Cosmology in the laboratory

Ulf Leonhardt

Light on the horizon

Light on the horizon

Observation of Stimulated Hawking Radiation from an Optical Analogue of the Event Horizon

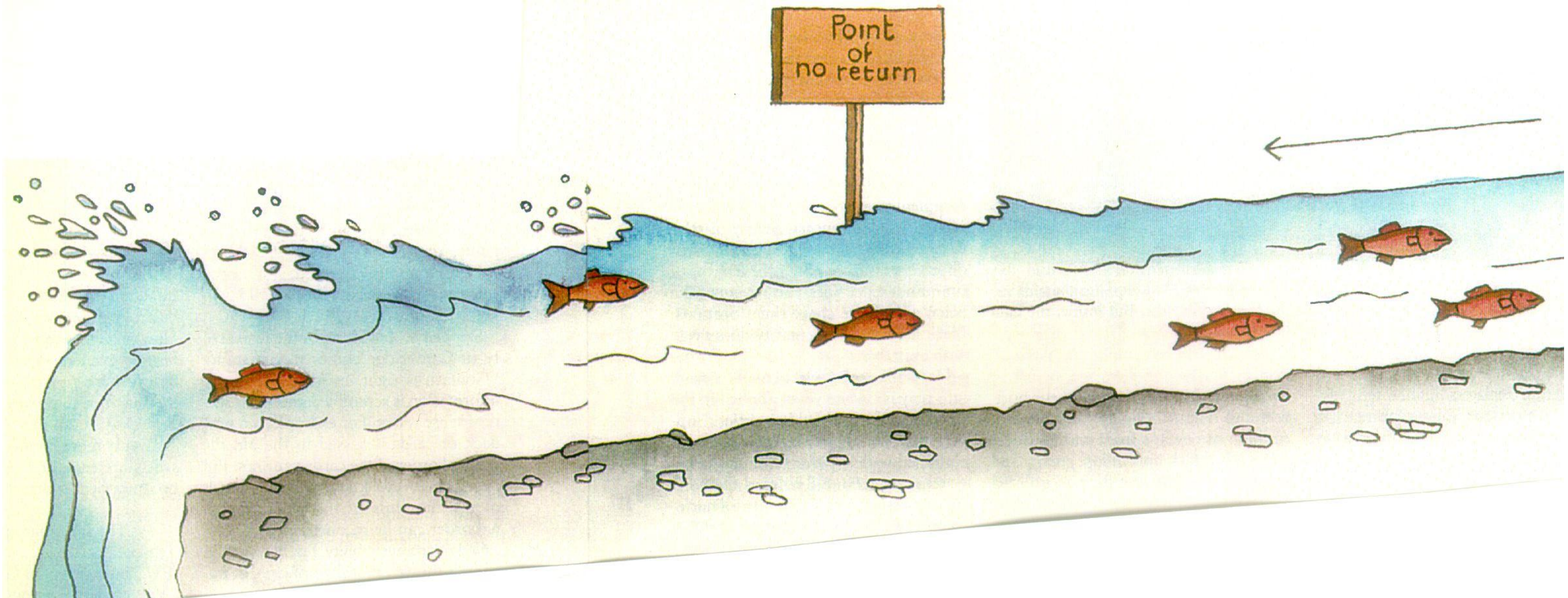
Ulf Leonhardt, Weizmann Institute

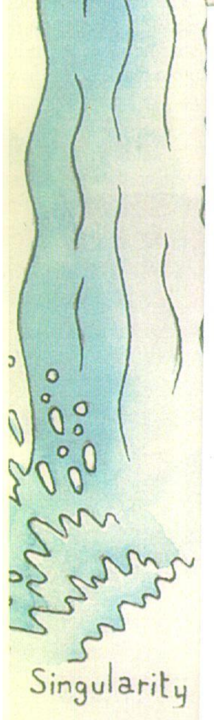
Jonathan Drori

Yuval Rosenberg

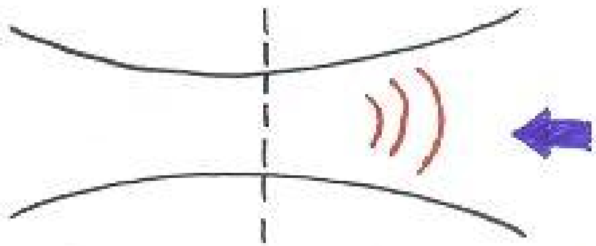
David Bermudez
Cinvestav University

Yaron Silberberg

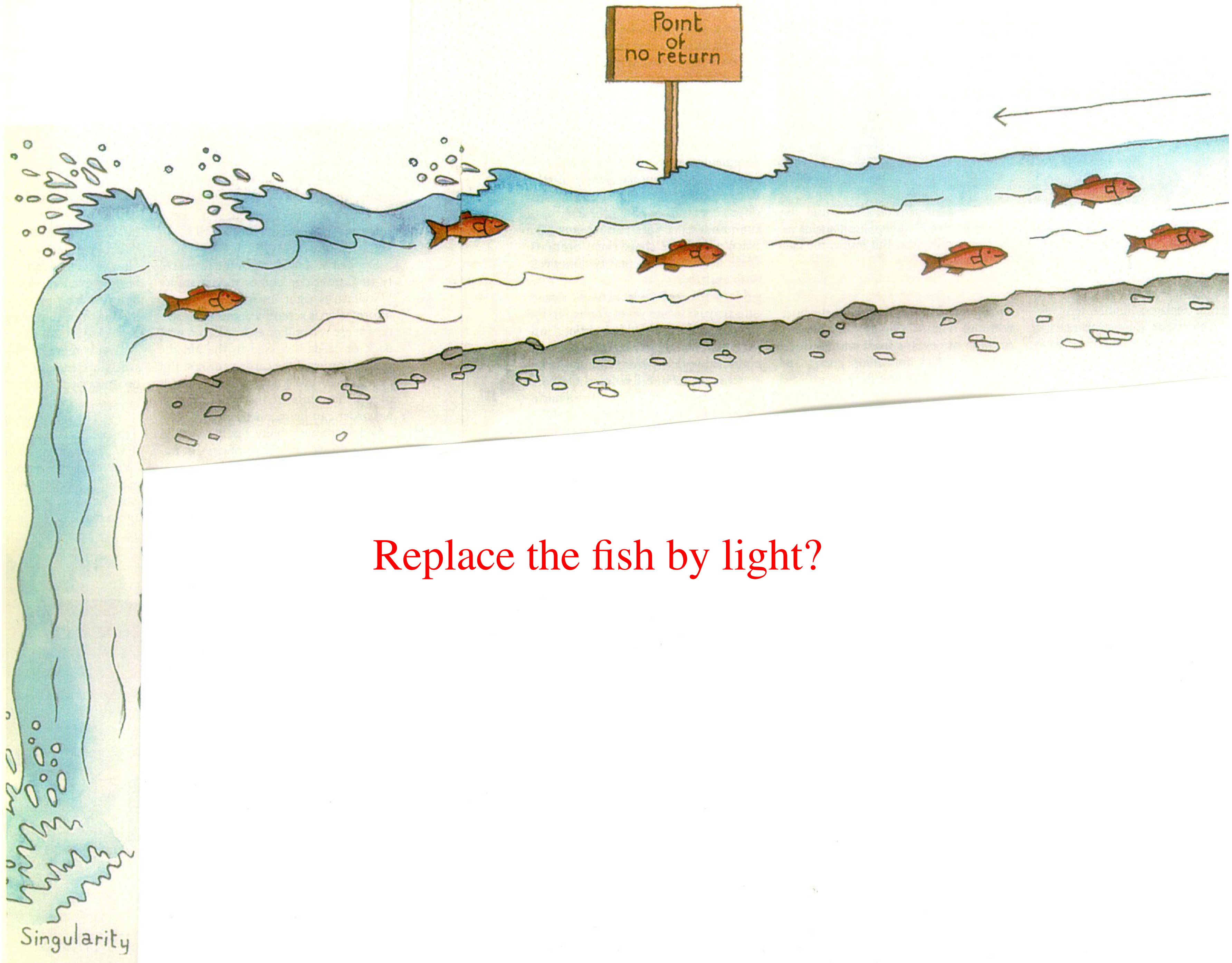




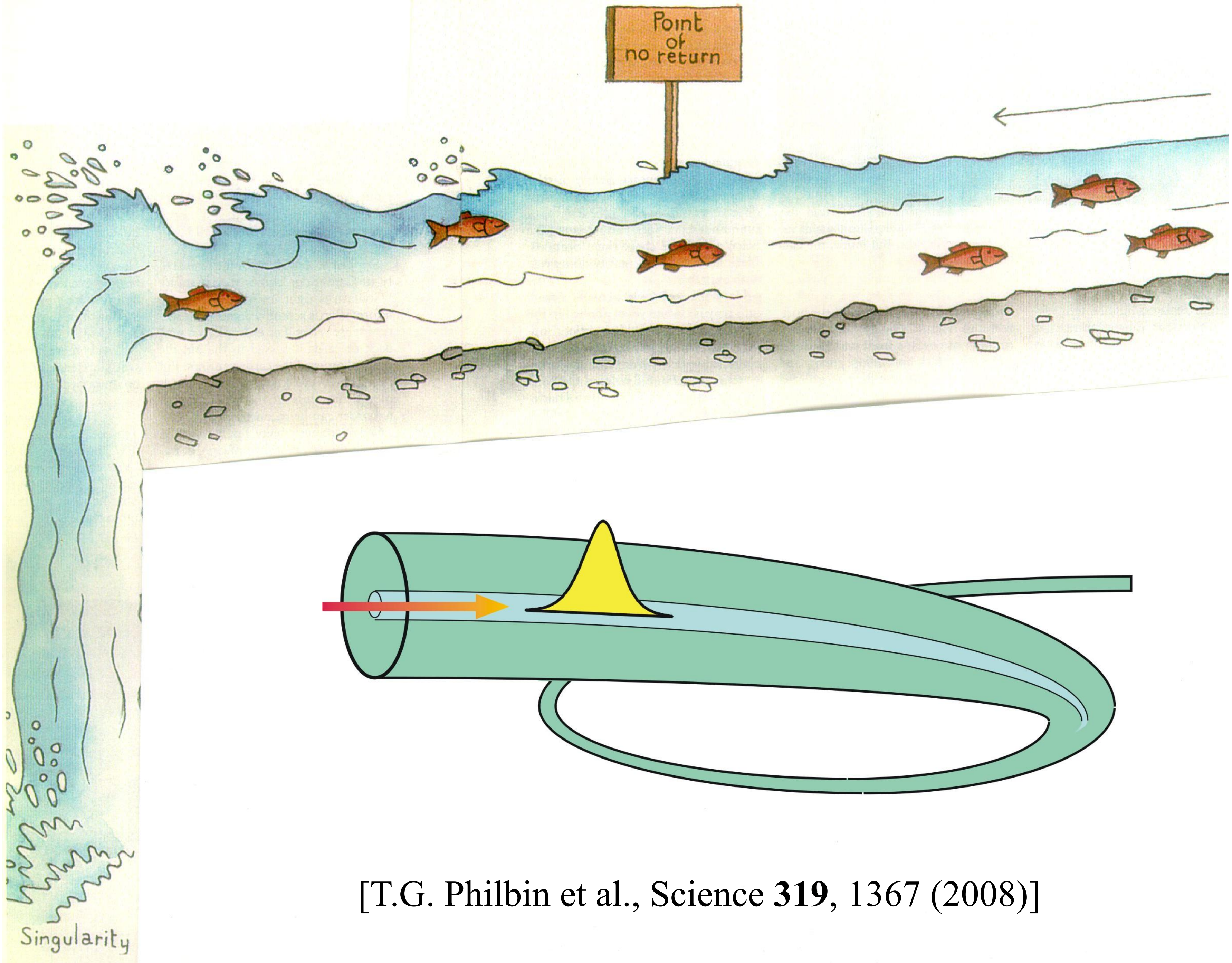
WAVES IN MOVING FLUIDS



$$\partial_\mu \sqrt{-g}\, g^{\mu\nu}\, \partial_\nu S = 0\,, \quad g^{\mu\nu} = \begin{pmatrix} 1 & \vec{u} \\ \vec{u} & -c^2 \mathbb{1} + \vec{u} \otimes \vec{u} \end{pmatrix}$$



Replace the fish by light?



