Title: Quantum Gravity Laboratory

Date: Oct 27, 2011 11:00 AM

URL: http://www.pirsa.org/11100063

Abstract: At the level of effective field theory it is possible to establish analogies between non-gravitational and gravitational systems. For example, first order perturbation equations in an analogue gravity model can be written as a wave equation in a curved spacetime. Perhaps the most intriguing application of analogue gravity systems is the possibility to experimentally investigate open questions in semi-classical quantum gravity, such as the black hole evaporation process. I will briefly discuss our recent black hole experiment, which demonstrates the universality of the Hawking process. If time permits, I will discuss the possibility to extend the analogue gravity programme, and outline the necessary steps towards full quantum gravity experiments.

Emergent Gravity

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MARIE CURIE ACTIONS

Phys. Rev. Lett. 106, 021302 (2011)

Quantum gravity laboratory

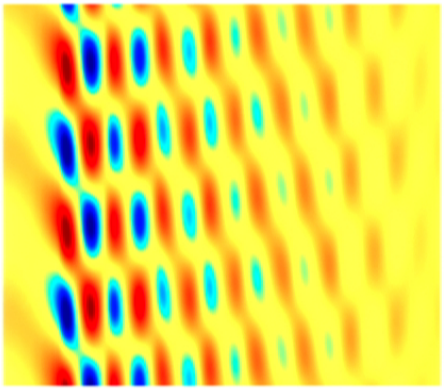
Analogue gravity are nice, but will they really work out? Is there any hope to extend the analogue gravity idea to analogue quantum gravity..?

UBC

by

- Greg Lawrence
- Matt Penrice
- Ted Tedford
- Bill Unruh
- (Mauricio Richartz)

Silke Weinfurtner



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Our experiment and goals

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

Our experiment in a nutshell

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

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

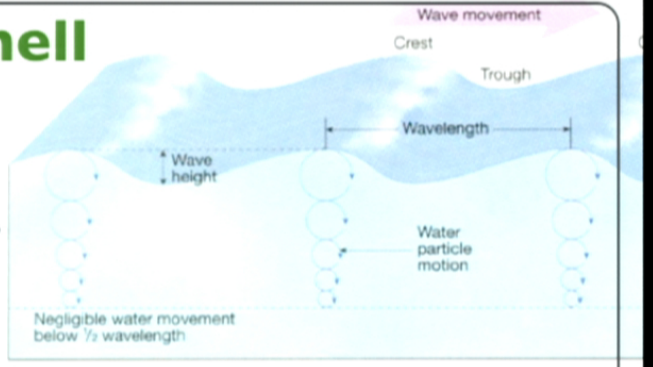

Figure 14.2 This diagram illustrates the basic parts of a wave as well as the movement wave. Negligible water movement occurs below a depth equal to one-half the wavelen

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

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 HS.

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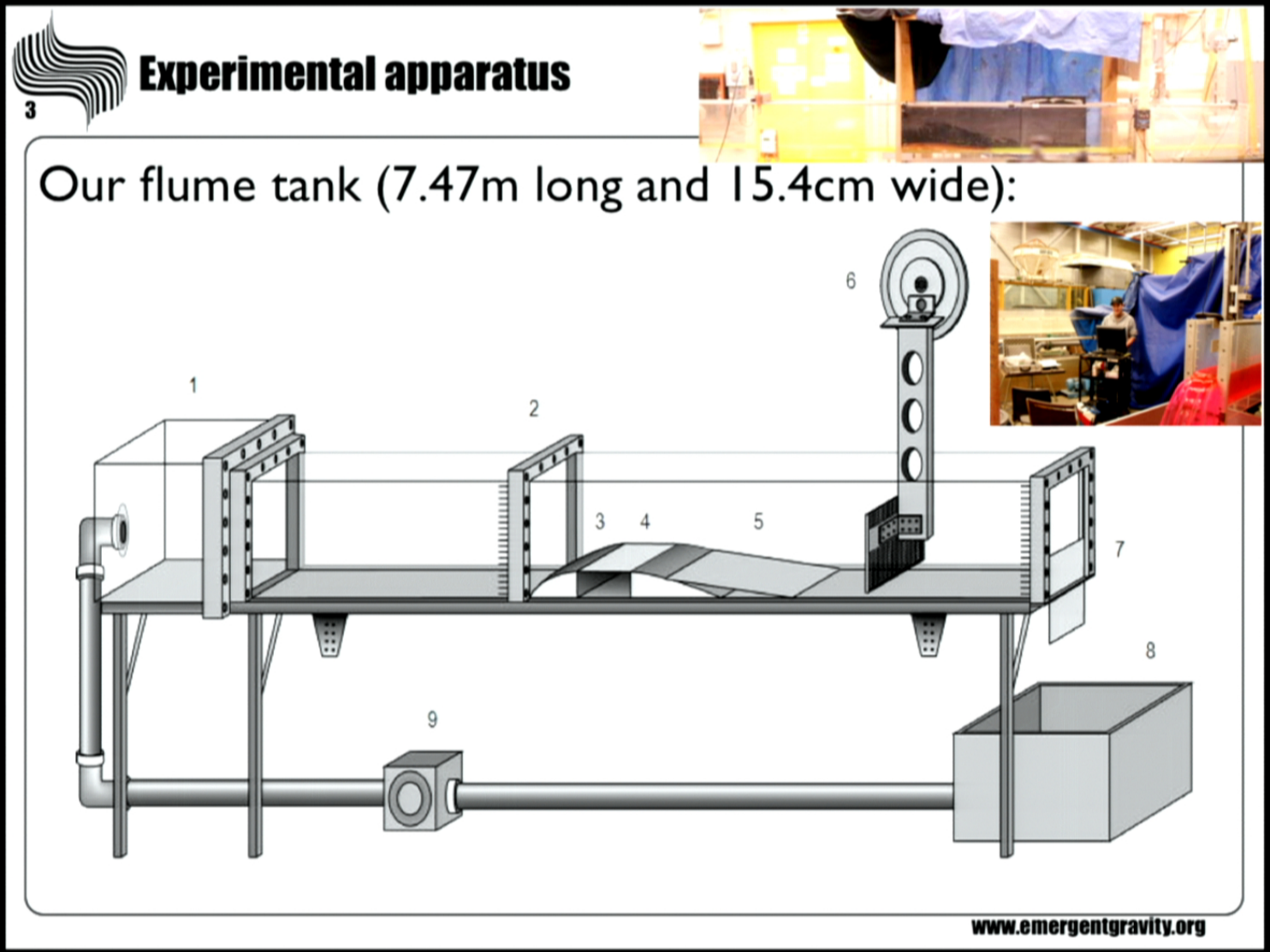
3
Experimental apparatus
Our flume tank (7.47m long and 15.4cm wide):
1
2
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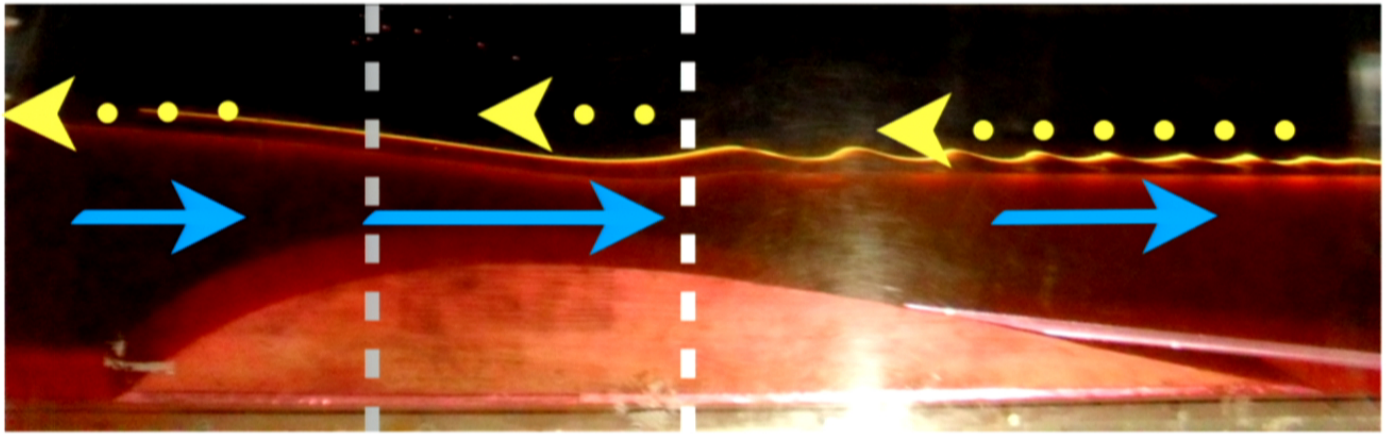
Why black AND white holes..?

