Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

School of Mathematical and Computing Sciences
Te Kura Pangarau, Rorohiko

Analogue Spacetimes: What on Earth?

Matt Visser

Emergence in Marine Ecosystems
ICTP Trieste
Wednesday 27 October 2010

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

And I cherish more than anything else the Analogies,
my most trustworthy masters.
They know all the secrets of Nature,
and they ought least to be neglected in Geometry.

--- Johannes Kepler

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

The black hole at Monticello

2006.01.08

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

What on earth?

(Not a special effect; this is a real photograph.)

It's just the spillway at Monticello dam, Napa Valley, California

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Why are "analogue spacetimes" interesting?

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Analogue spacetimes provide you with solid physically well-defined and physically well-understood concrete models of some (not all) aspects of black hole physics.

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Experiments with real general relativity black holes are impossible.

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Experiments with "analogue black holes" are do-able (and interesting).

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

There are analogies based on:

--- Surface waves.

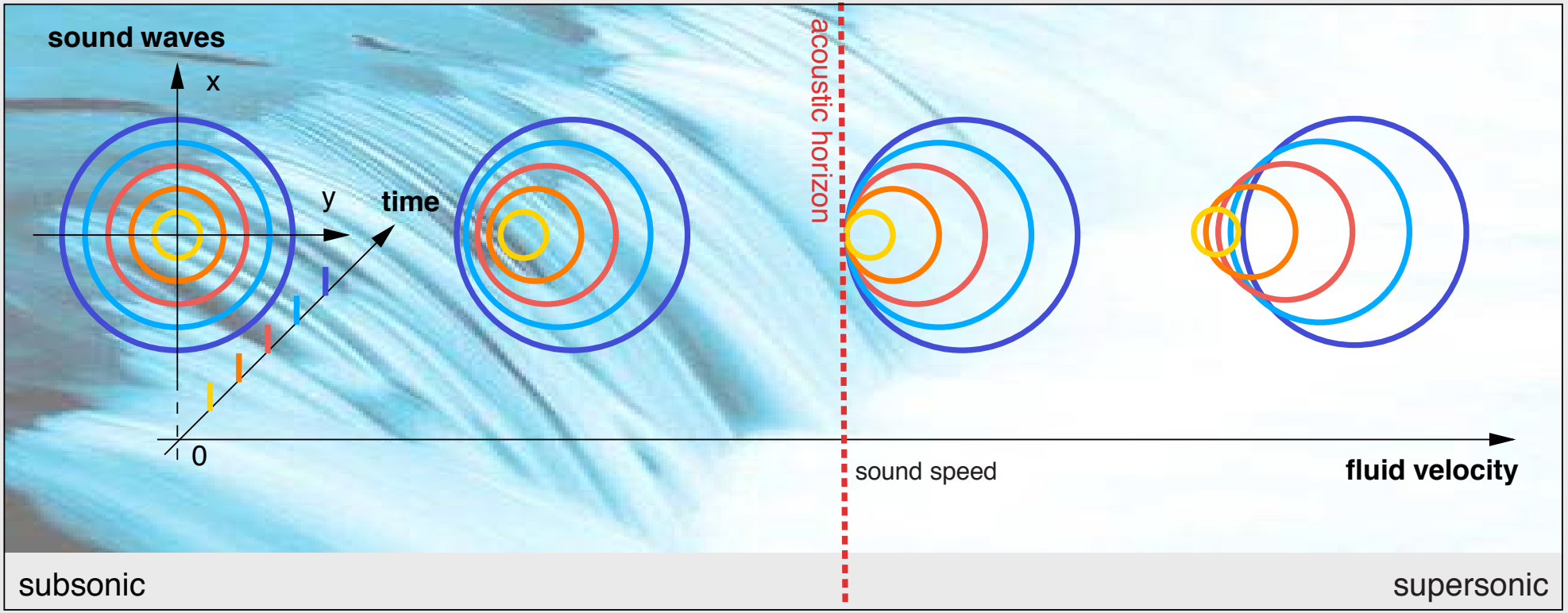
--- Acoustic waves.

--- Fibre optics.

--- Just about anything else
we can lay our hands on.

Acoustic spacetime:

The simplest "analogue spacetimes" are the "acoustic spacetimes"...



Consider sound waves in a moving fluid... [Unruh]

Acoustic spacetime:

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Theorem: Consider an irrotational, inviscid, barotropic perfect fluid, governed by the Euler equation, continuity equation, and an equation of state.

The dynamics of the linearized perturbations (sound, phonons) is governed by a D'Alembertian equation

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

involving an "acoustic metric".

[Algebraic function of the background fields.]