[T.G. Philbin et al., Science **319**, 1367 (2008)]

Optical experiments

Fiber-Optical Analog of the Event Horizon

SCIENCE VOL 319 7 MARCH 2008

Thomas G. Philbin,[1,2] Chris Kuklewicz,[1] Scott Robertson,[1] Stephen Hill,[1] Friedrich König,[1] Ulf Leonhardt[1*]

Selected for a Viewpoint in *Physics*
PRL **105,** 203901 (2010) PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2010

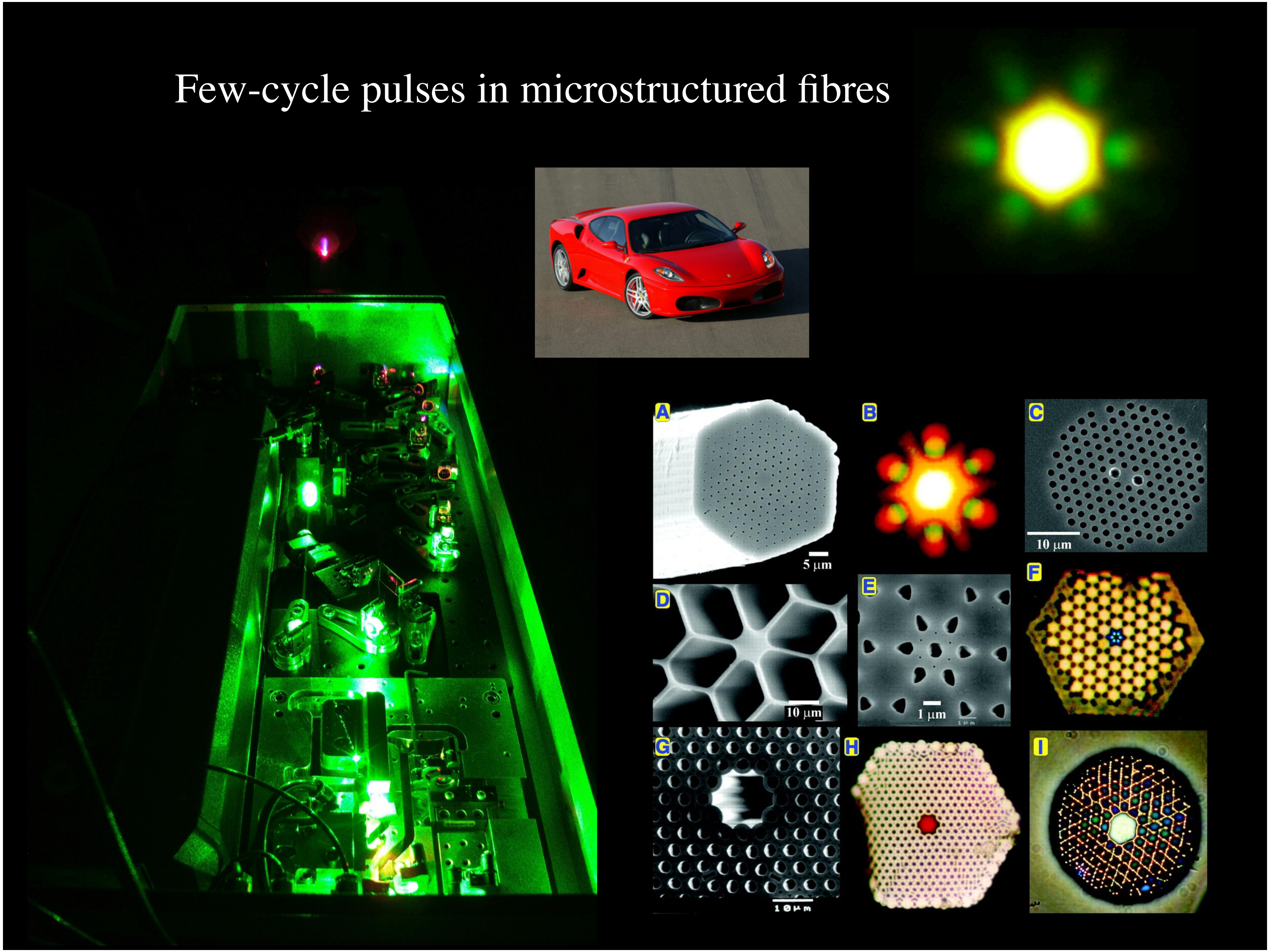
Hawking Radiation from Ultrashort Laser Pulse Filaments

F. Belgiorno,[1] S. L. Cacciatori,[2,3] M. Clerici,[3] V. Gorini,[2,3] G. Ortenzi,[4] L. Rizzi,[3] E. Rubino,[3] V. G. Sala,[3] and D. Faccio[3,5,*]

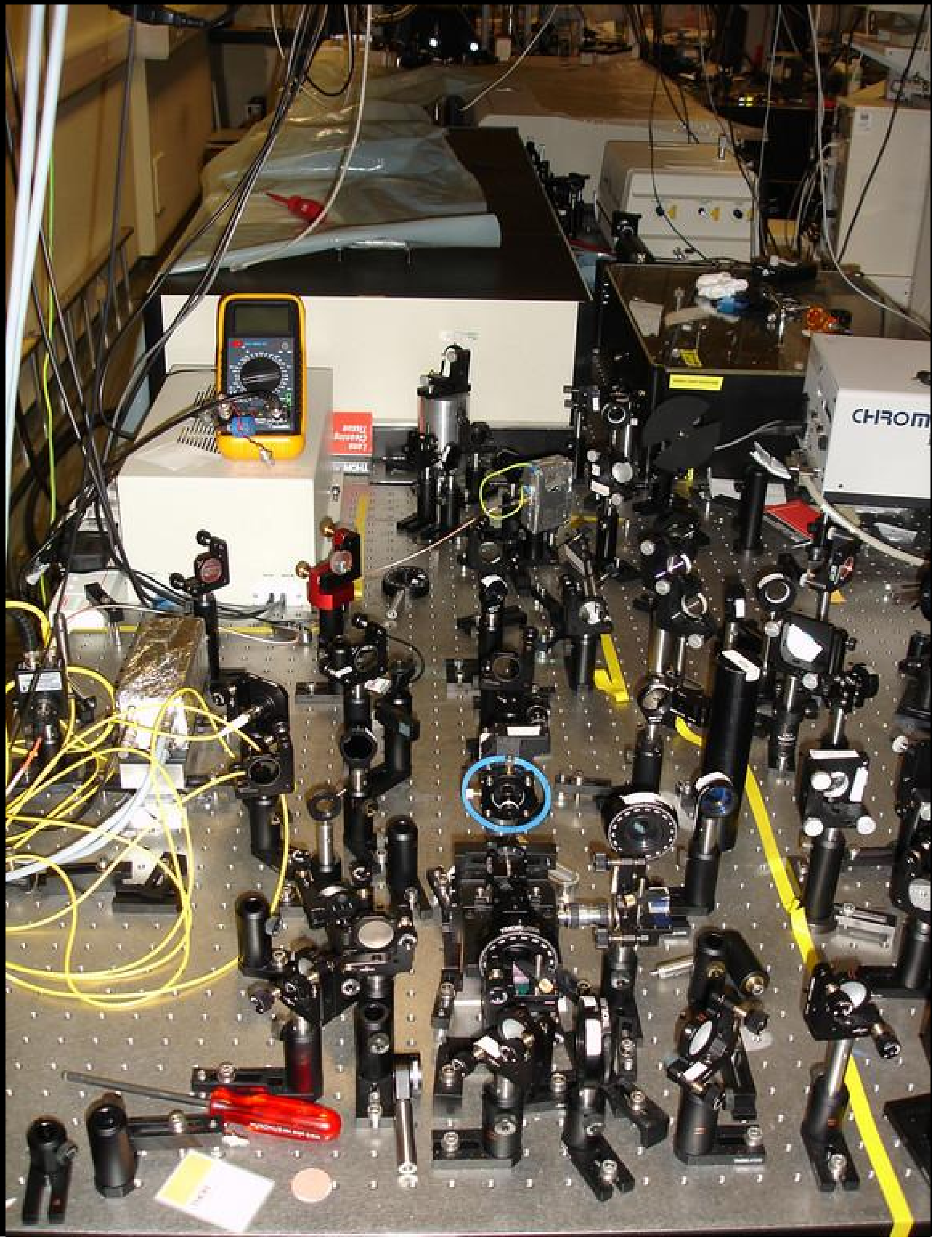
Selected for a Viewpoint in *Physics*
PRL **108,** 253901 (2012) PHYSICAL REVIEW LETTERS week ending 22 JUNE 2012

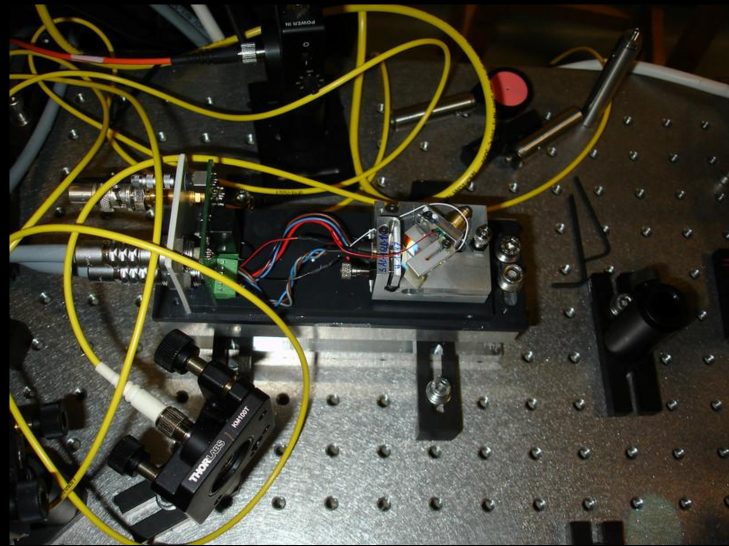
Negative-Frequency Resonant Radiation

E. Rubino,[1] J. McLenaghan,[2] S. C. Kehr,[2] F. Belgiorno,[3] D. Townsend,[4] S. Rohr,[2] C. E. Kuklewicz,[4] U. Leonhardt,[2] F. König,[2,†] and D. Faccio[4,*]


Few-cycle pulses in microstructured fibres
A
5 μm
B
C
10 μm
D
10 μm
E
1 μm
F
G
10 μm
H
I