effective
white hole



effective
black hole

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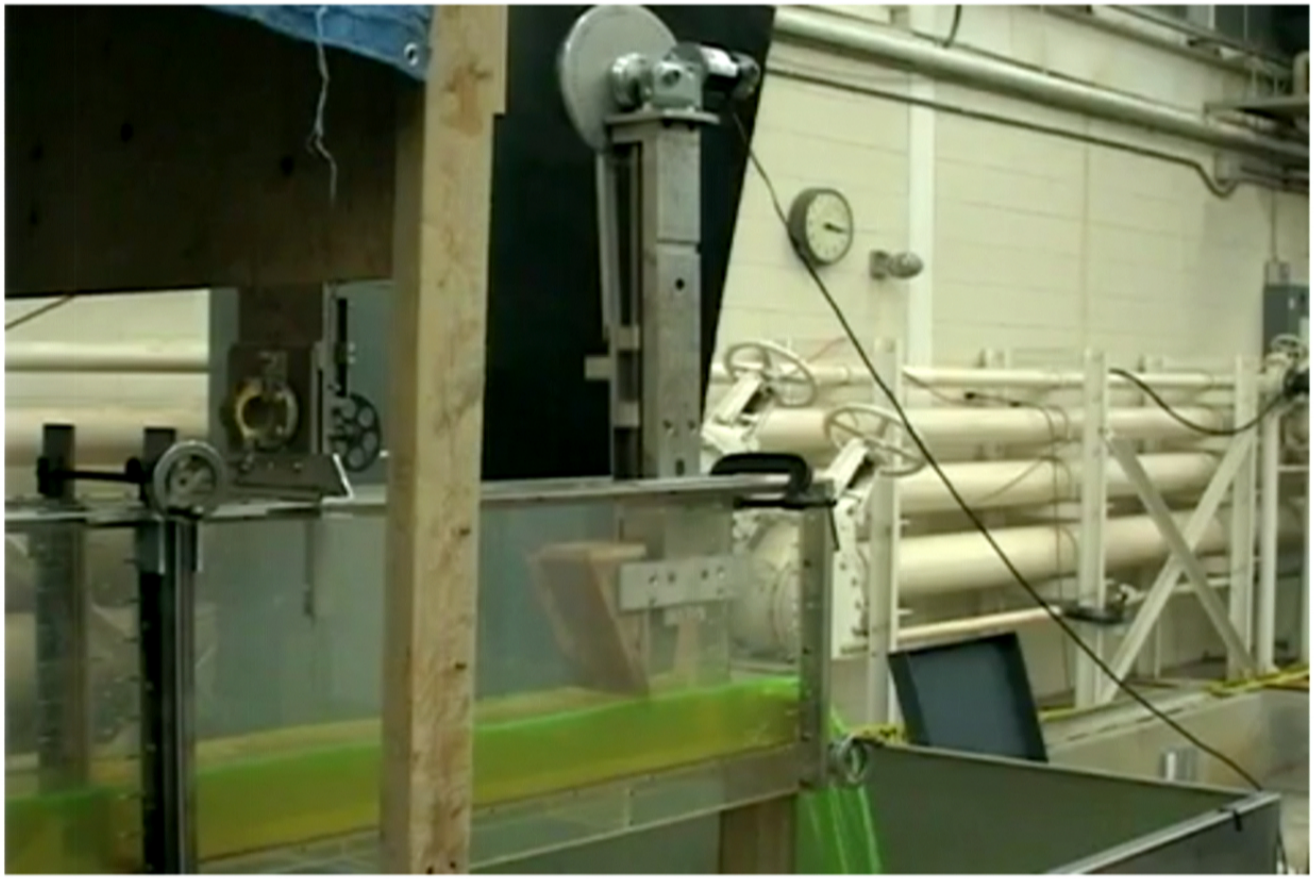
The experiment (early experiment with bigger waves)



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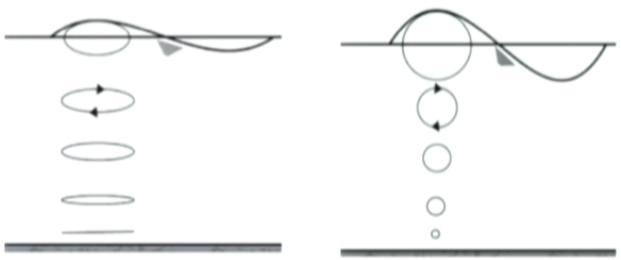
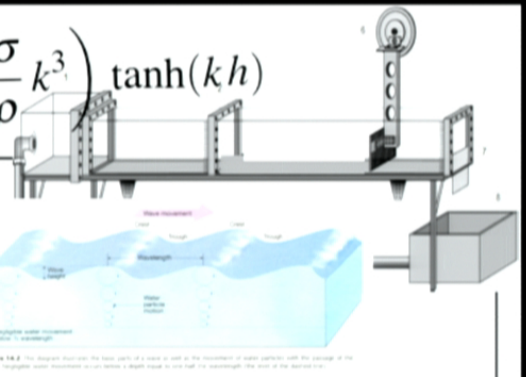
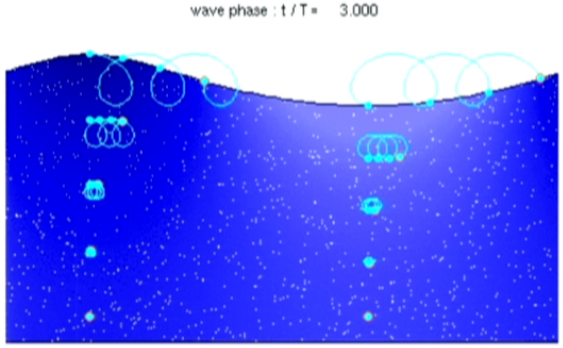
Physics of surface waves $\Omega^2 = \left(gk + \frac{\sigma}{\rho}k^3\right)\tanh(kh)$