Acoustic spacetime:

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Theorem:

(3+1 dimensions)

$$g^{\mu\nu}(t,\vec{x}) \equiv \frac{1}{\rho_0 c}\begin{bmatrix} -1 & \vdots & -v_0^j \\ \cdots\cdots & \cdot & \cdots\cdots\cdots\cdots \\ -v_0^i & \vdots & (c^2\,\delta^{ij} - v_0^i\,v_0^j) \end{bmatrix}.$$

$$g_{\mu\nu}(t,\vec{x}) \equiv \frac{\rho_0}{c}\begin{bmatrix} -(c^2 - v_0^2) & \vdots & -v_0^j \\ \cdots\cdots\cdots\cdots & \cdot & \cdots\cdots \\ -v_0^i & \vdots & \delta_{ij} \end{bmatrix}.$$

$$\mathrm{d}s^2 \equiv g_{\mu\nu}\,\mathrm{d}x^\mu\,\mathrm{d}x^\nu = \frac{\rho_0}{c}\left[-c^2\,\mathrm{d}t^2 + (\mathrm{d}x^i - v_0^i\,\mathrm{d}t)\,\delta_{ij}\,(\mathrm{d}x^j - v_0^j\,\mathrm{d}t)\right].$$

ARTIFICIAL BLACK HOLES

Editors

Mário Novello
Matt Visser
Grigori Volovik

World Scientific

[2002]

Analogue Gravity

Carlos Barceló
Instituto de Astrofísica de Andalucía (CSIC)
Camino Bajo de Huetor 50,
18008 Granada, Spain
carlos@iaa.es
http://www.iaa.csic.es/

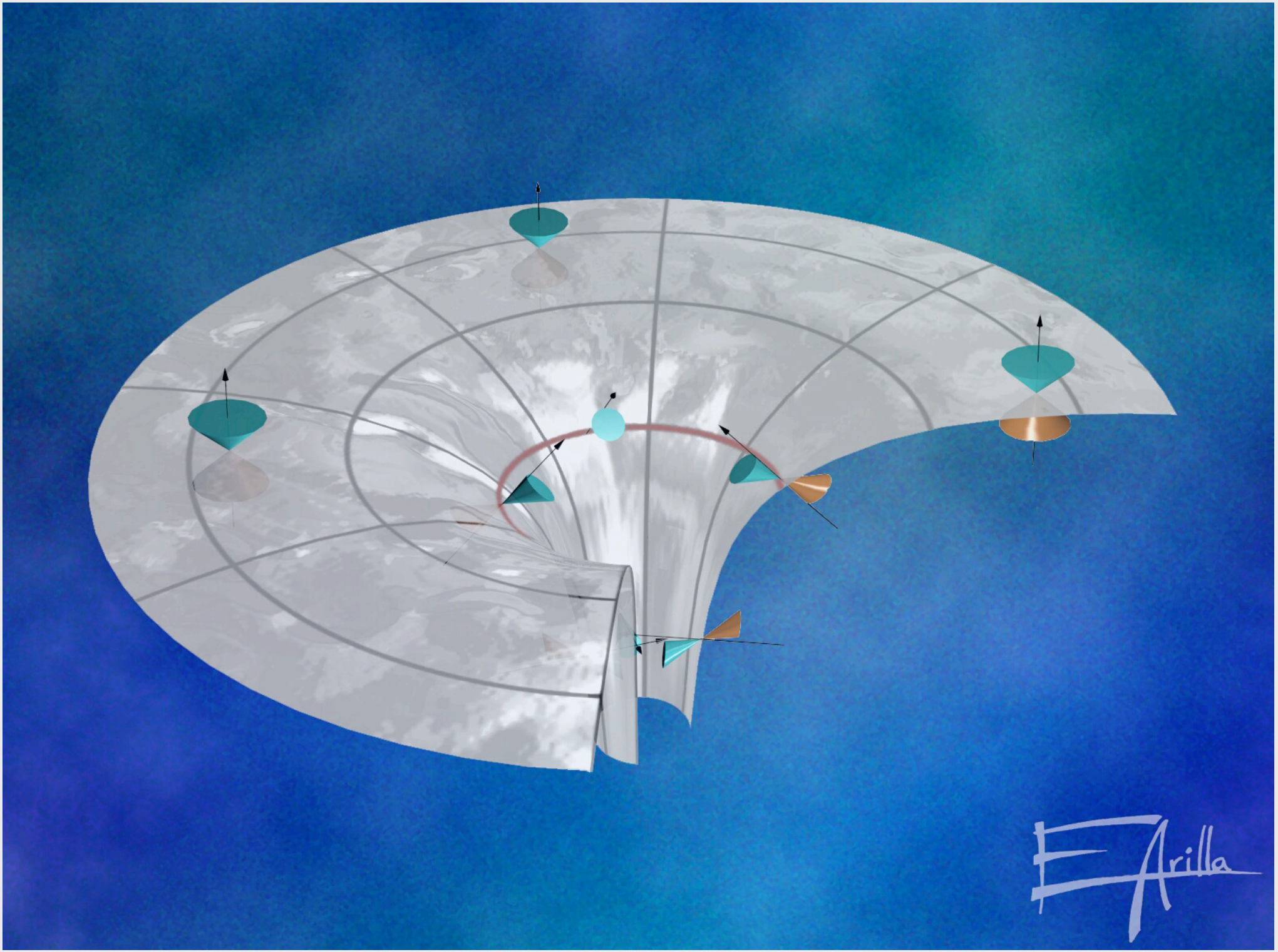
Stefano Liberati
International School for Advanced Studies and INFN
Via Beirut 2-4,
34014 Trieste, Italy
liberati@sissa.it
http://www.sissa.it/~liberati

Matt Visser
School of Mathematics, Statistics, and Computer Science
Victoria University of Wellington; PO Box 600
Wellington, New Zealand
matt.visser@mcs.vuw.ac.nz
http://www.mcs.vuw.ac.nz/~visser

[2005]

[update]

[2010]


EArilla

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

For various technical reasons we do not have as good a mathematical theorem for surface waves...