St Andrews experiment

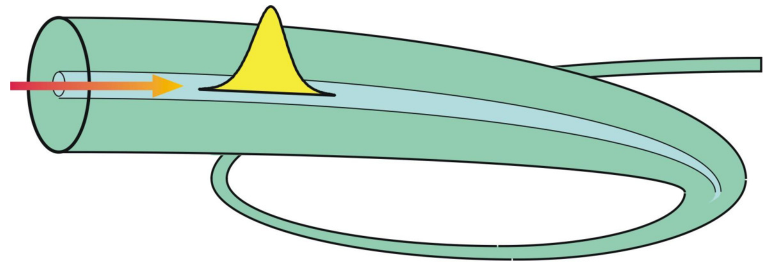


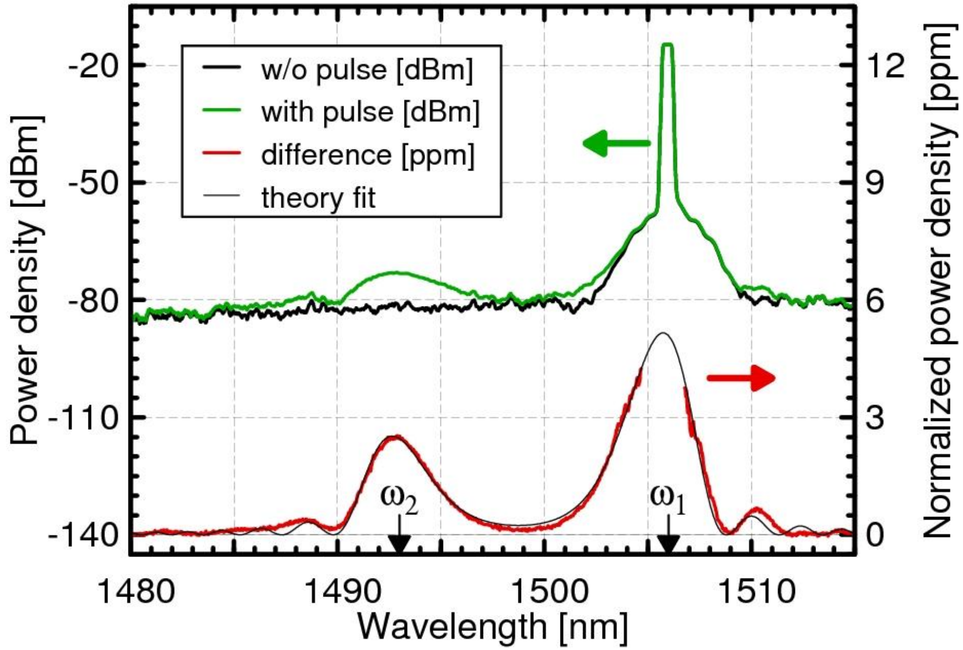


Probe laser

Experiment: blue-shifting

[Philbin et al., Science **319**, 1367 (2008)]