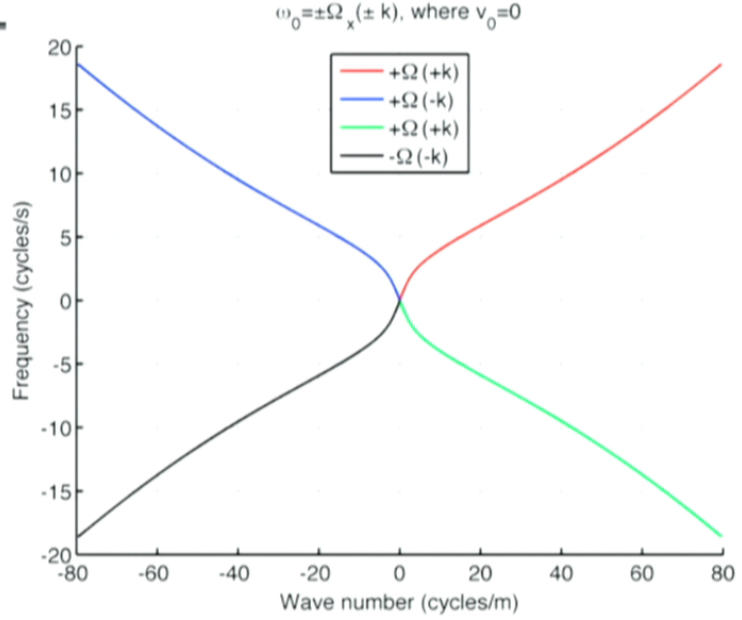




shallow: $\Omega = \sqrt{gh}\,k$

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





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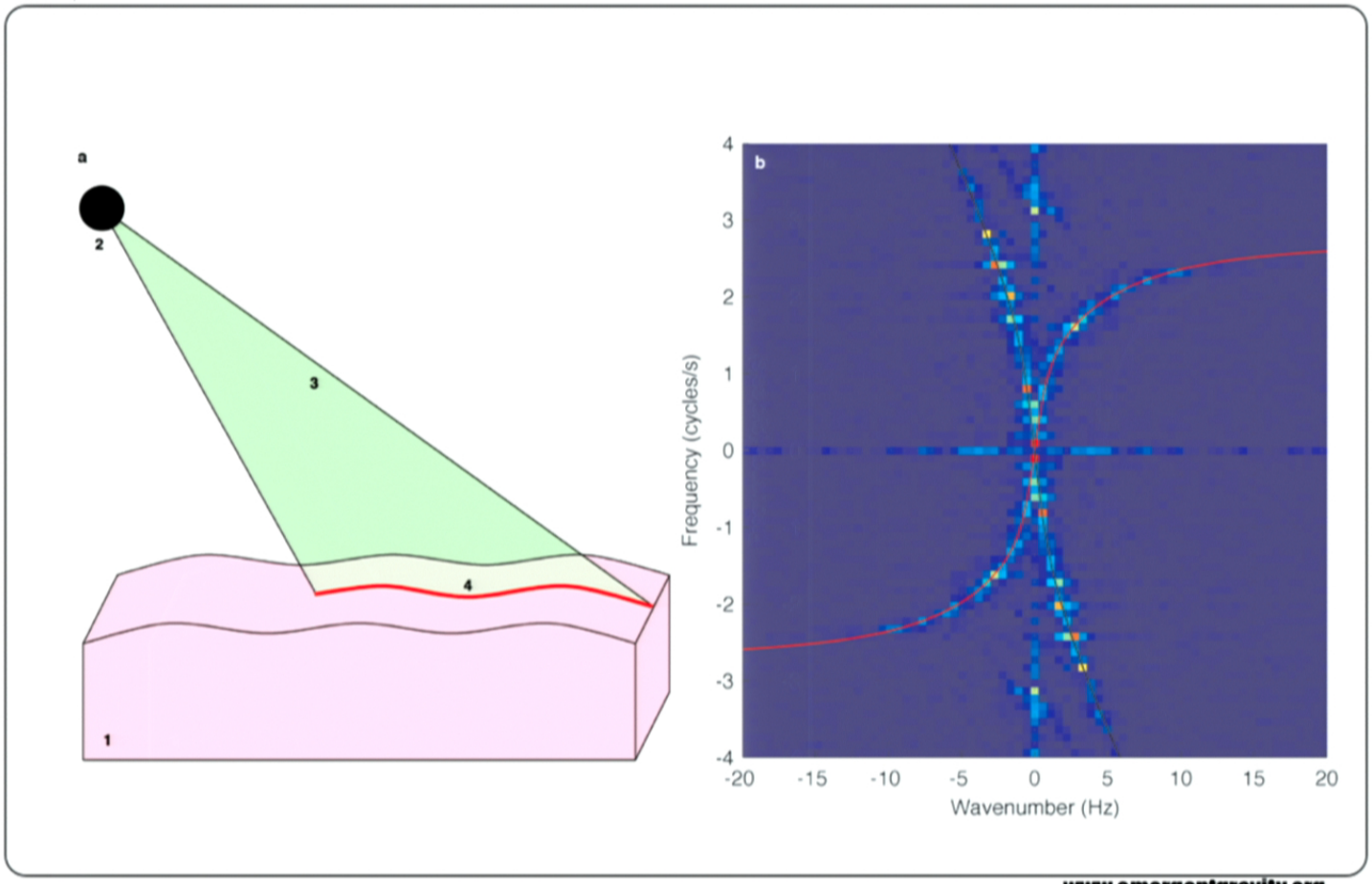
Free surface: our observable



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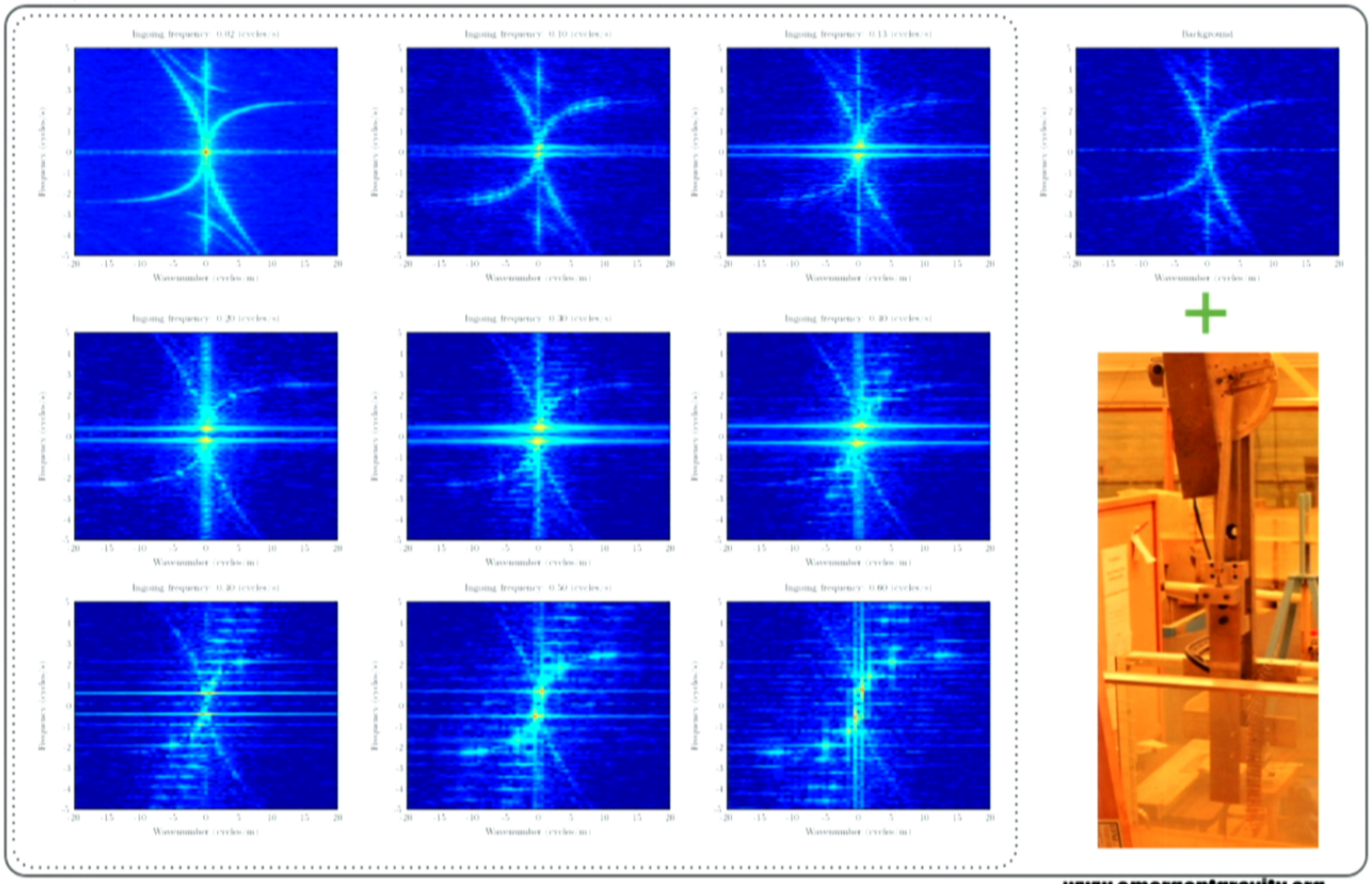
Stimulated system - generated ingoing waves



