.

New experiment ➤ Superradiant wave scattering

Particle current: $J_n := |A_n|^2 \left.\Omega\right|_{\pm\infty} \left.\frac{d\omega}{dk}\right|_{k_n}$





$$|R|^2 = 1 - \frac{(\omega - m\Omega_{BH})}{\omega}|T|^2$$

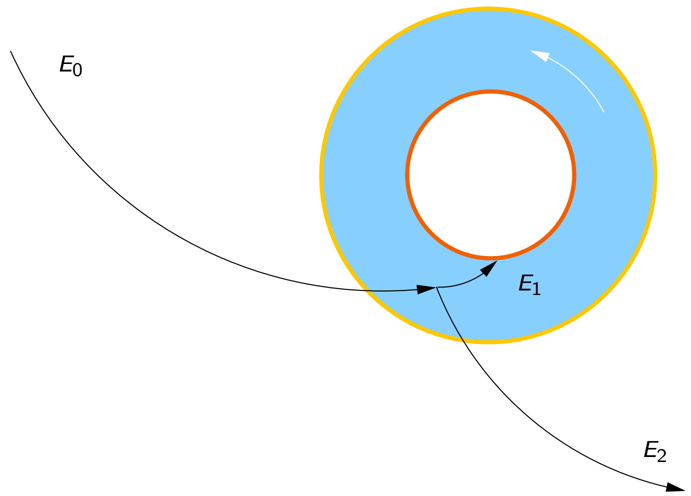
$$1 \quad + \quad 0 \quad = |\alpha_\omega|^2 + -\frac{(\omega - m\Omega_{BH})}{\omega}|\beta_\omega|^2$$

Dispersive superradiant scattering (A. Prain, M. Richartz, S.W., S. Liberati)

Rotating Black holes: Linear Classical and Quantum Field Amplifier!

New experiment ➤ Superradiant wave scattering

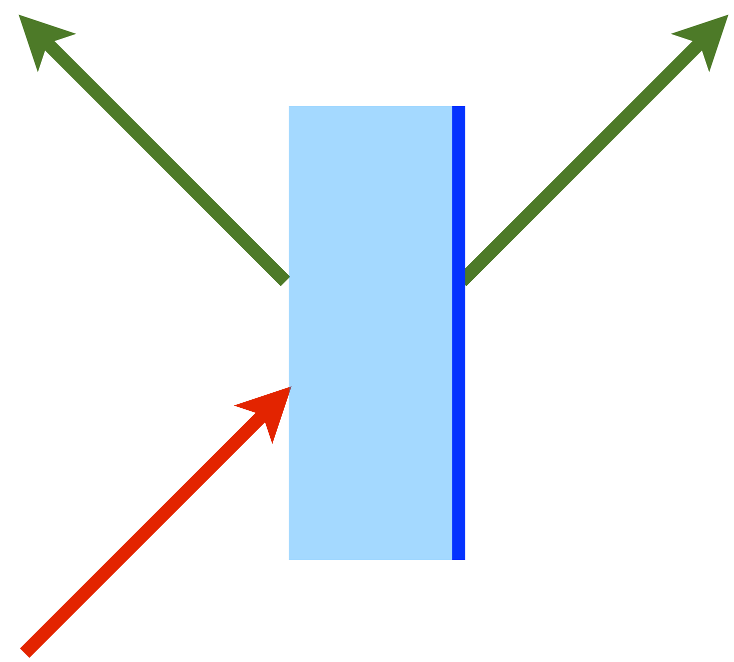
Particle current: $J_n := |A_n|^2 \, \Omega|_{\pm\infty} \left.\frac{d\omega}{dk}\right|_{k_n}$



$$|R|^2 = 1 - \frac{(\omega - m\Omega_{BH})}{\omega}|T|^2$$

Dispersive superradiant scattering (A. Prain, M. Richartz, S.W., S. Liberati)

$$J_b \propto |\alpha_\omega|^2 \qquad J_B \propto -\frac{(\omega - m\Omega_{BH})}{\omega}|\beta_\omega|^2$$