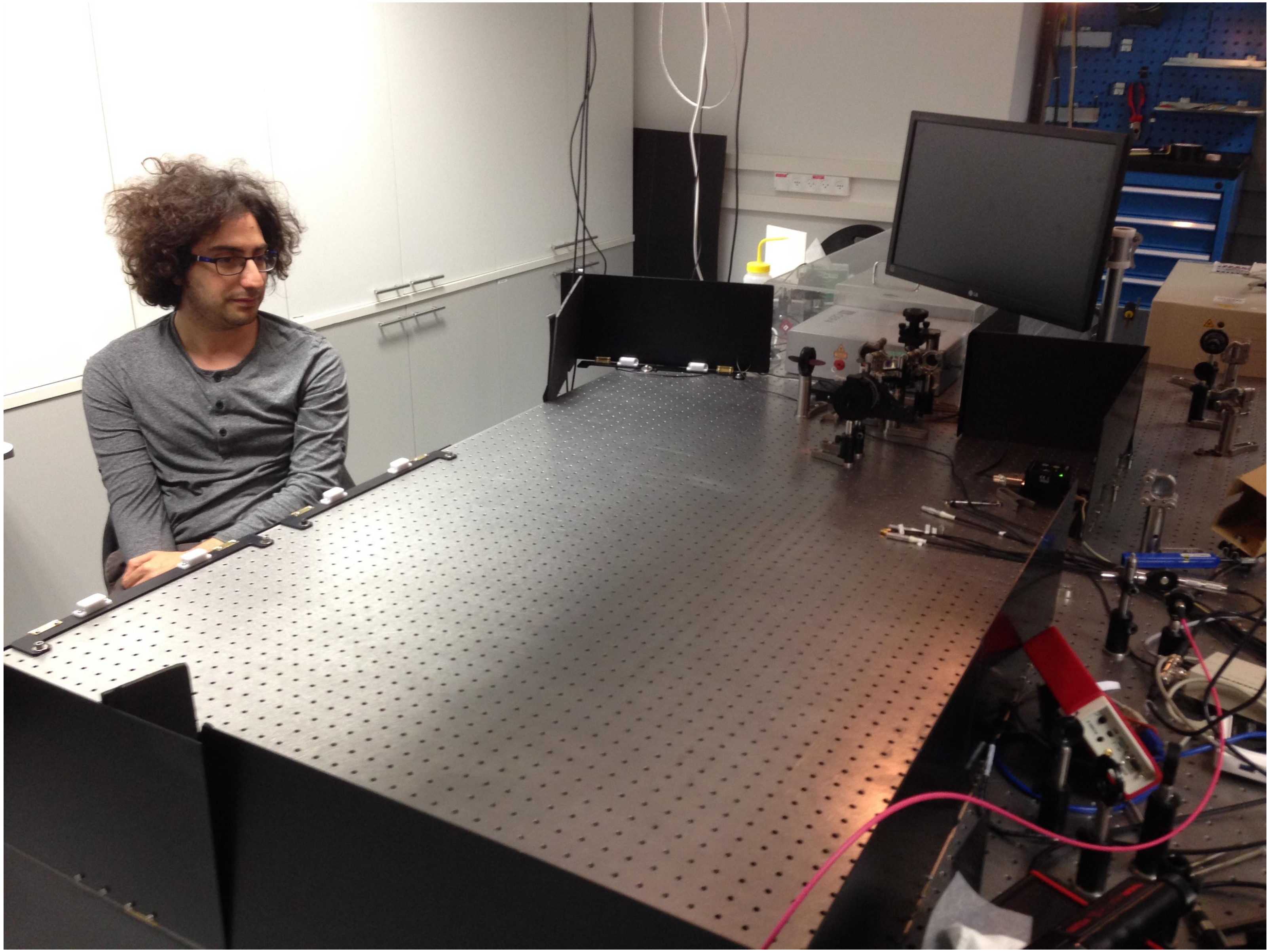




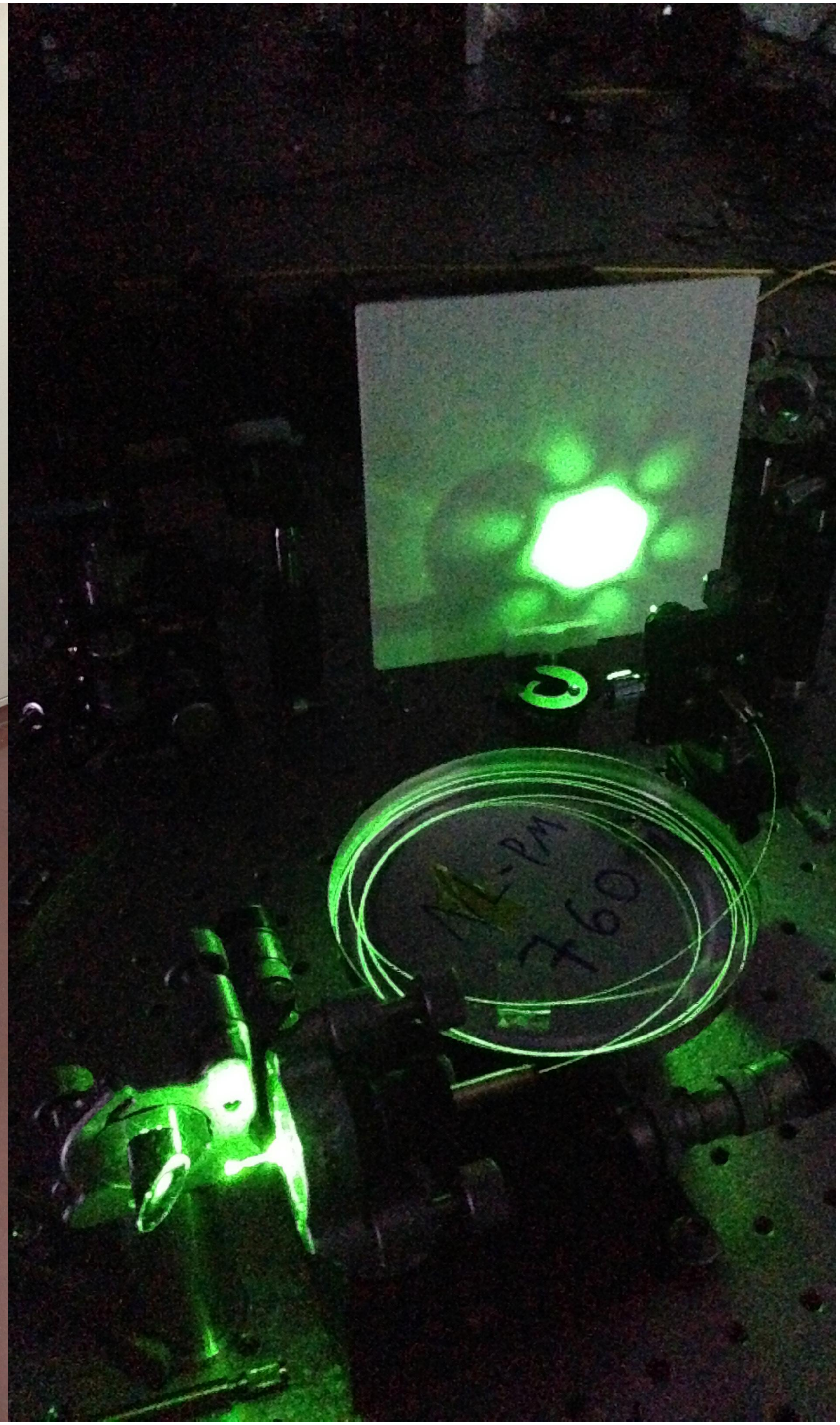
Weizmann laboratory

with Jonathan Drori and Yuval Rosenberg

Weizmann laboratory

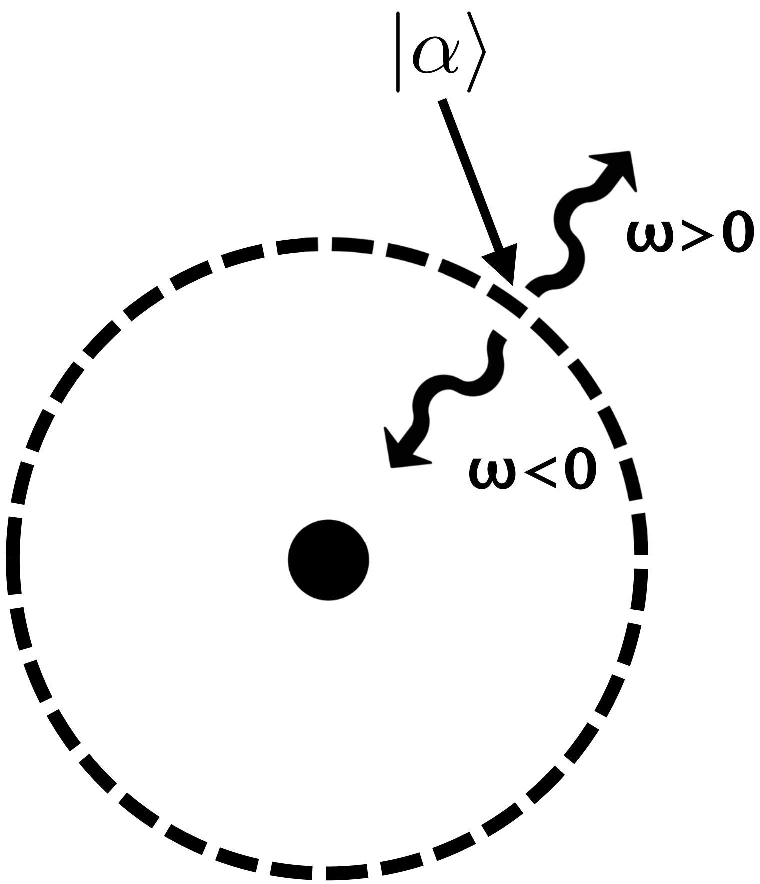



שמיכה
לכיבוי אש
FIRE BLANKET
PULL TAPES
OCTAVIUS
196

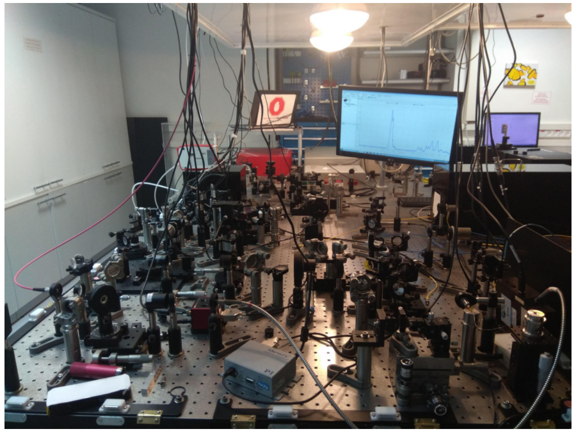

760

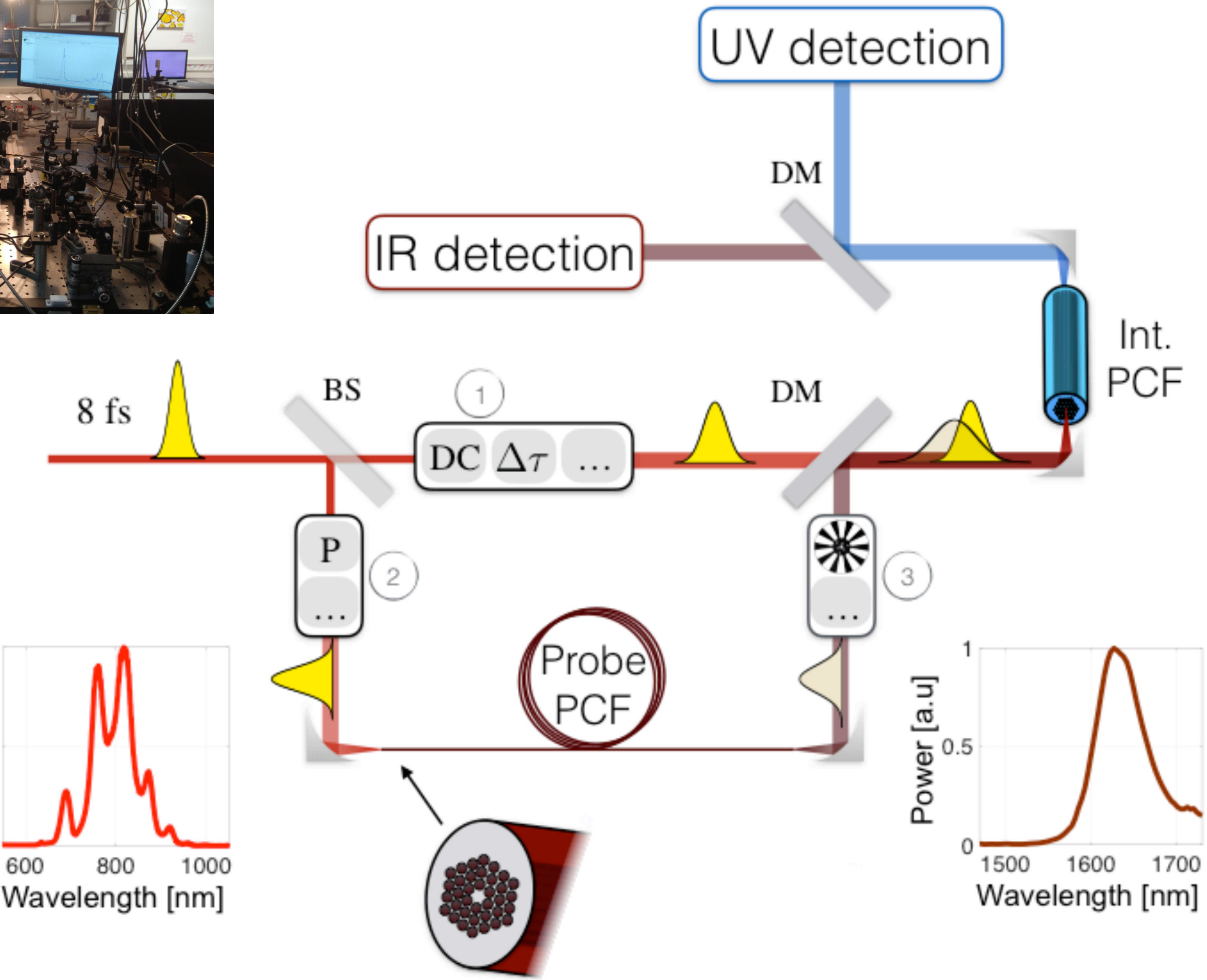
Weizmann laboratory

Stimulated Hawking radiation

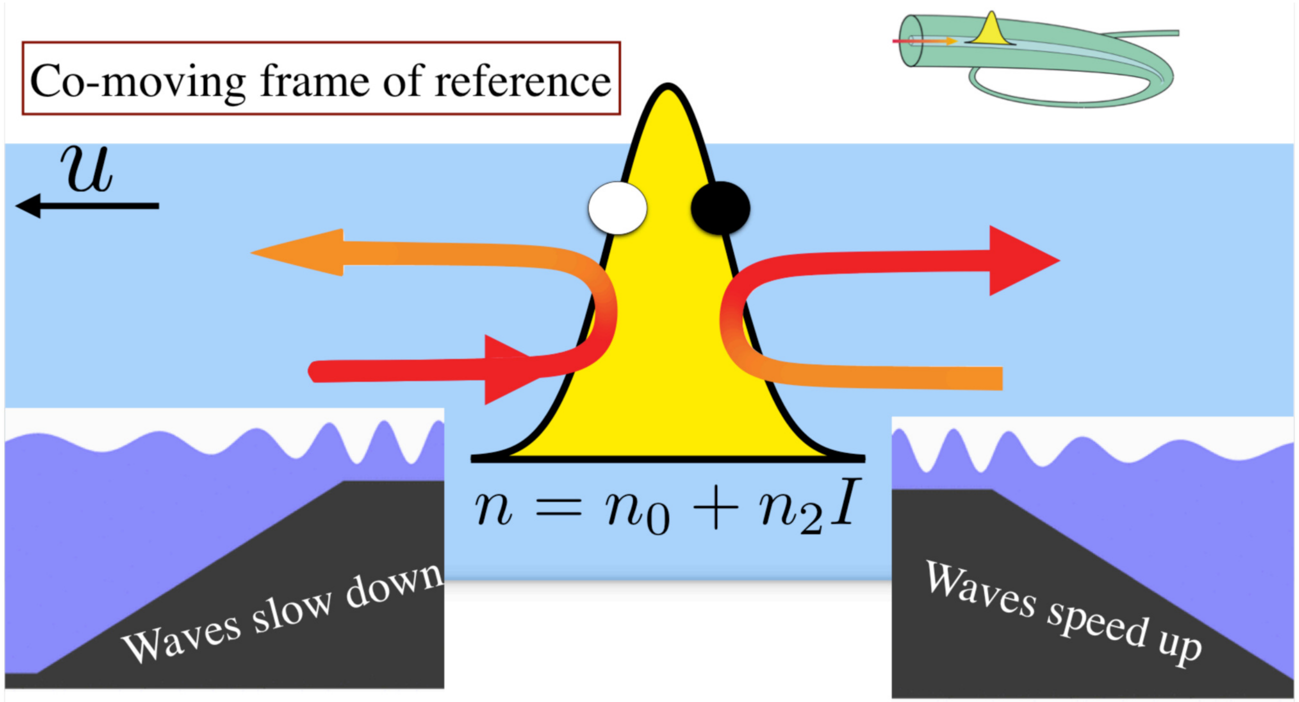


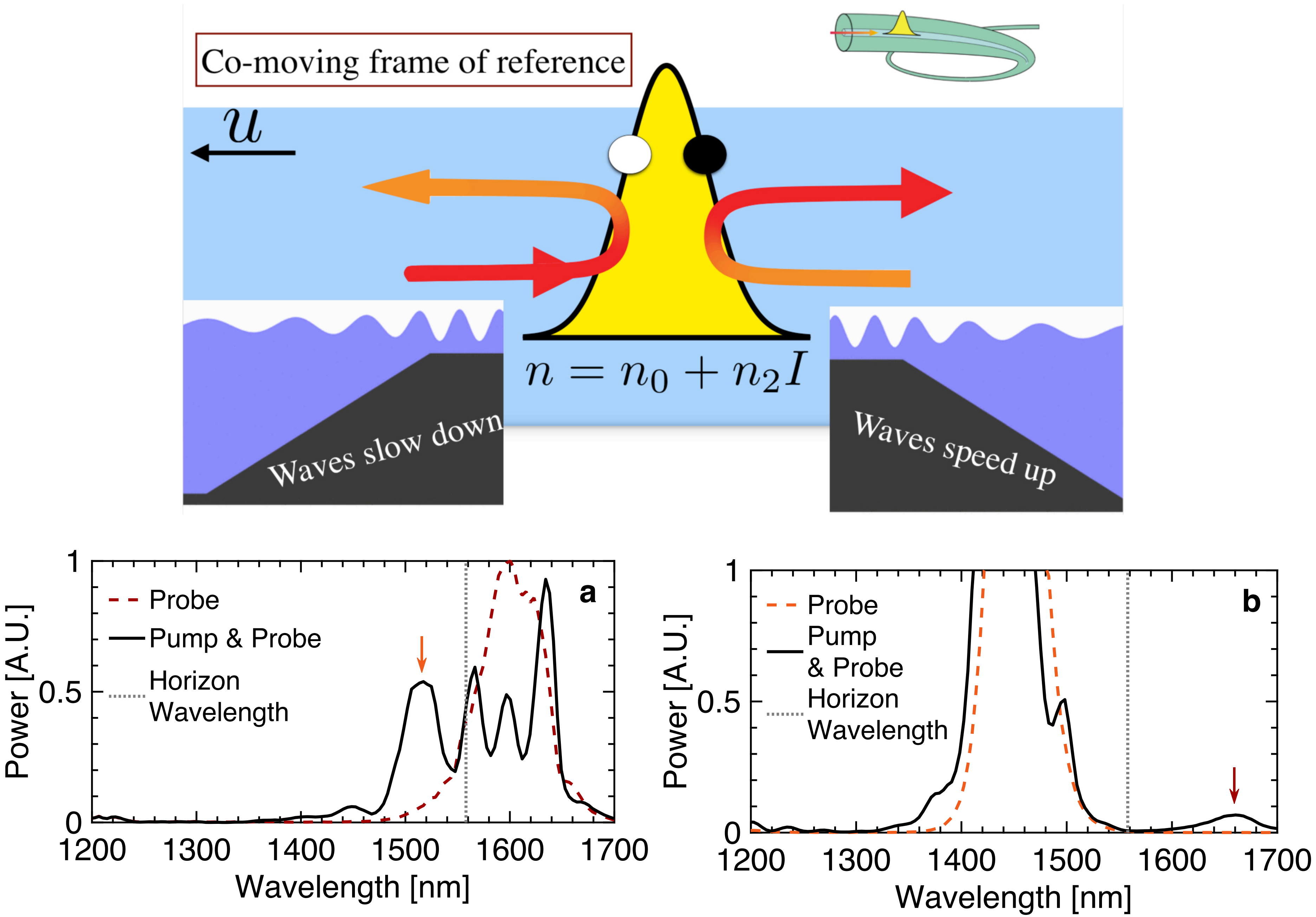
Experimental setup for stimulated Hawking radiation