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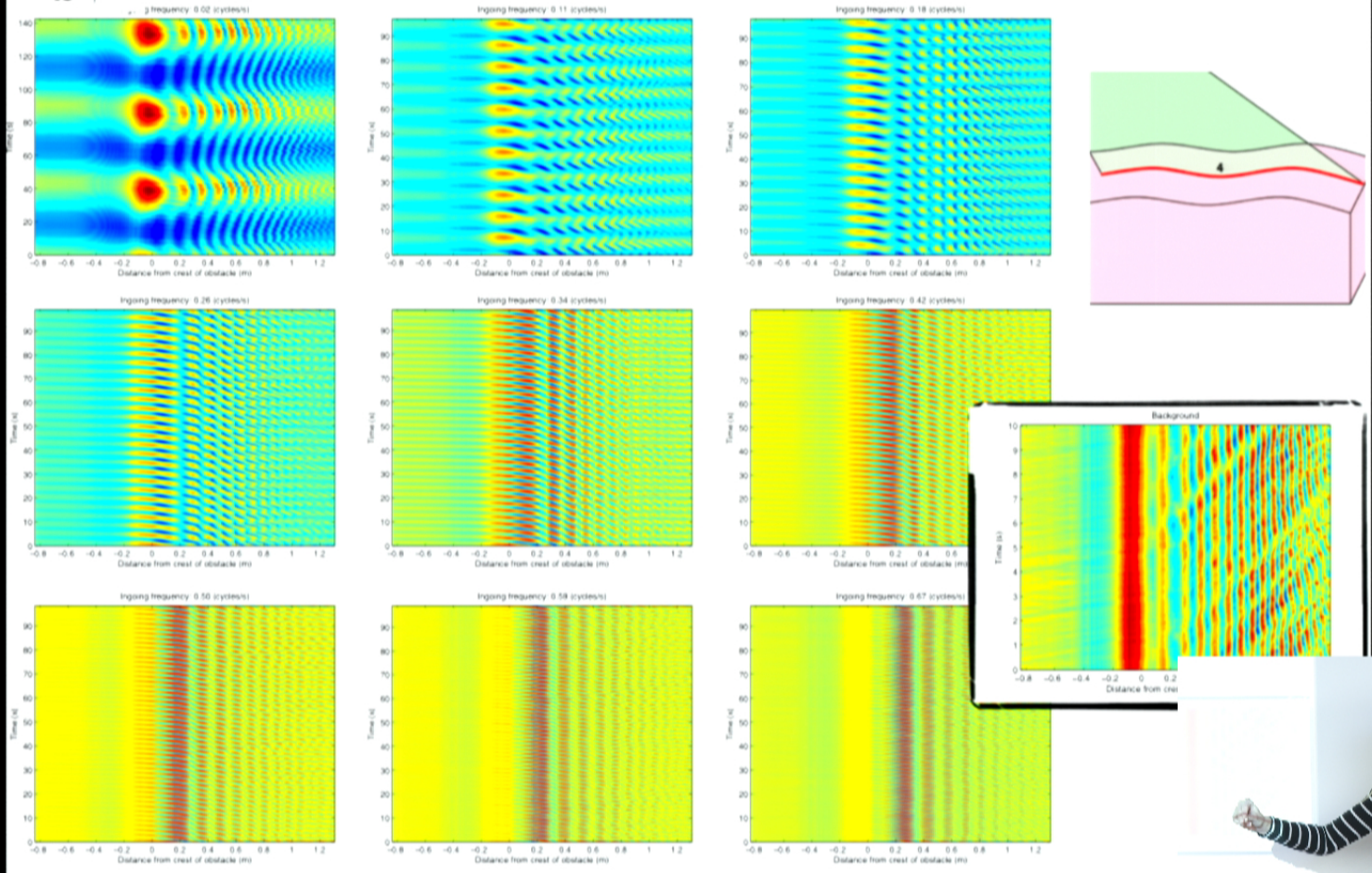
Wave characteristics for various driving frequencies

10



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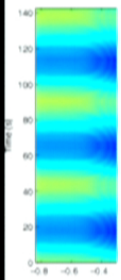

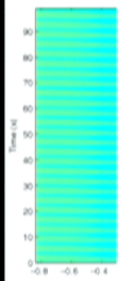

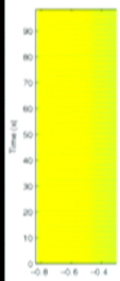

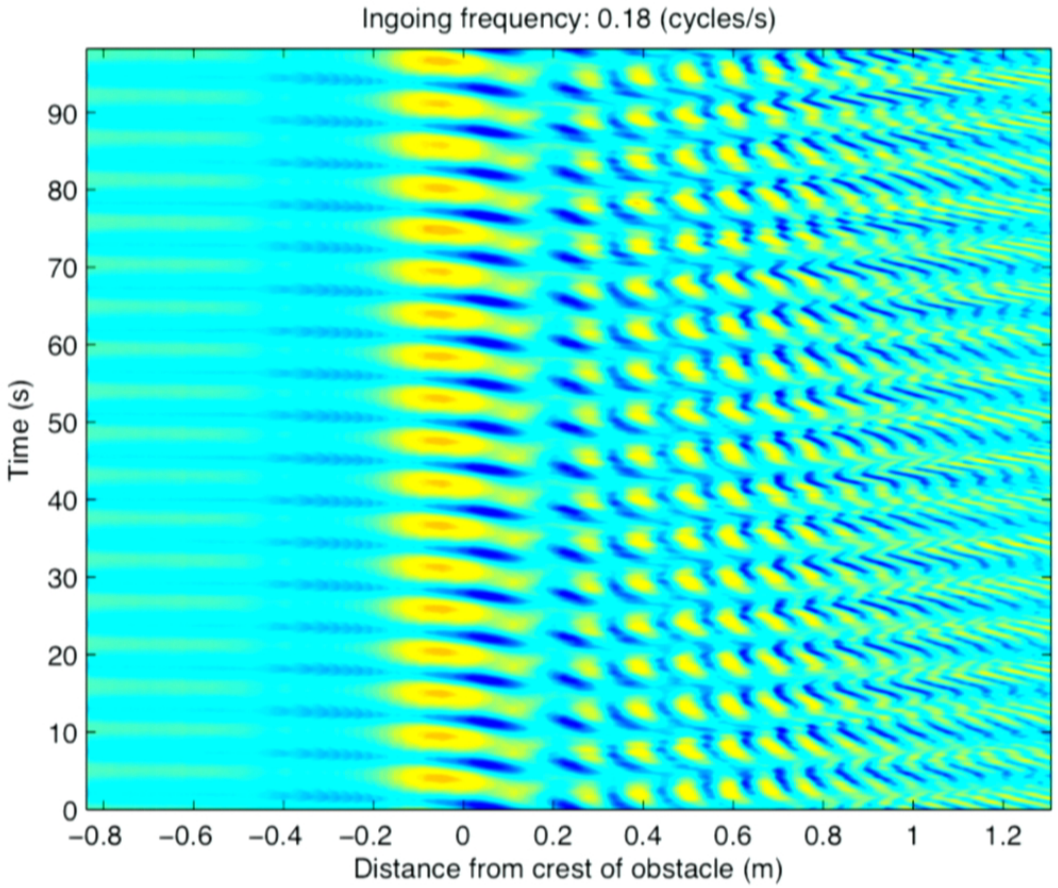

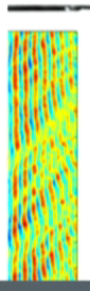

Interlude - The black hole evaporation process

[Images taken from 'The road to Reality', by Roger Penrose.]