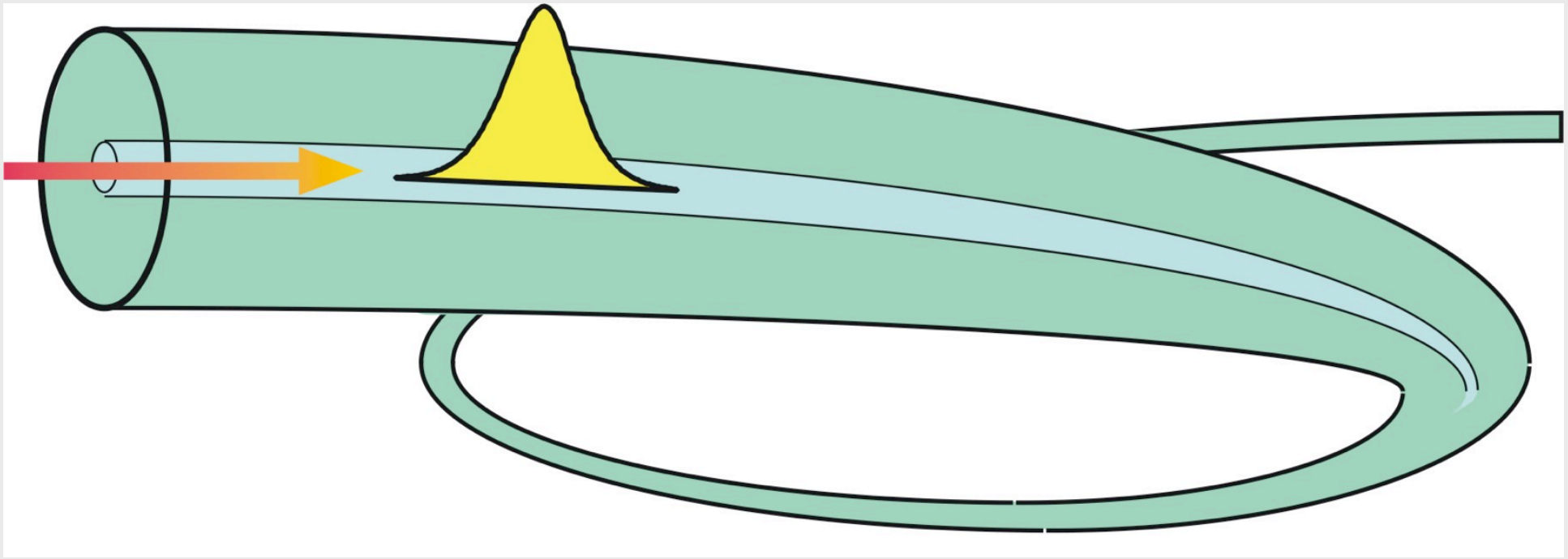
(ongoing research to tidy things up...)

There is however no doubt that the effect is there...

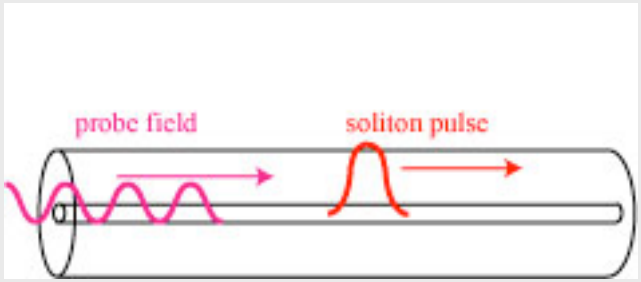
And we have some lovely experiments...