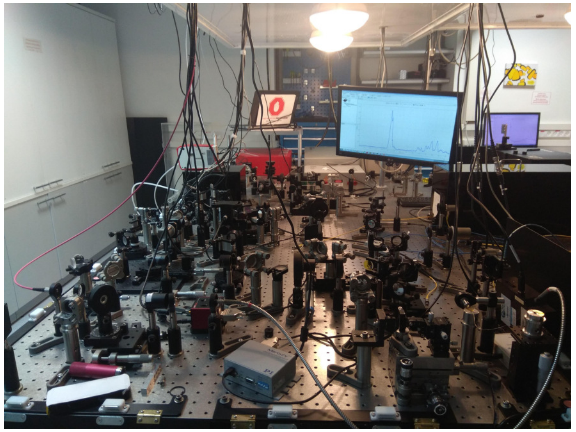


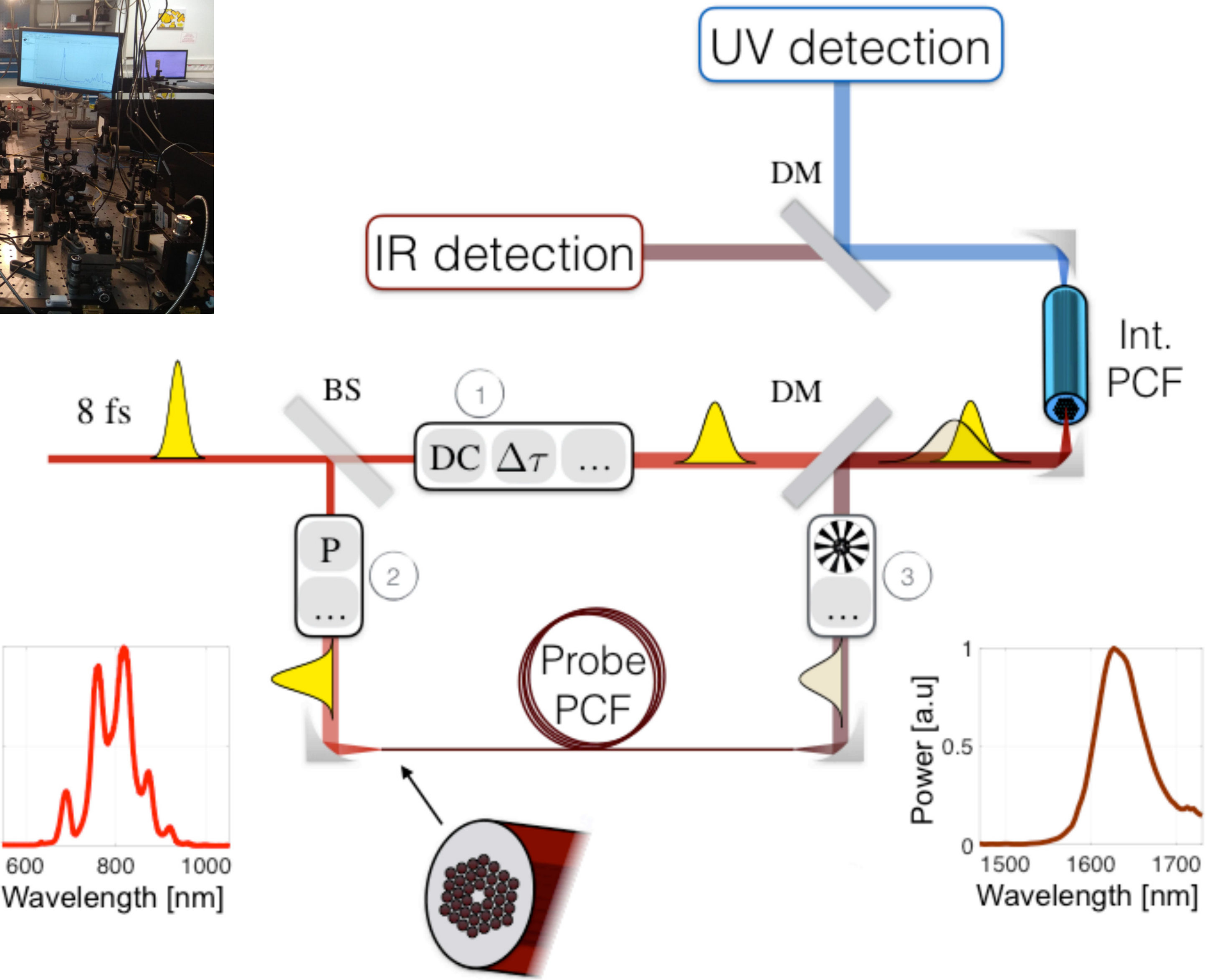
Red and blue shifting at horizons



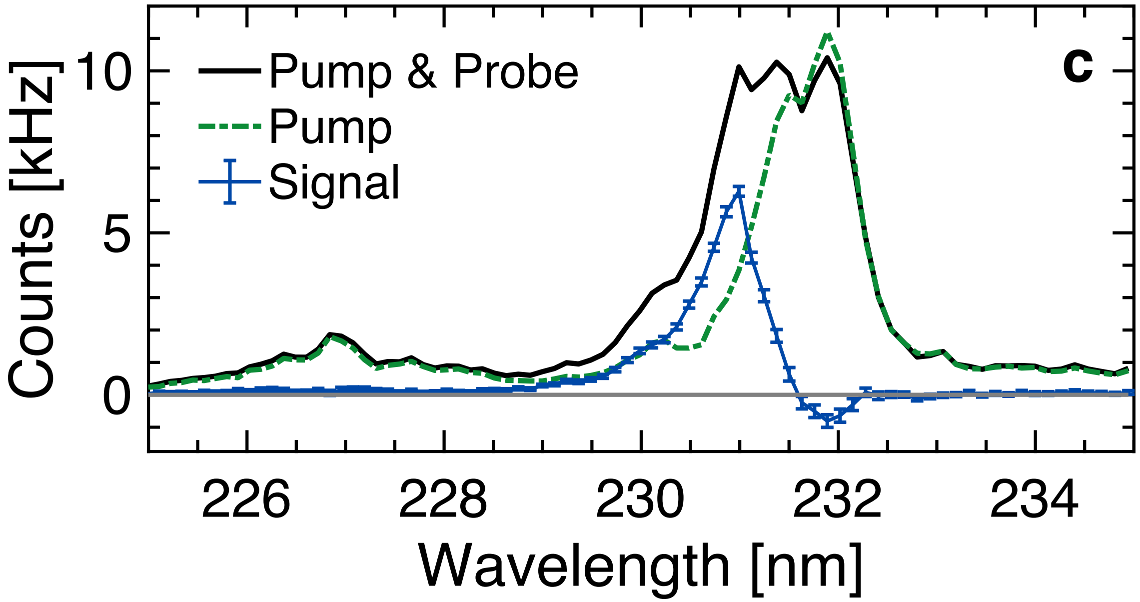

Co-moving frame of reference
u
$n = n_0 + n_2 I$
Waves slow down
Waves speed up
Probe
Pump & Probe
Horizon Wavelength
a
Power [A.U.]
Wavelength [nm]
Probe
Pump & Probe
Horizon Wavelength
b
Power [A.U.]
Wavelength [nm]

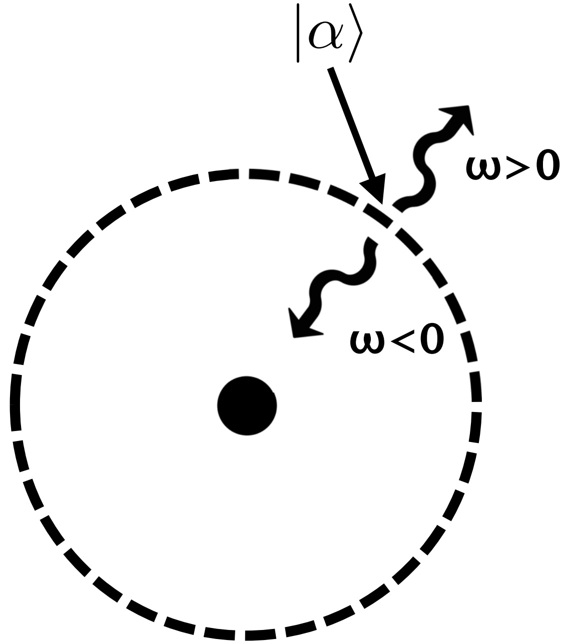
Experimental setup for stimulated Hawking radiation