$$T = \frac{g_H}{2\pi}$$

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]

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

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

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

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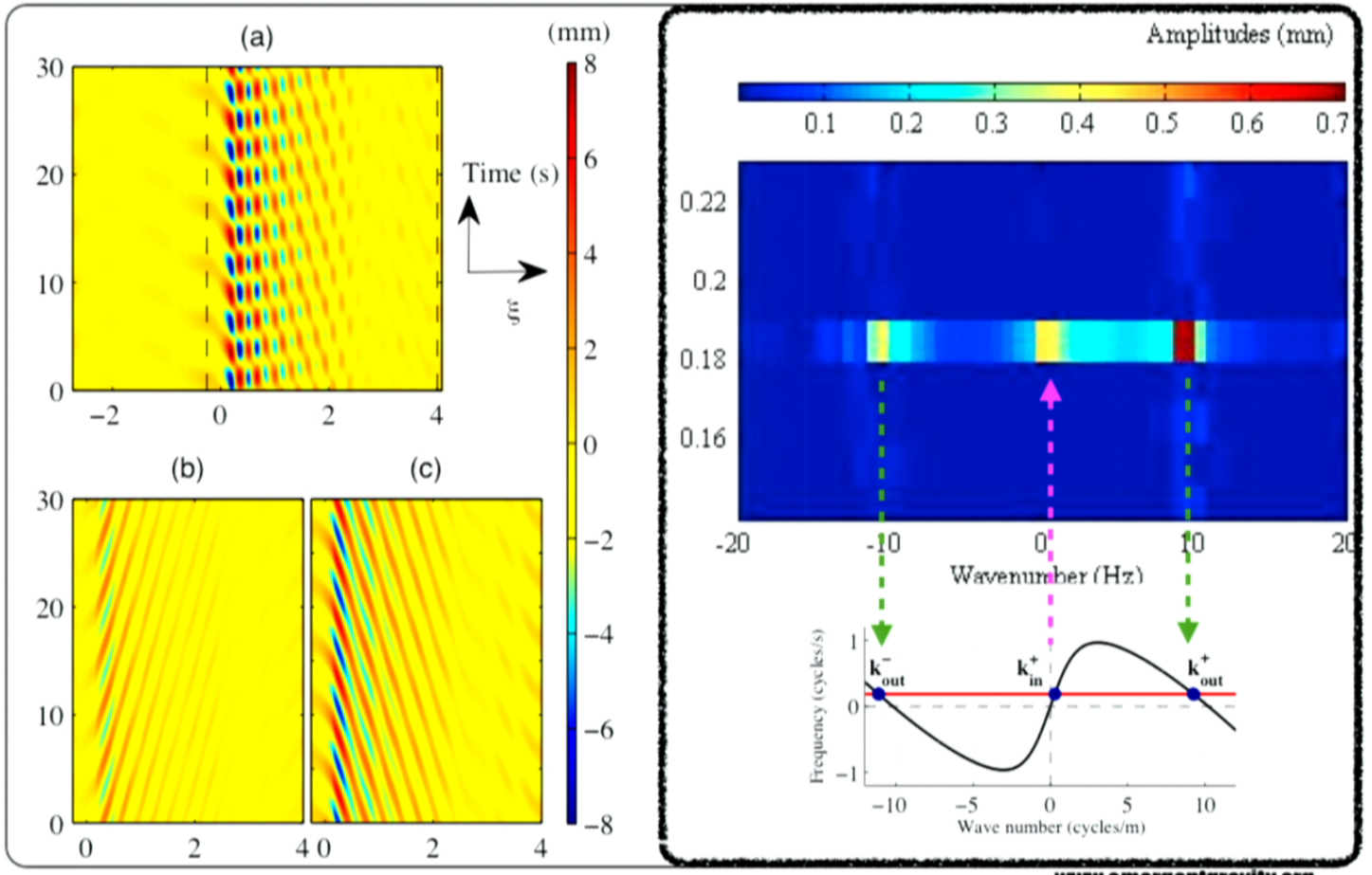
Right and left moving waves: Pair-creation process



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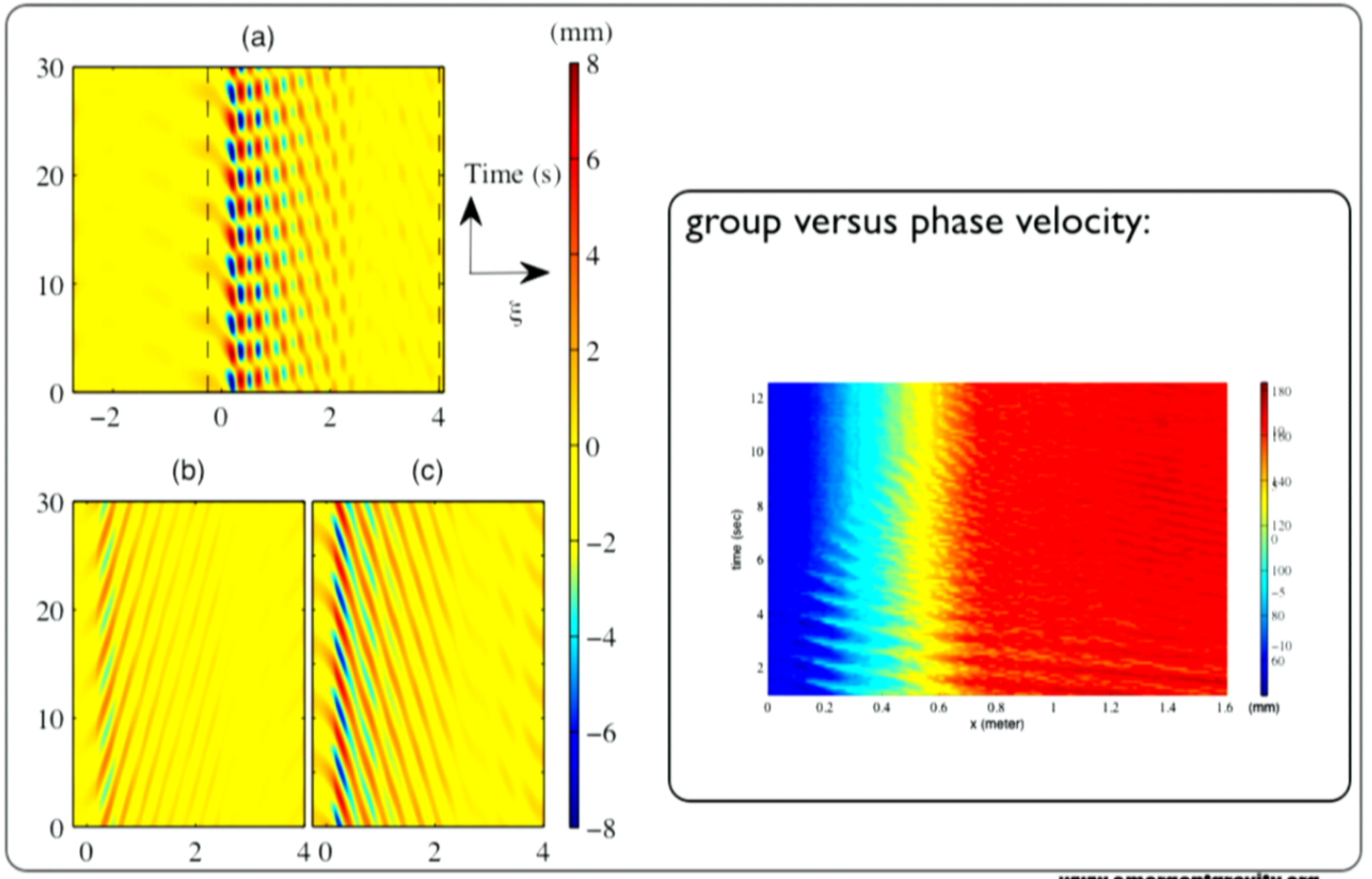