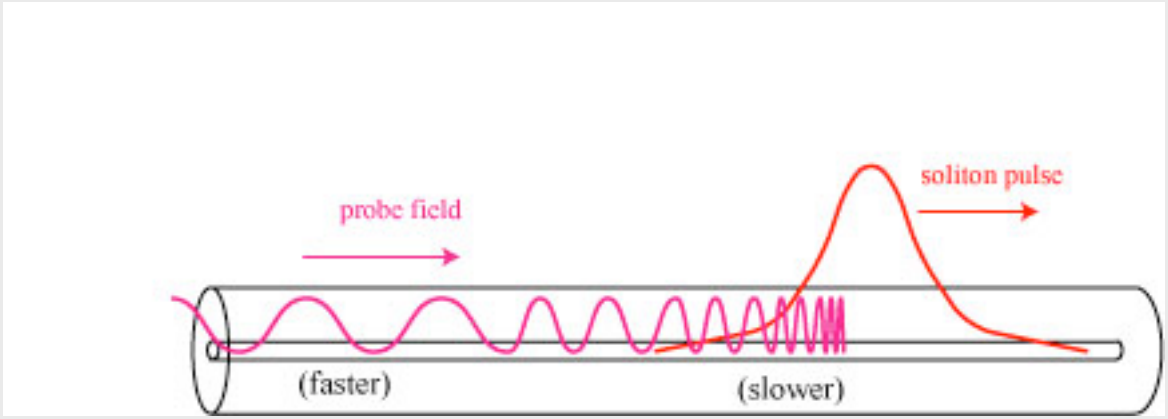
See Dr Weinfurtner's talk.

Fibre optics:



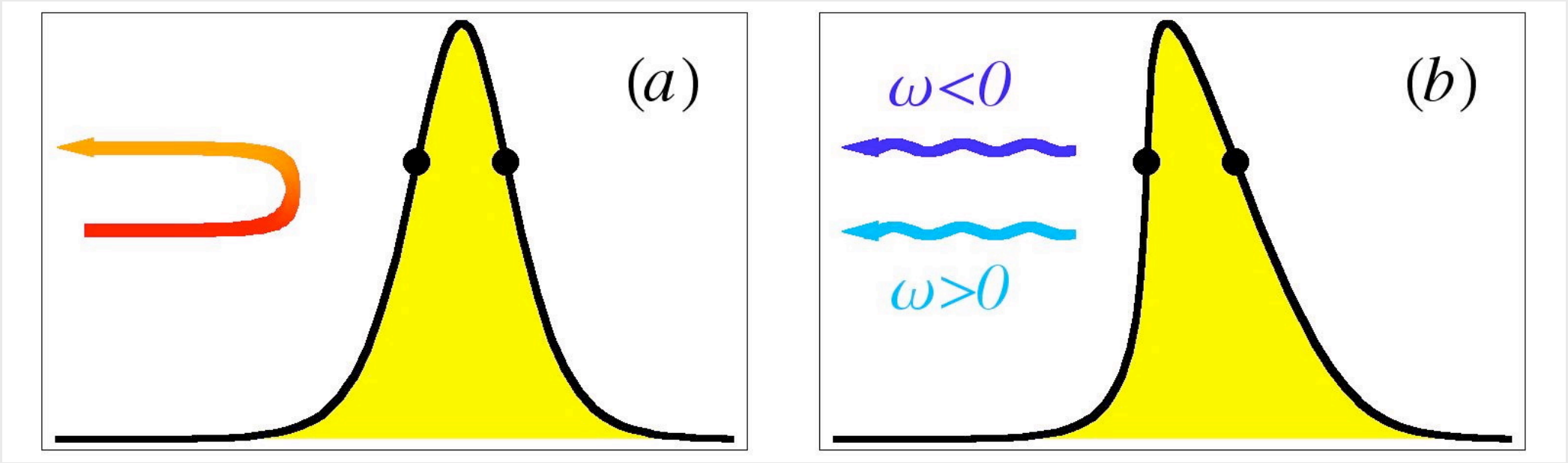
Pulse of light changes the refractive index and slows down other light...





Pulse of light changes the refractive index and slows down other light...