$$J_a \propto 1$$

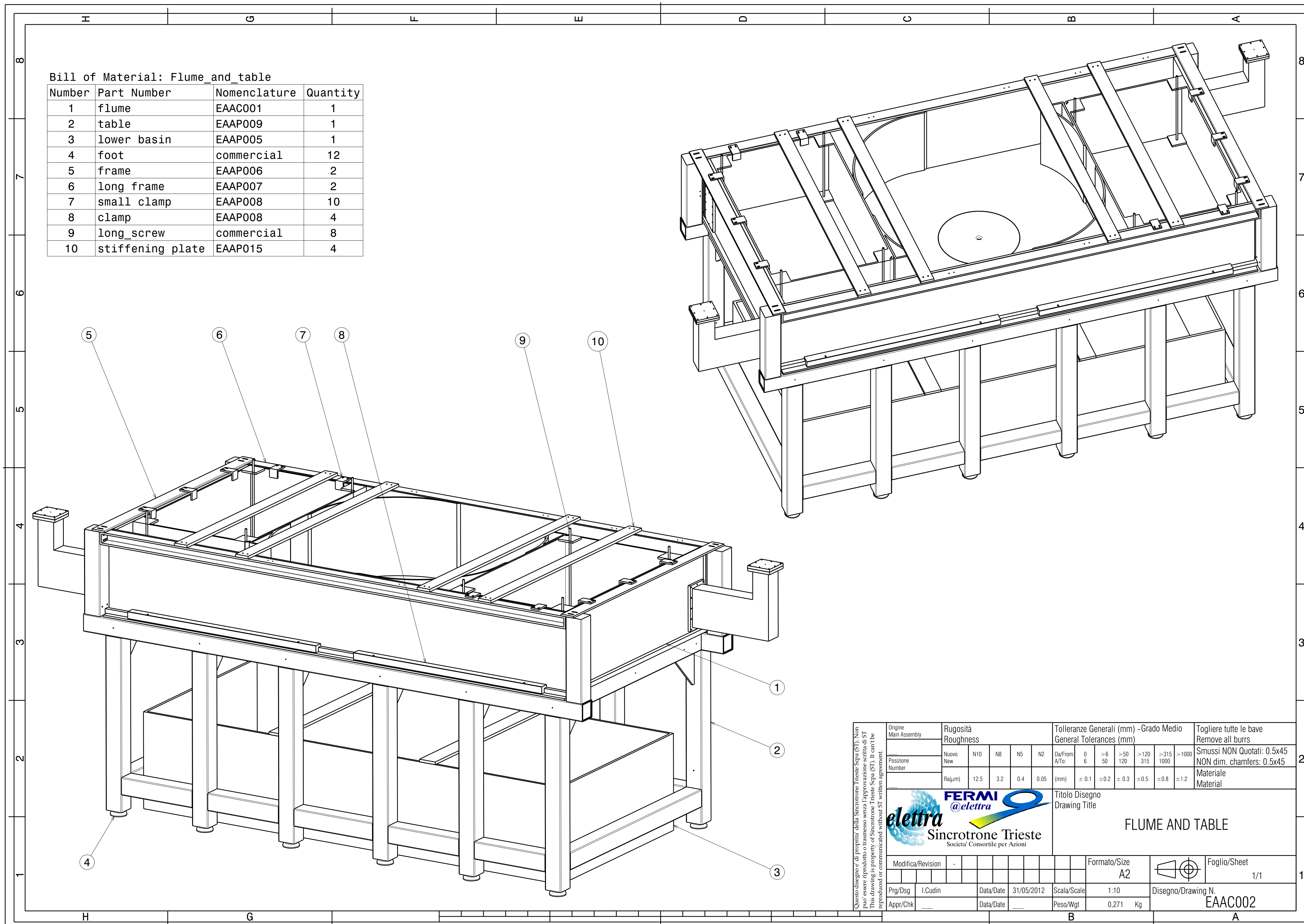
$$1 \quad + \quad 0 \qquad = |\alpha_\omega|^2 + -\frac{(\omega - m\Omega_{BH})}{\omega}|\beta_\omega|^2$$

Rotating Black holes: Linear Classical and Quantum Field Amplifier!