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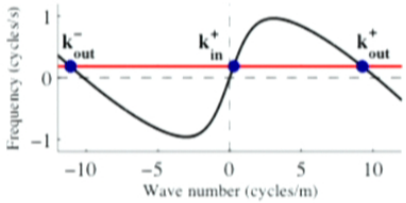
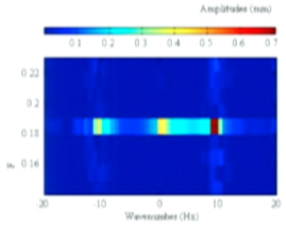
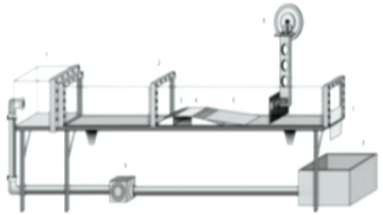
From amplitudes to Hawking spectra

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



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





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

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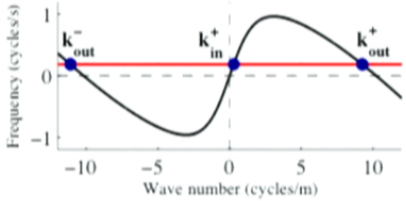

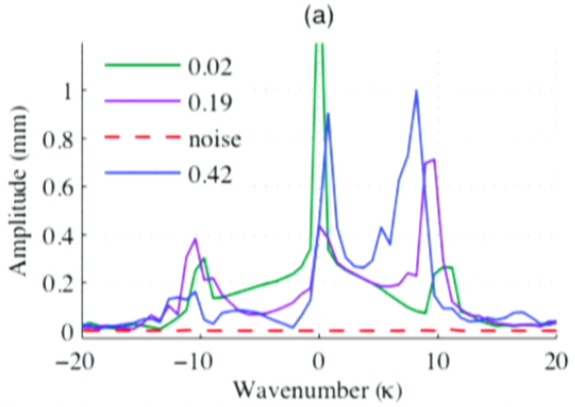

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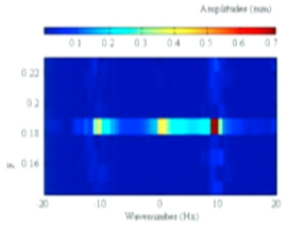

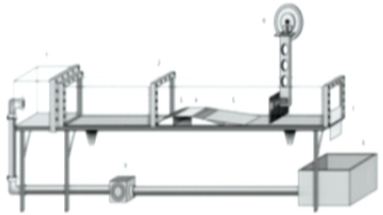

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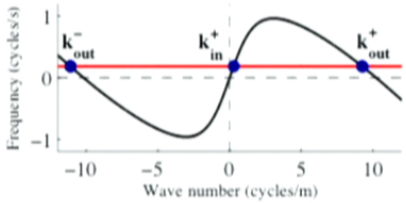

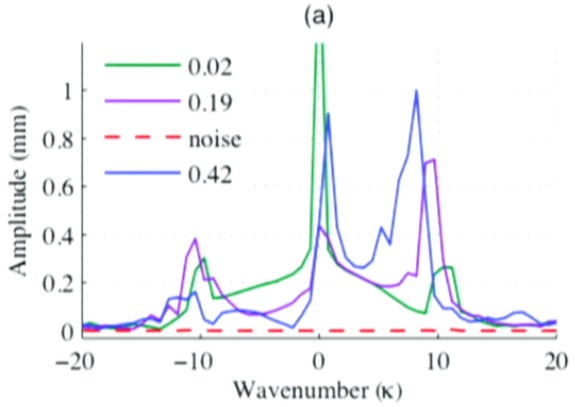

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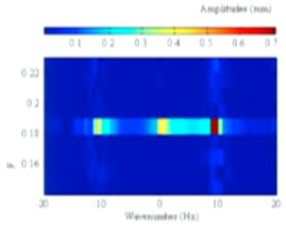

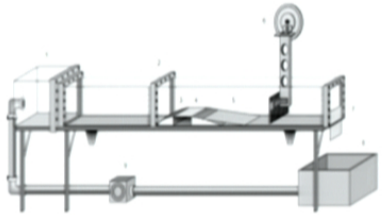

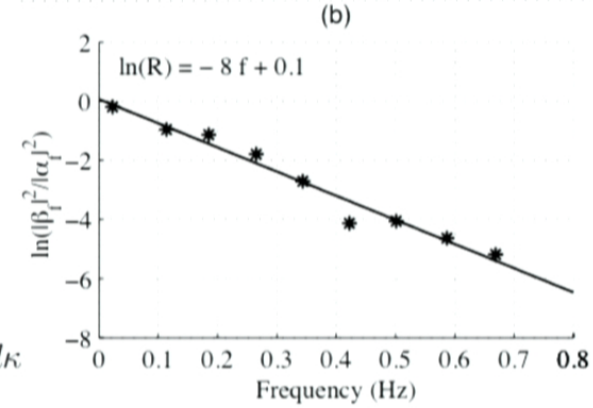

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From amplitudes to Hawking spectra

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

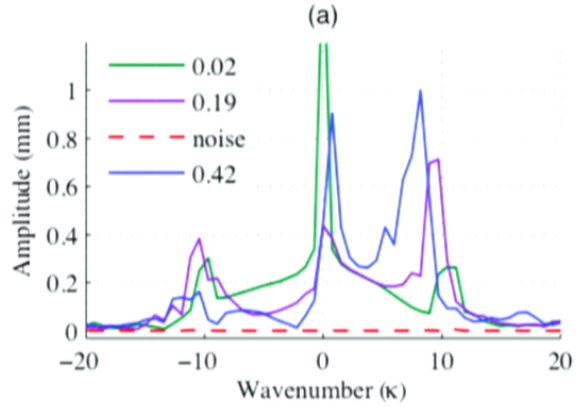
(ii) what is a wave (particle) nearby the white hole horizon..?

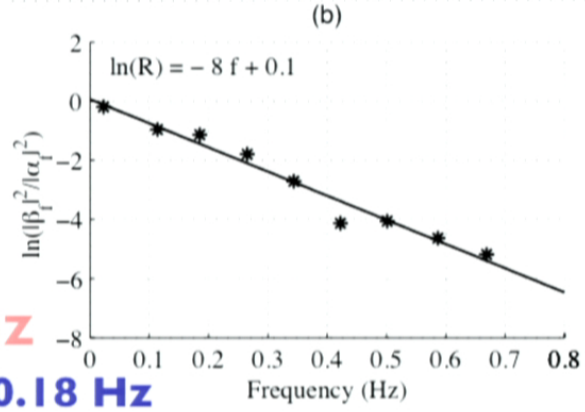
(ii) Norm is conserved: $\sim \int \frac{|A(f,\kappa)|^2}{f+\kappa} d\kappa$

(ii) Compare with surface gravity:

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

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





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

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

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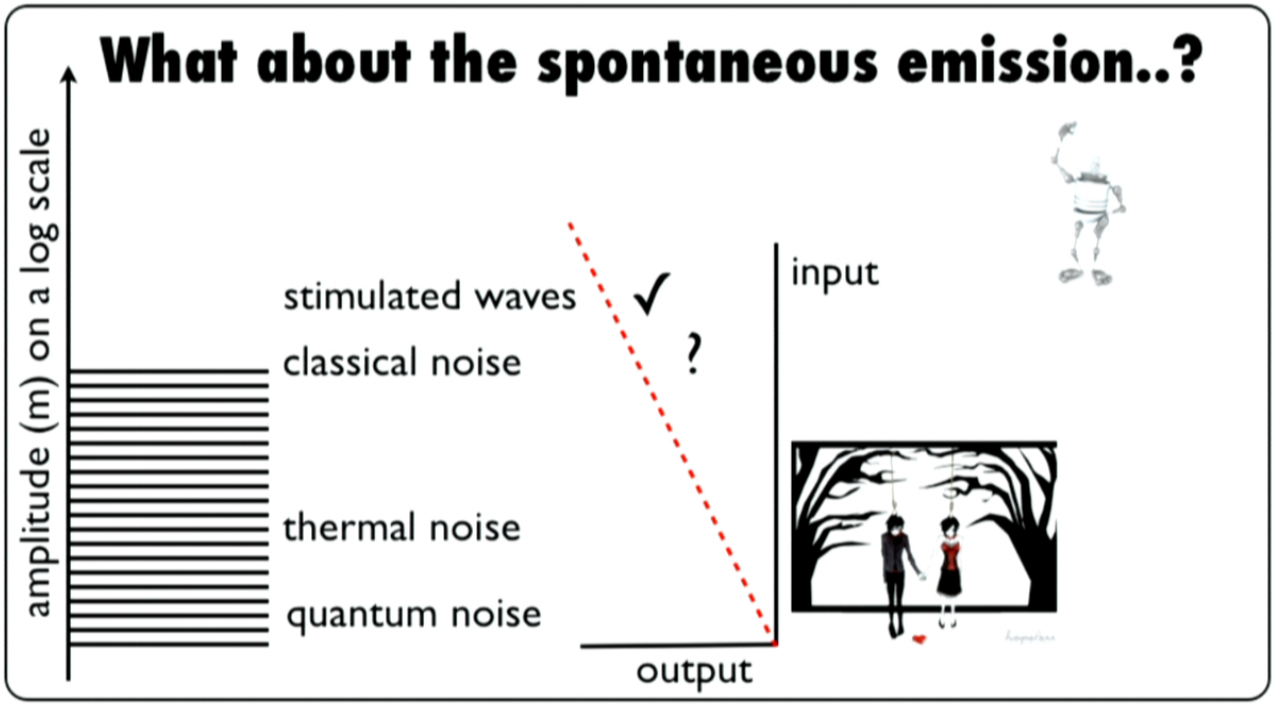
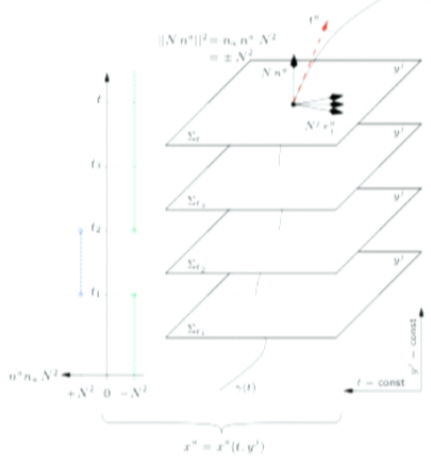
Result: Stimulated Hawking process [pair-creation with a thermal spectra] is confirmed at white hole in analogue gravity system.

Lesson: The thermal emission is a universal phenomenon, surviving fluid-dynamic deviations (viscosity, vorticity) and vastly altered dispersion relations.



How to extend this idea to quantum gravity?

Horava-Lifshitz gravity: A theory with a preferred spacelike foliation. *The existence of the preferred foliation allows for higher order spatial derivatives in the theory without having higher order time derivatives*. This leads to significantly improved ultraviolet behaviour which actually renders the theory power-counting renormalizable, at the expense of giving up Lorentz invariance.



In 2+1 dimension the most general Horava-Lifshitz gravity theory is:

$$S = \frac{M_{\rm pl}^2}{2}\int {\rm d}^d x\, {\rm d}t\, N\sqrt{g}\left(K^{ij}K_{ij} - \lambda K^2 + \mathcal{V}\right)$$

$$\begin{aligned}\mathcal{V} \;=\; & \xi R + \eta\, a^2 + g_1\, R^2 + g_2\, \nabla^2 R + g_3\, a^4 + g_4\, R a^2 \\ & + g_5 a^2(\nabla^j a_j) + g_6(\nabla^i a_i)^2 + g_7(\nabla_i a_j)(\nabla^i a^j),\end{aligned}$$

extrinsic curvature: $K_{ij} = \left(\dot{g}_{ij} - \nabla_i N_j - \nabla_j N_i\right)/(2N)$

+ anisotropic scaling:

$$[{\rm d}x] = [\kappa]^{-1}; \qquad [{\rm d}t] = [\kappa]^{-z}$$

Indication for improved UV-behaviour:

=> gravitational coupling constant DIMENSIONLESS:

$$[g_K] = [\kappa]^{(d-z)}$$

[Thomas Sotiriou, Matt Visser, S.W., Phys.Rev.D83:124021,2011]

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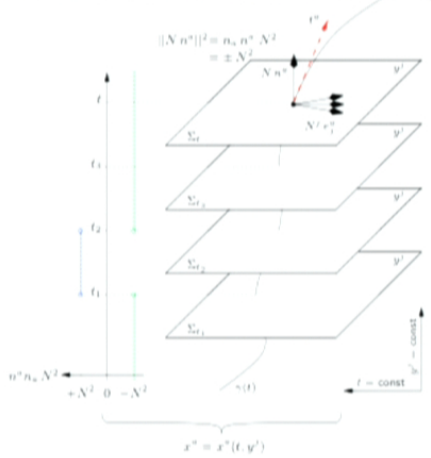

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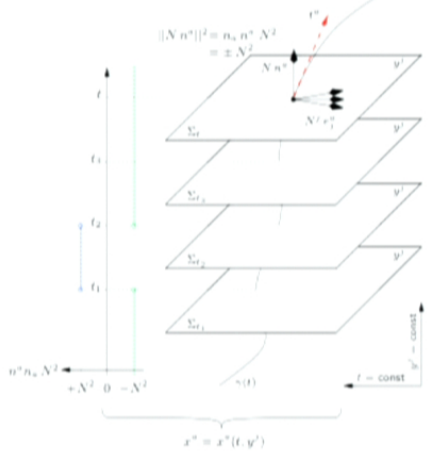

Excitations:
spin-0 & spin-2 gravitational fluctuations AND quantum field theory

$$\omega^2 = \Omega(k)^2 \equiv f(k)$$

+ anisotropic scaling:

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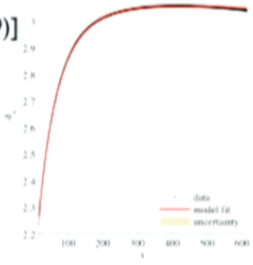
Emergence of HL-gravity..?