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui



Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

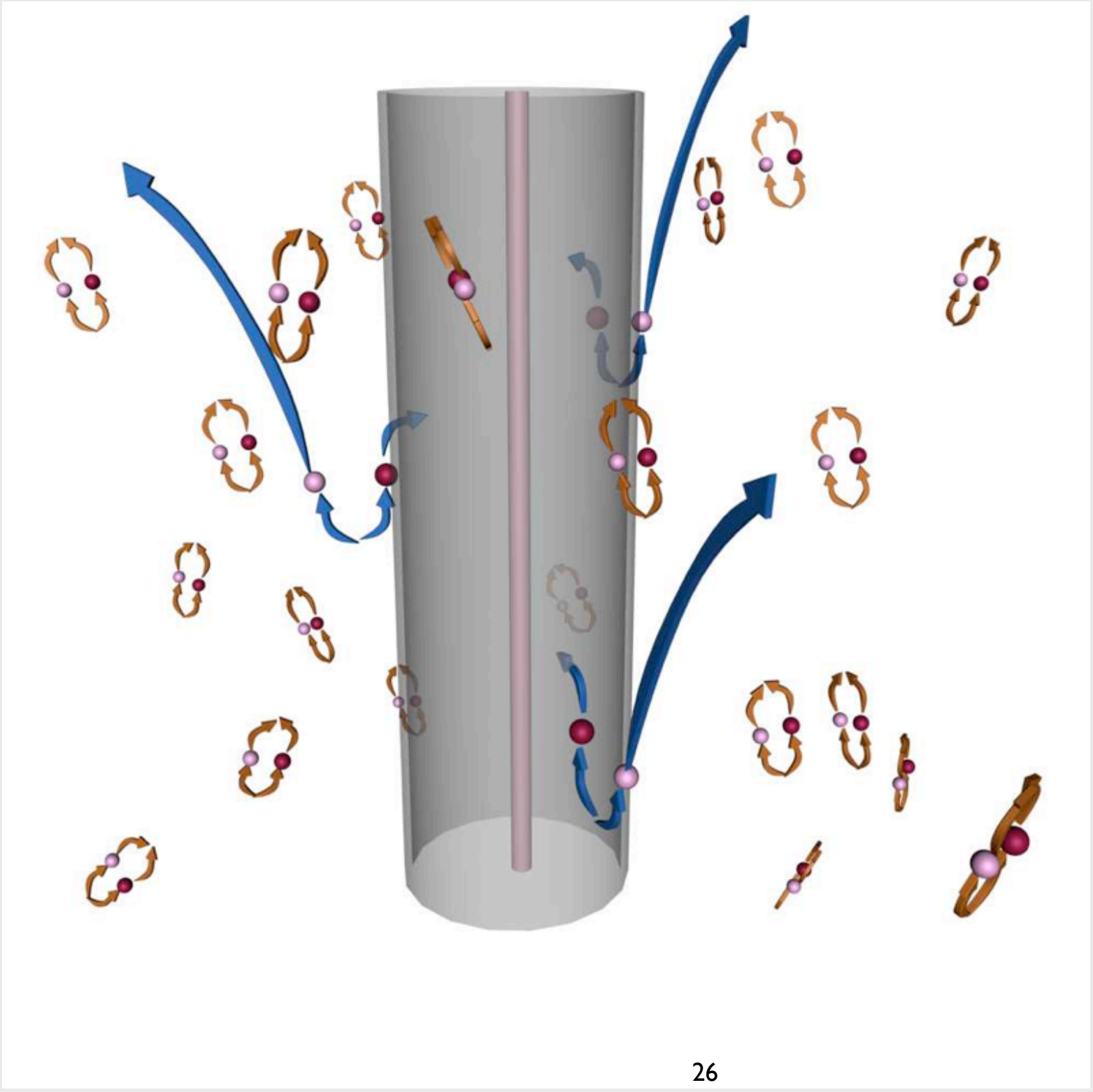
For all these systems:

--- Surface waves.

--- Acoustic waves.

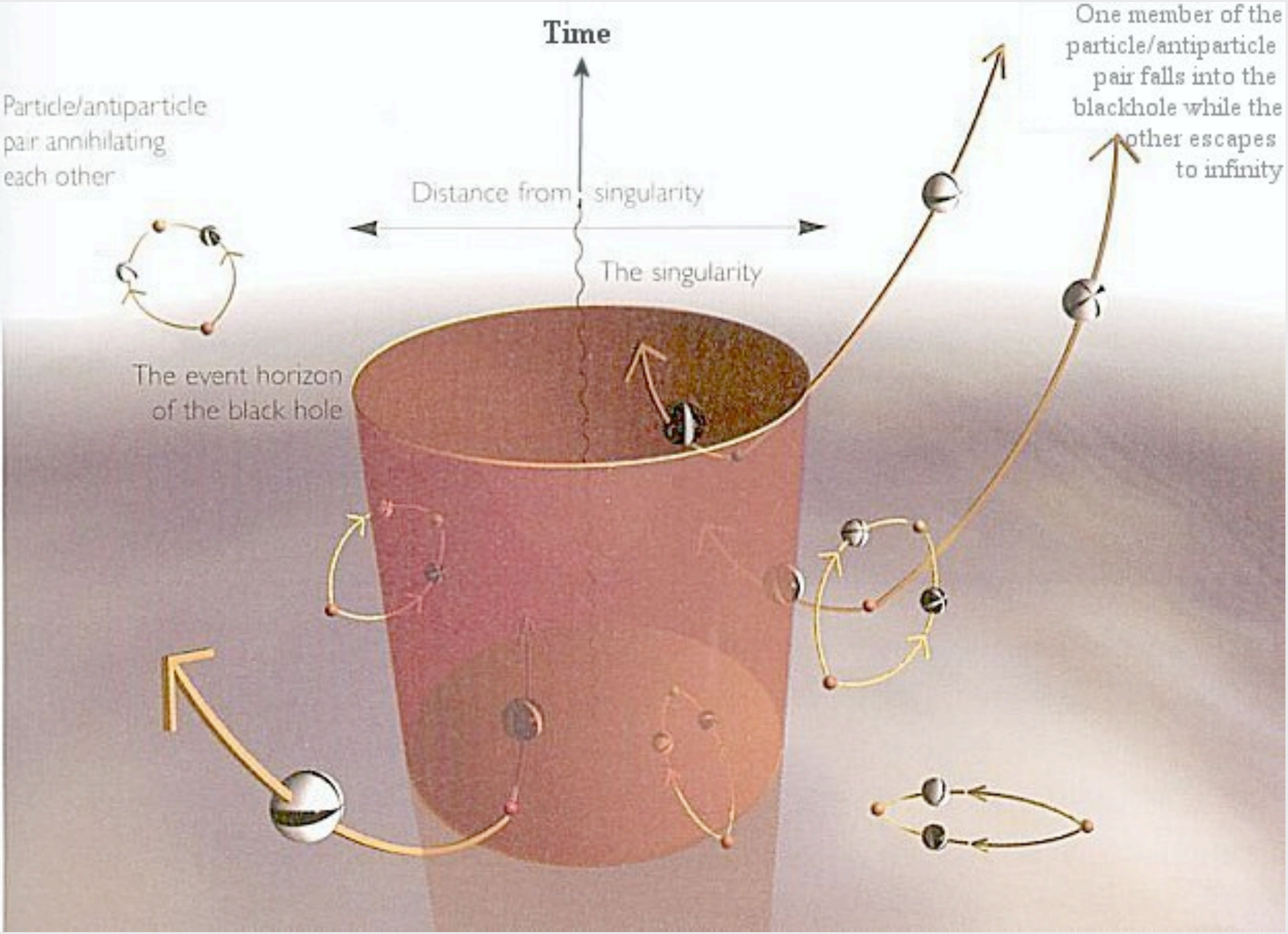
--- Fibre optics.