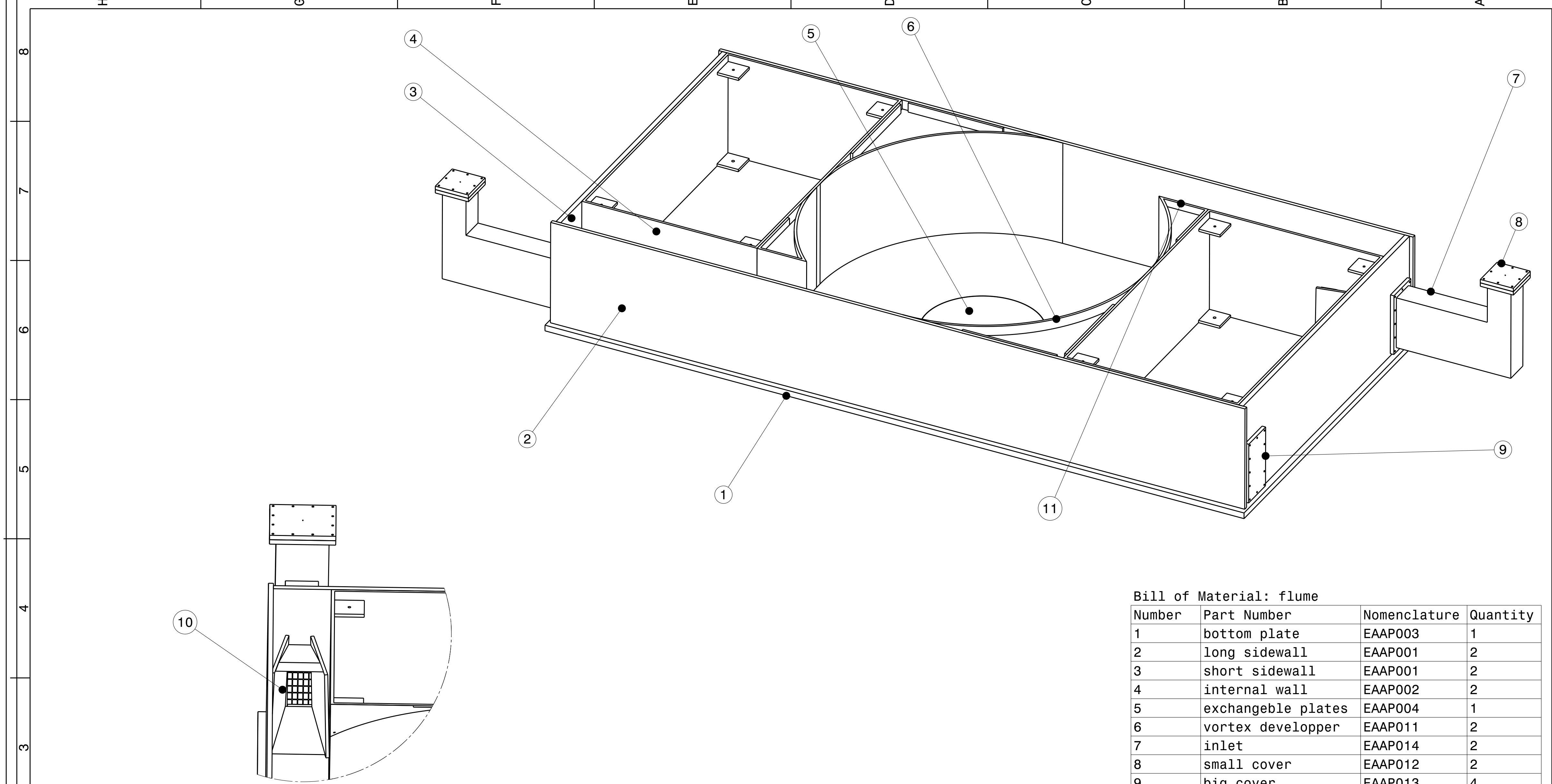
New experiment - ongoing experiments at SISSA/ICTP/Elettra

Bill of Material: Flume_and_table

Number	Part Number	Nomenclature	Quantity
1	flume	EAAC001	1
2	table	EAAP009	1
3	lower basin	EAAP005	1
4	foot	commercial	12
5	frame	EAAP006	2
6	long frame	EAAP007	2
7	small clamp	EAAP008	10
8	clamp	EAAP008	4
9	long_screw	commercial	8
10	stiffening plate	EAAP015	4



New experiment - ongoing experiments at SISSA/ICTP/Elettra



Bill of Material: flume

Number	Part Number	Nomenclature	Quantity
1	bottom plate	EAAP003	1
2	long sidewall	EAAP001	2
3	short sidewall	EAAP001	2
4	internal wall	EAAP002	2
5	exchangeble plates	EAAP004	1
6	vortex developper	EAAP011	2
7	inlet	EAAP014	2
8	small cover	EAAP012	2
9	big cover	EAAP013	4
10	slope	EAAP016	2
11	vortex developper 2	EAAP016	2

Origine Main Assembly	Rugosità Roughness					Tolleranze Generali (mm) - Grado Medio General Tolerances (mm)						Togliere tutte le bave Remove all burrs
Posizione Number	Nuovo New	N10	N8	N5	N2	Da/From: A/To:	0 6	>6 50	>50 120	>120 315	>315 1000	>1000	Smussi NON Quotati: 0.5x45 NON dim. chamfers: 0.5x45
	Ra(μm)	12.5	3.2	0.4	0.05	(mm)	± 0.1	±0.2	± 0.3	±0.5	±0.8	±1.2	Materiale Material PLEXIGLAS

FERMI @elettra
elettra Sincrotrone Trieste
Societa' Consortile per Azioni

Titolo Disegno / Drawing Title: FLUME ASSEMBLY

Modifica/Revision: -

Formato/Size: A2

Foglio/Sheet: 1/1

Prg/Dsg: I.Cudin | Data/Date: 05/07/2012 | Scala/Scale: 1:10

Appr/Chk: ___ | Data/Date: ___ | Peso/Wgt: 0,271 Kg

Disegno/Drawing N. EAAC001