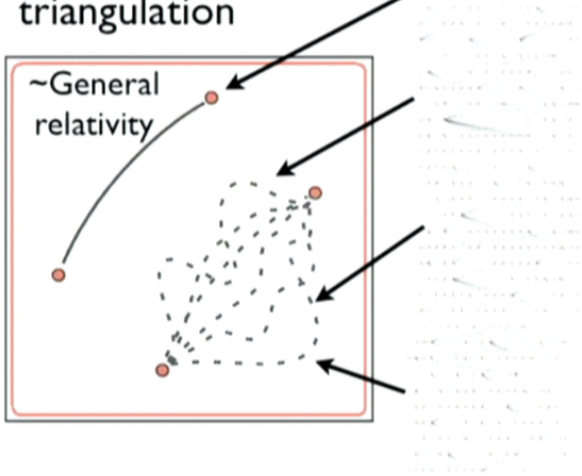
[T. P. Sotiriou, M. Visser S.W., PRL 107, 131303 (2011)]

[Horava PRL 16 161301 (2009)]



HL-gravity

Causal dynamical triangulation



[Jacobson, Phys.Rev.D81:101502,2010]

Einstein-Aether

Ted Jacobon's talk

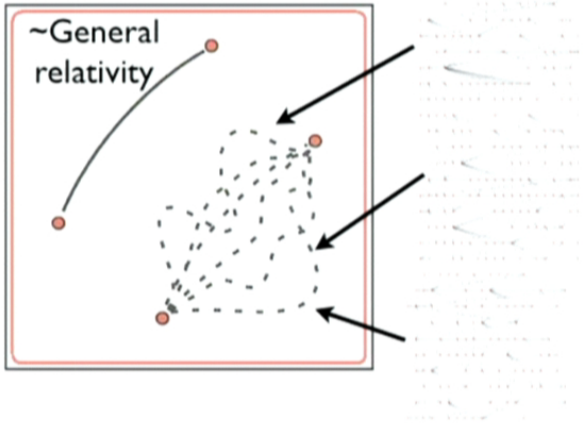
www.emergentgravity.org

Quantum gravity from bit: A new framework for CDT

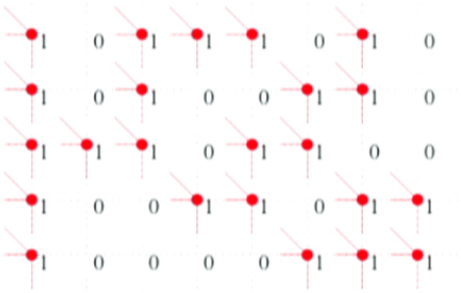
[Work in progress; Collaborators: Gemma De las Cuevas, M.A. Martin-Delgado, H. J. Briegel]

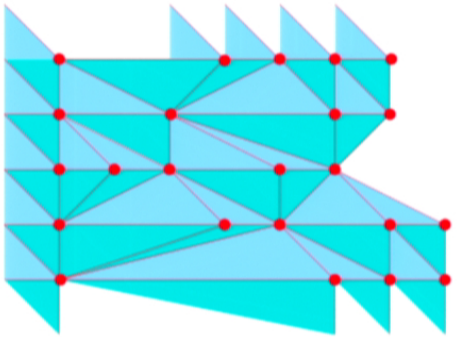
Instead of building blocks, could there be a physical system that behaves just like that..?

Causal dynamical triangulation



Work in progress...





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Conclusions

- [x] different systems can share **some** phenomenological aspects (not very surprising)

Analogue gravity systems:

- [ ] hide there true degrees of freedom (to some extend) and at the regime of validity the full dynamical equations only determine the background configuration
- [ ] are different enough to attest for the generality of the particular phenomenon under investigation
- [ ] offer a link between real life system and (semi-classical) quantum gravity, and as such offer the possibility of table-top experiments

VOLUME 46 25 MAY 1981 NUMBER 21

Experimental Black-Hole Evaporation?

W. G. Unruh
Department of Physics, University of British Columbia, Vancouver, British Columbia V6T 2A6, Canada
(Received 8 December 1980)

It is shown that the same arguments which lead to black-hole evaporation also predict that a thermal spectrum of sound waves should be given out from the sonic horizon in transsonic fluid flow.

maybe → Experimental quantum gravity?

Conclusions

☑ different systems can share **some** phenomenological aspects (not very surprising)

Analogue gravity systems:

☐ hide there true degrees of freedom (to some extend) and at the regime of validity the full dynamical equations only determine the background configuration

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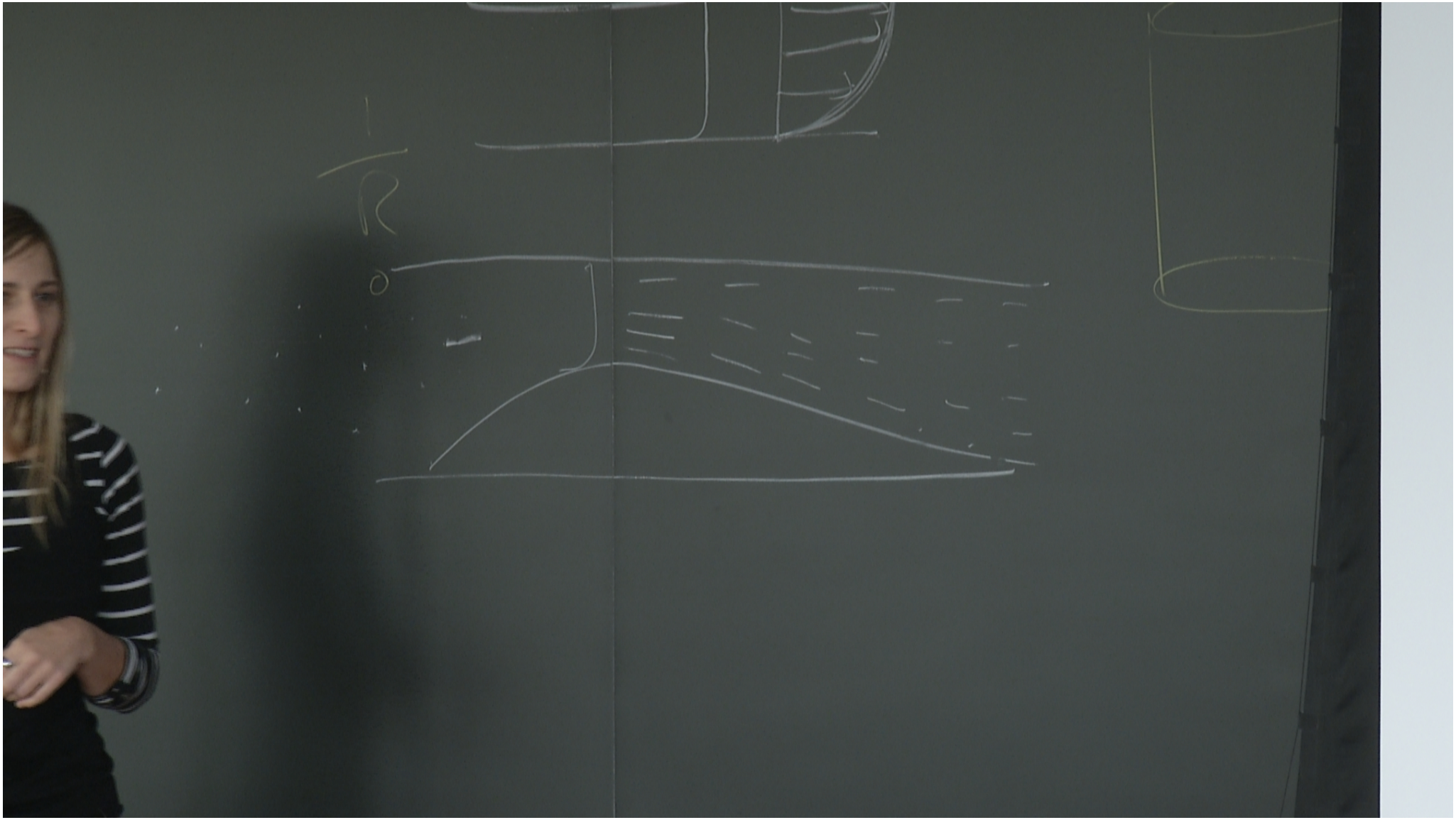
I don't much about the general concept of emergence or why effective field theory work so well, but I trust in analogies.