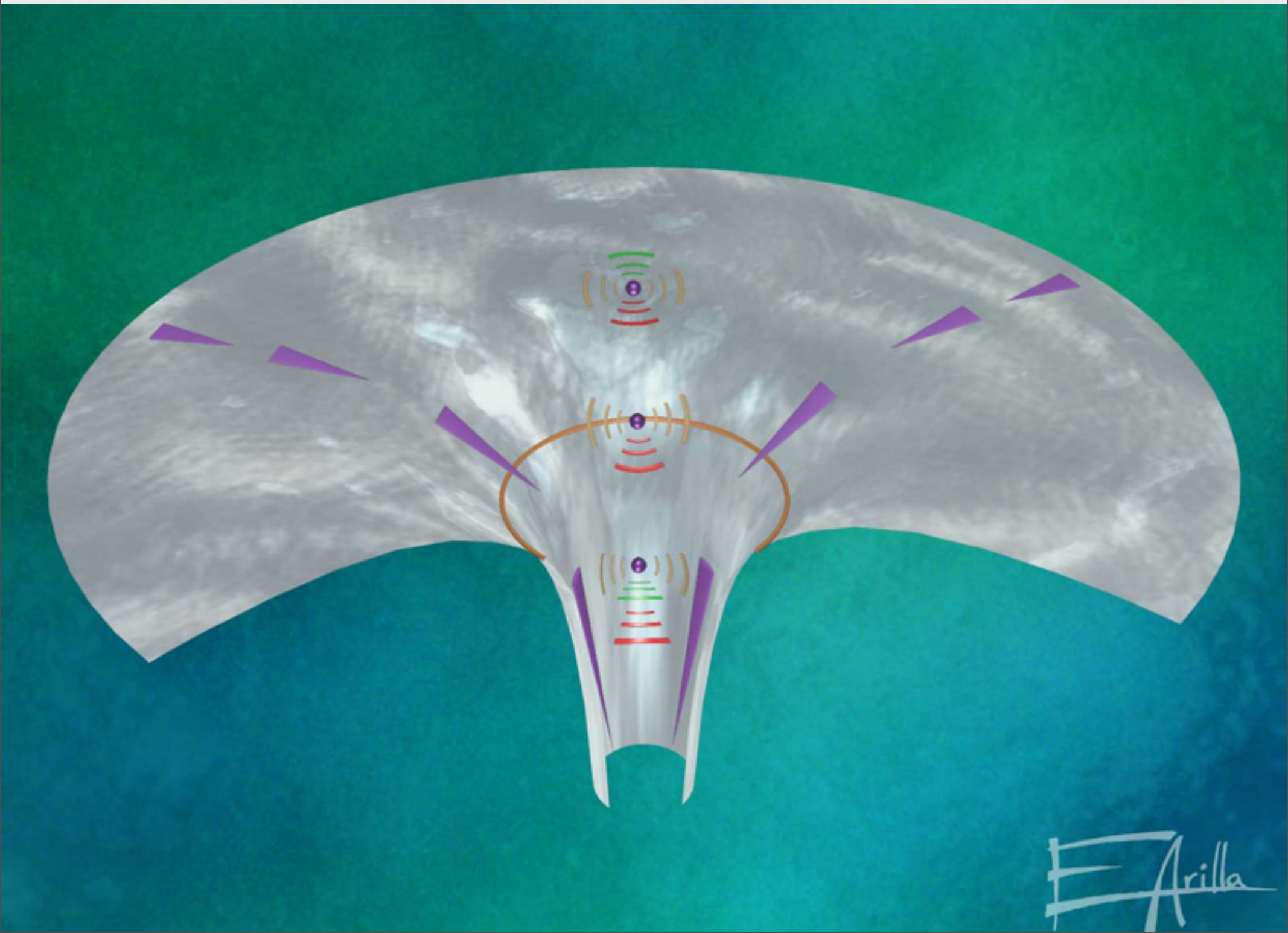
--- Whatever...