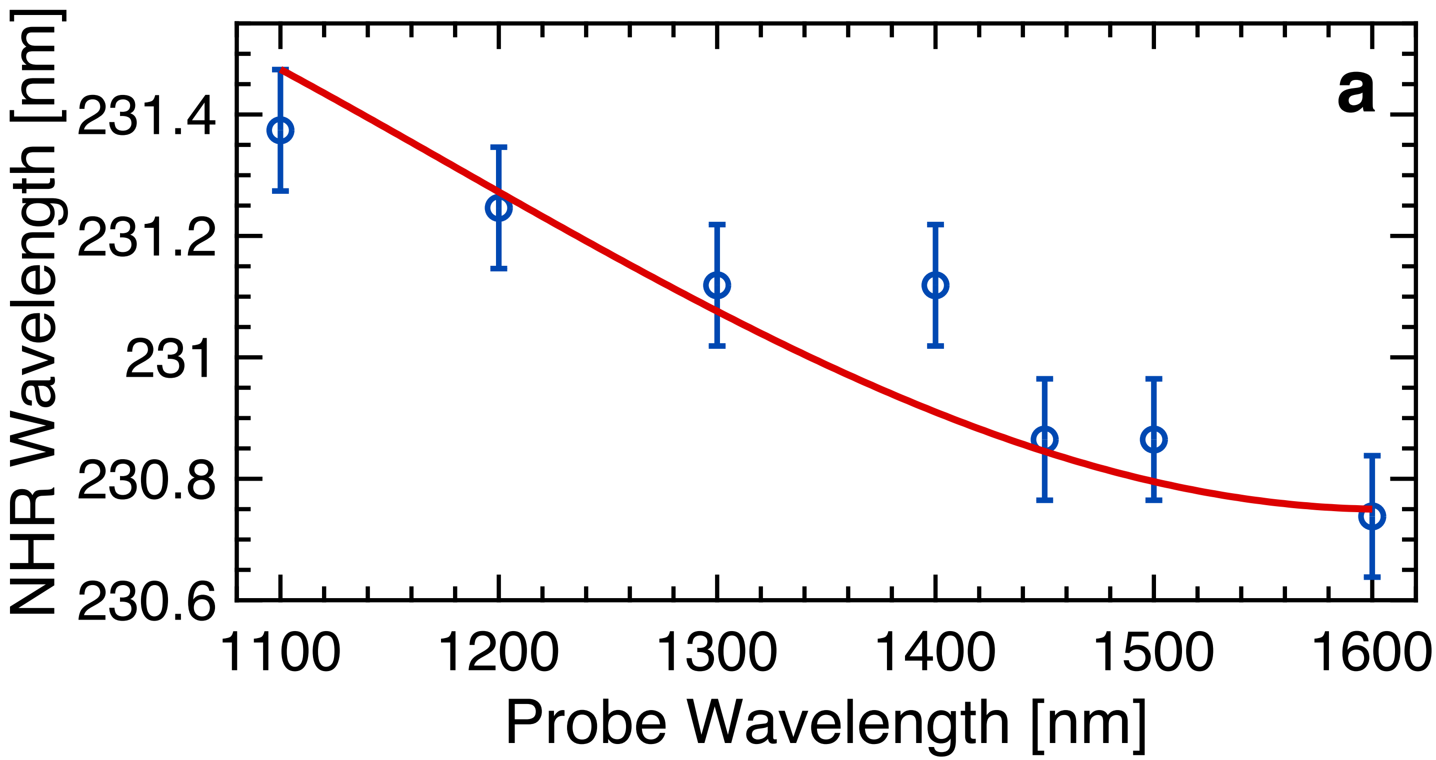
Measurement of stimulated Hawking radiation



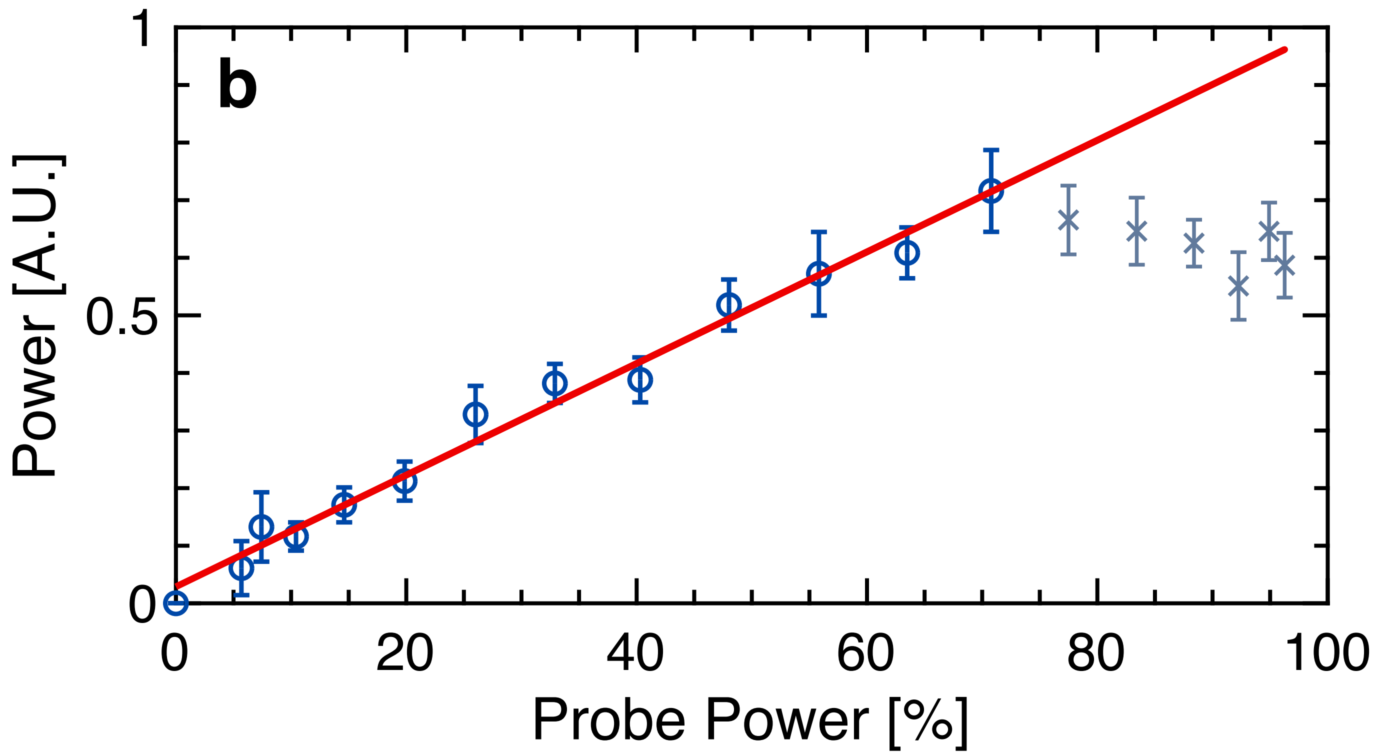


Probe at 1450 nm < horizon wavelength, red shifting regime

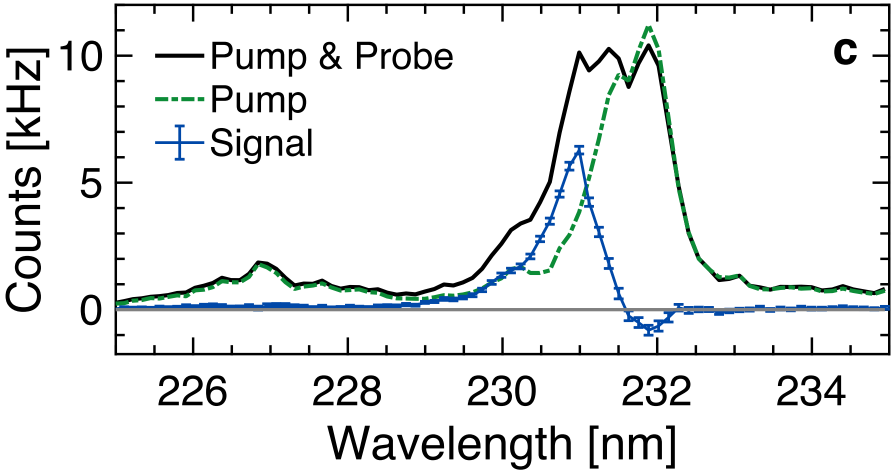
Comparison of stimulated Hawking radiation with dispersion curve



Linearity of measured stimulated Hawking radiation



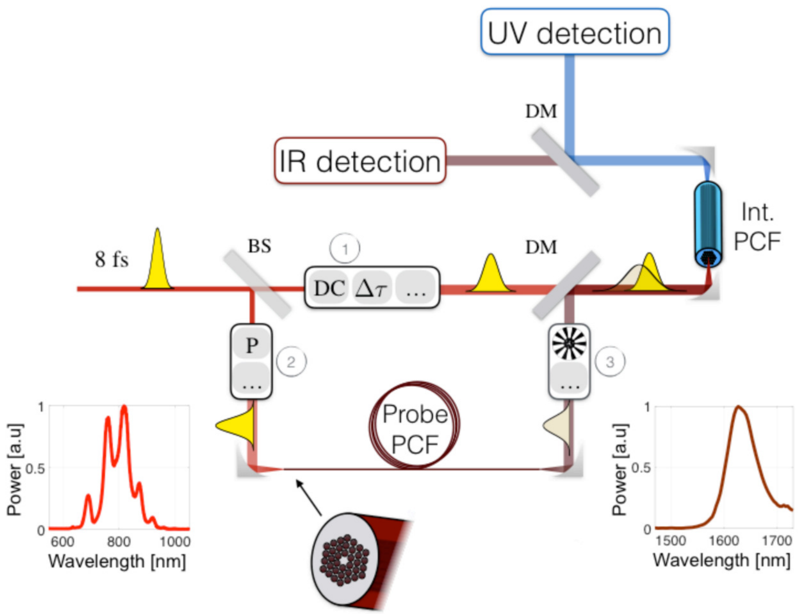
Summary: observation of stimulated Hawking radiation in optics



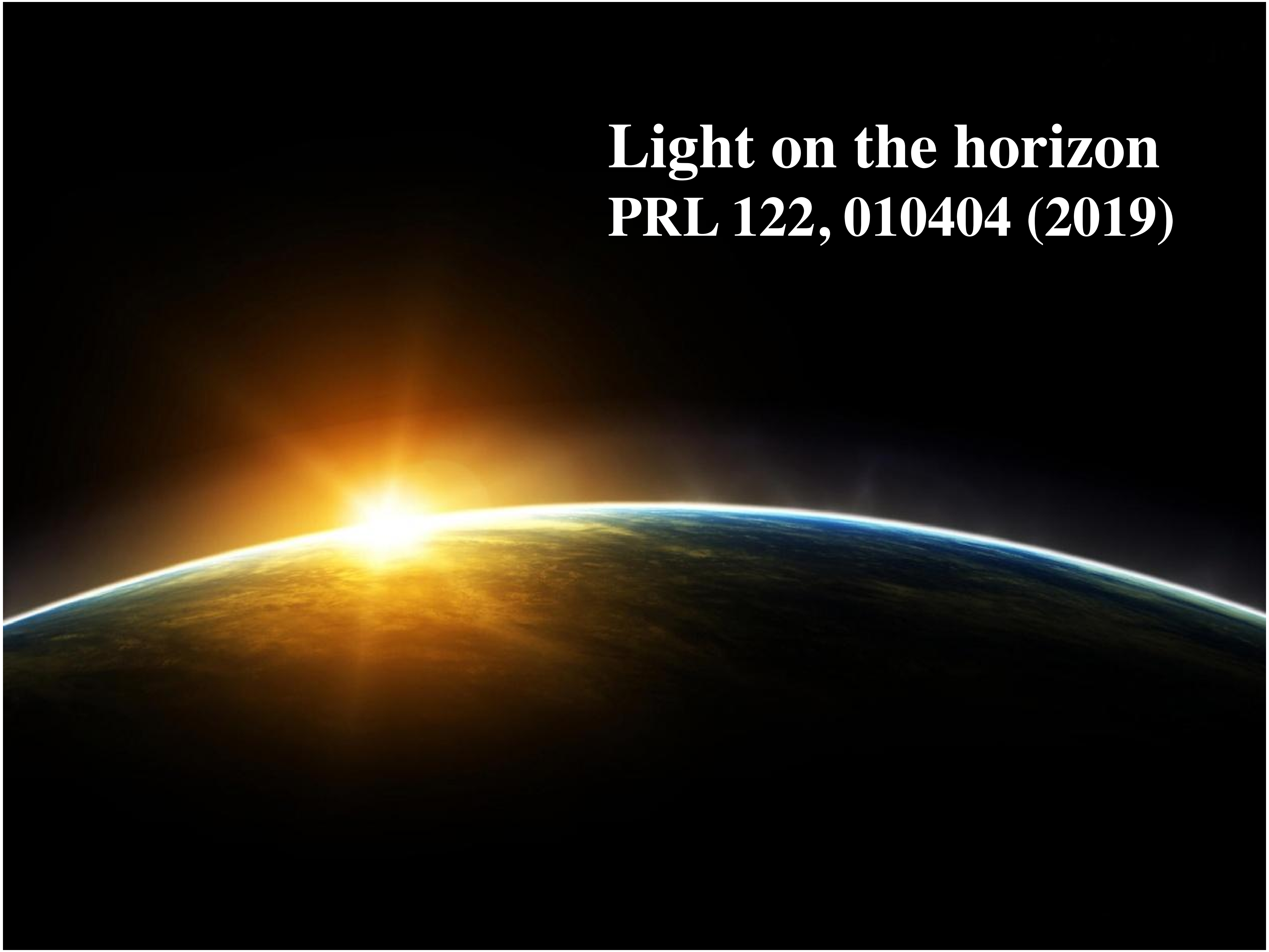
- consistent with dispersion data
- linear
- extreme nonlinear optics