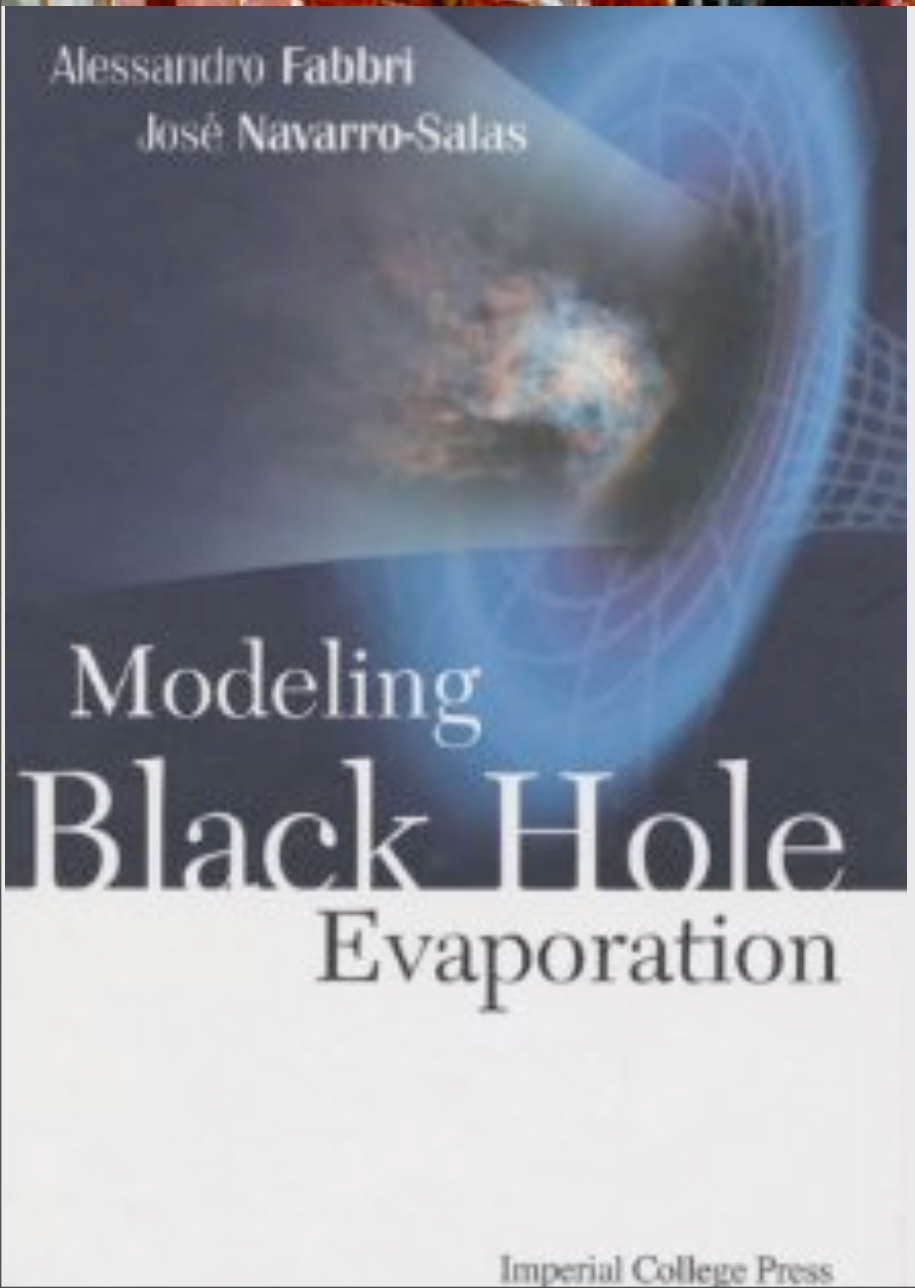
Hope:

Probe Hawking radiation.


Time
Particle/antiparticle pair annihilating each other
Distance from singularity
The singularity
One member of the particle/antiparticle pair falls into the blackhole while the other escapes to infinity
The event horizon of the black hole


E Arilla

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

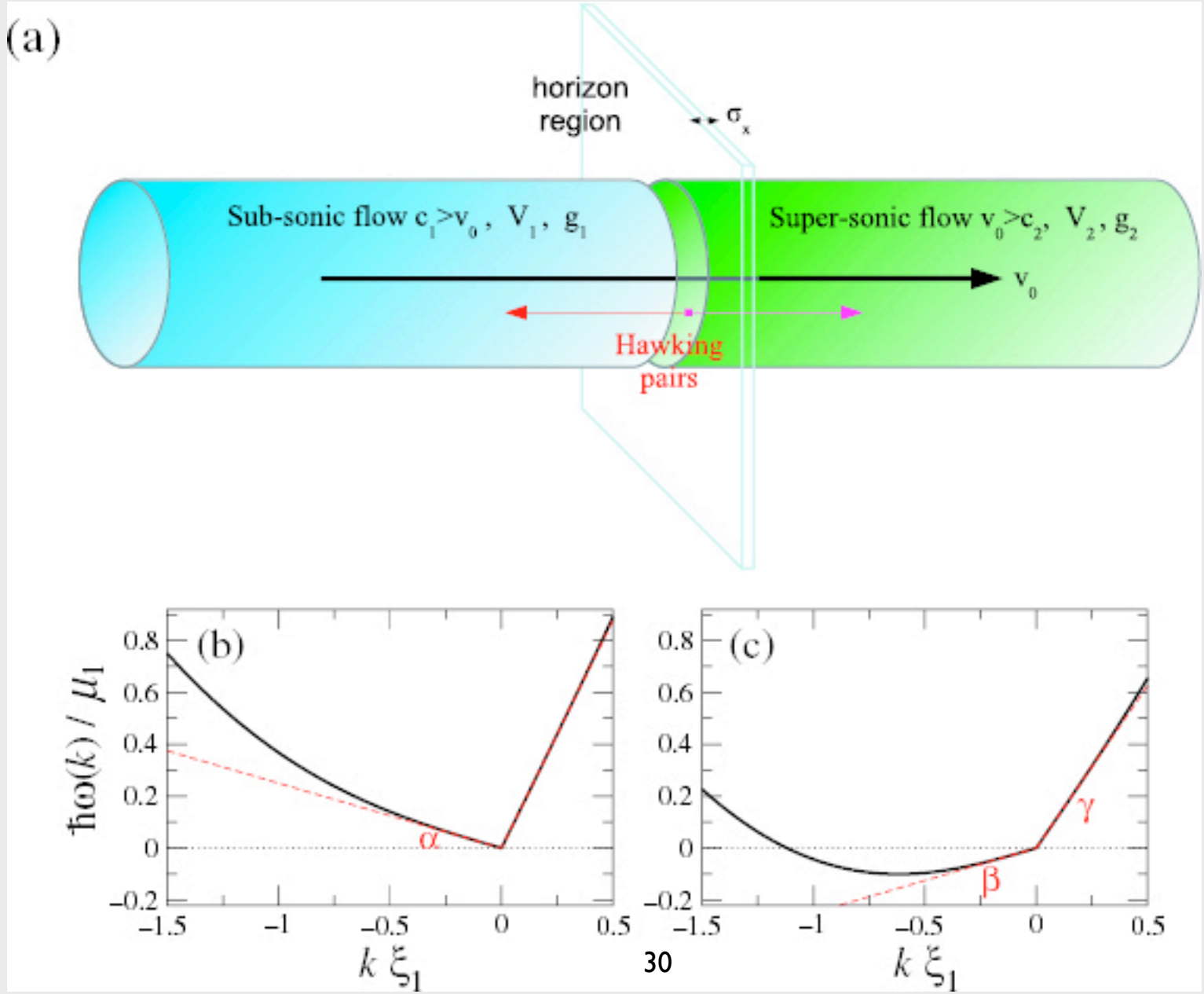


Theoretical calculation:

Hawking radiation will still occur for these "analogue spacetimes".

Theoretical calculation:

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui



Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Three experiments in the last 3 months:

Measurement of stimulated Hawking emission in an analogue system.
Silke Weinfurtner, Edmund W. Tedford, Matthew C.J. Penrice, William G. Unruh, Gregory A. Lawrence (British Columbia U.).
Aug 2010. 7 pp.
e-Print: **arXiv:1008.1911 [gr-qc]**

Hawking radiation from ultrashort laser pulse filaments.
F. Belgiorno, S.L. Cacciatori, M. Clerici, V. Gorini, G. Ortenzi, L. Rizzi, E. Rubino, V.G. Sala, D. Faccio.
Sep 2010. 4 pp.
e-Print: **arXiv:1009.4634 [gr-qc]**

The circular jump is a white hole.
G. Jannes, R. Piquet, P. Maissa, C. Mathis, G. Rousseaux.
Oct 2010. 4 pp.
e-Print: **arXiv:1010.1701 [physics.flu-dyn]**

Conclusion:

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

Many interesting extensions and modifications of the general relativity notion of spacetime have concrete and well controlled models within the "analogue spacetime" framework.

This tells us which rocks to start looking under...

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

"It is important to keep an open mind; just not so open that your brains fall out"

--- Albert Einstein

Emergence:

Victoria
UNIVERSITY OF WELLINGTON
Te Whare Wānanga
o te Ūpoko o te Ika a Māui

The word "emergence" is being tossed around an awful lot lately.....

But what does it really mean?

--- "More is different"?

--- The sum is greater than its parts?

--- Universality?

--- Mean field?

* Short-distance physics is often radically different from long-distance physics...