Outlook:

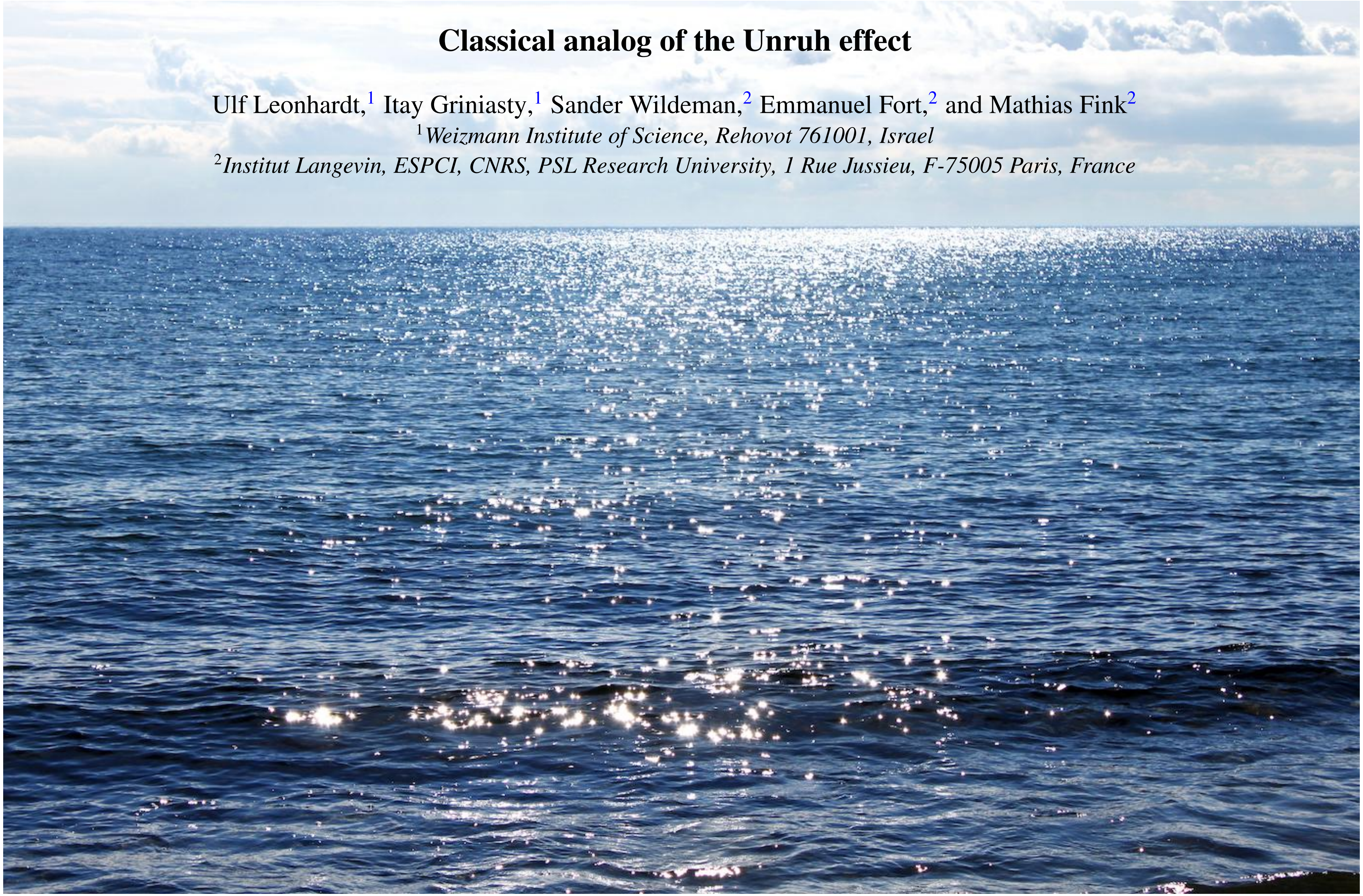
- pulse trapping
- spontaneous Hawking radiation



Jonathan Drori　　Yuval Rosenberg


Light on the horizon
PRL 122, 010404 (2019)

PHYSICAL REVIEW A **98**, 022118 (2018)



Classical analog of the Unruh effect

Ulf Leonhardt,[1] Itay Griniasty,[1] Sander Wildeman,[2] Emmanuel Fort,[2] and Mathias Fink[2]

[1]*Weizmann Institute of Science, Rehovot 761001, Israel*

[2]*Institut Langevin, ESPCI, CNRS, PSL Research University, 1 Rue Jussieu, F-75005 Paris, France*

Classical analog of the Unruh effect

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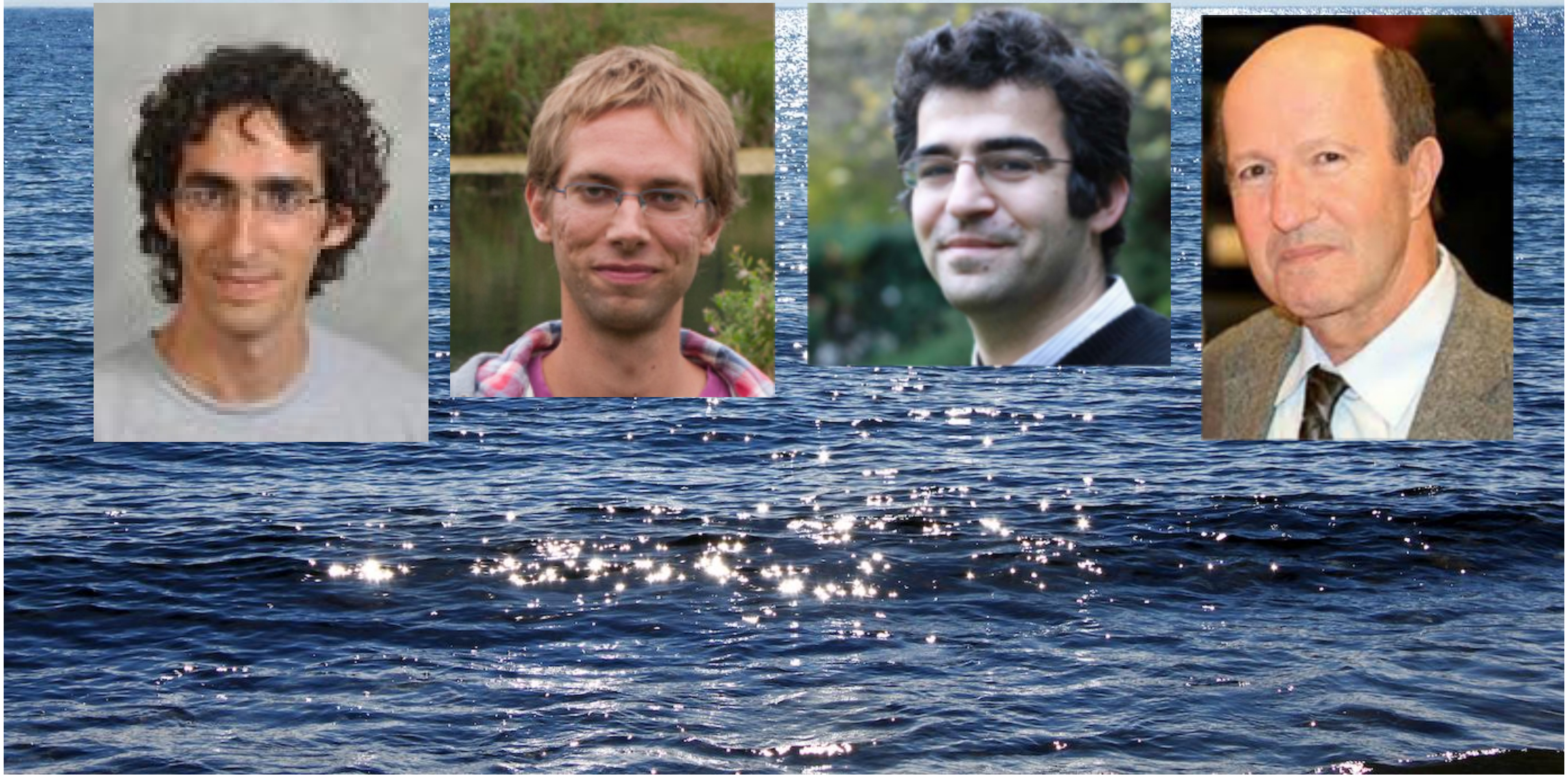
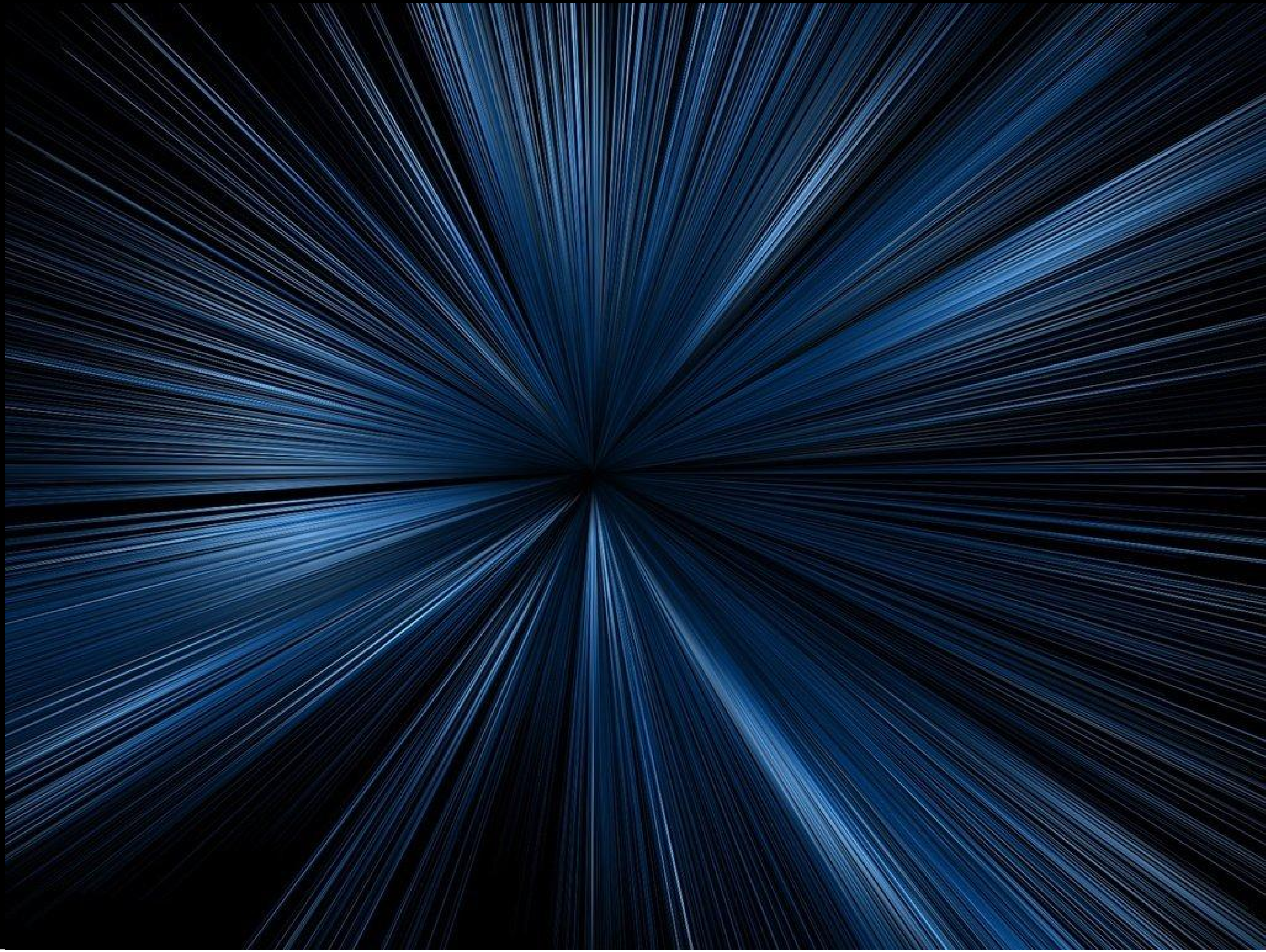


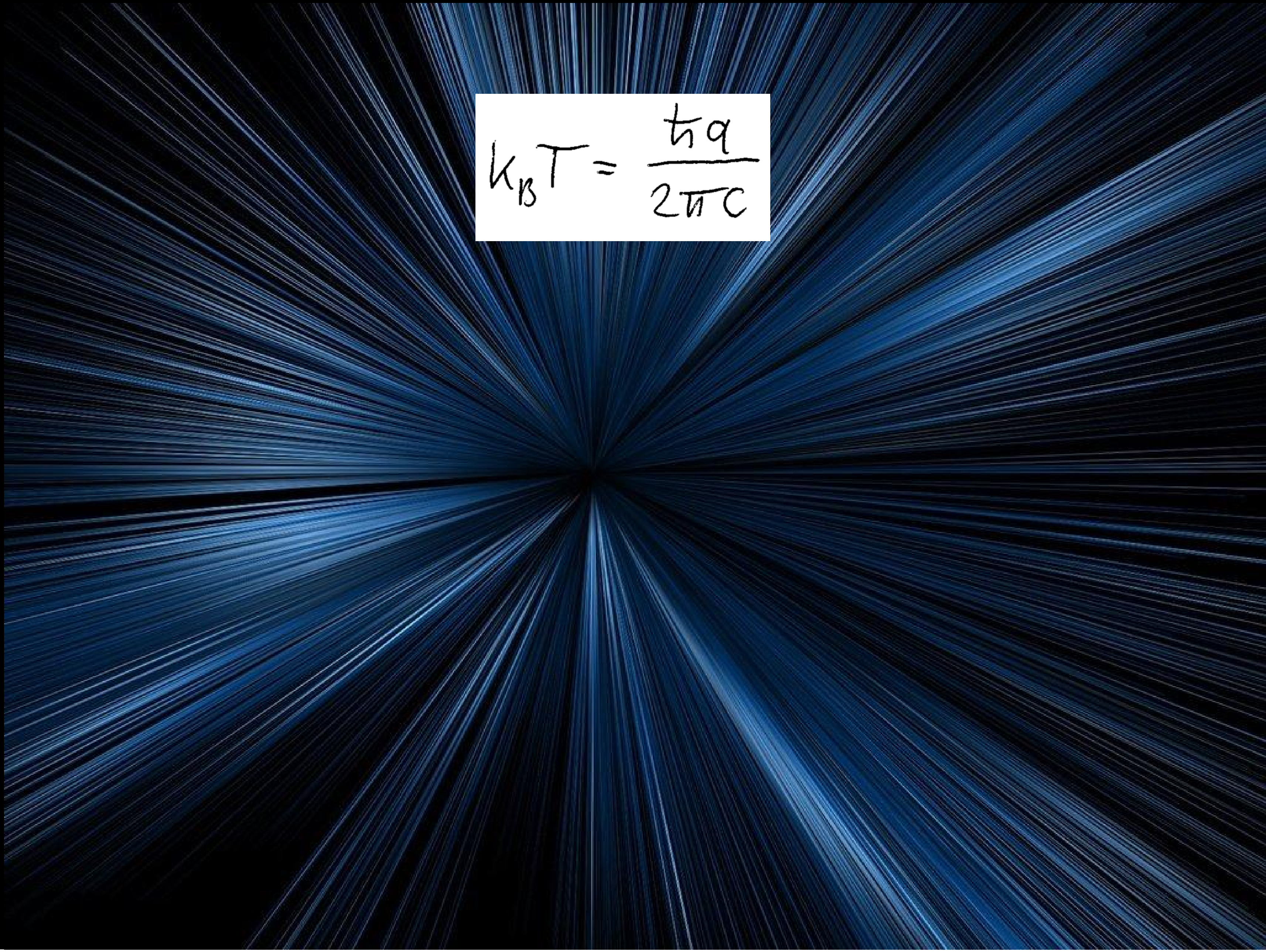
Empty space

Acceleration in empty space



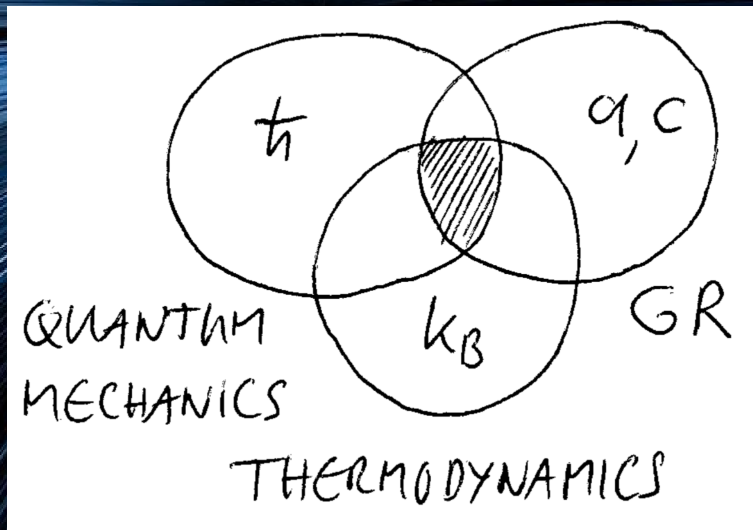
Acceleration in empty space: Unruh effect

$$k_B T = \frac{\hbar a}{2\pi c}$$



Unruh effect: the connections

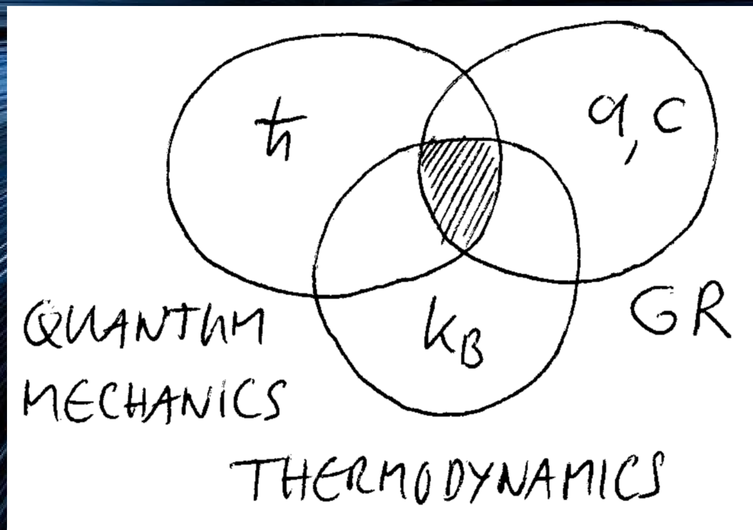
$$k_B T = \frac{\hbar a}{2\pi c}$$



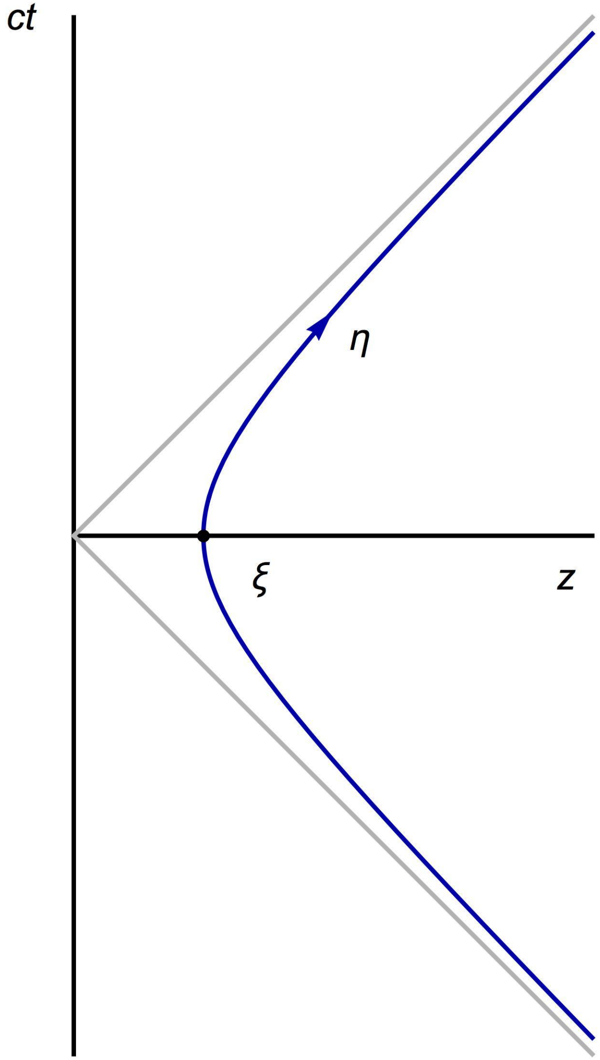
Unruh effect: the numbers

$$k_B T = \frac{\hbar a}{2\pi c}$$

$T = 300\text{K}$ $\qquad$ $a = 10^{21}\text{g}$

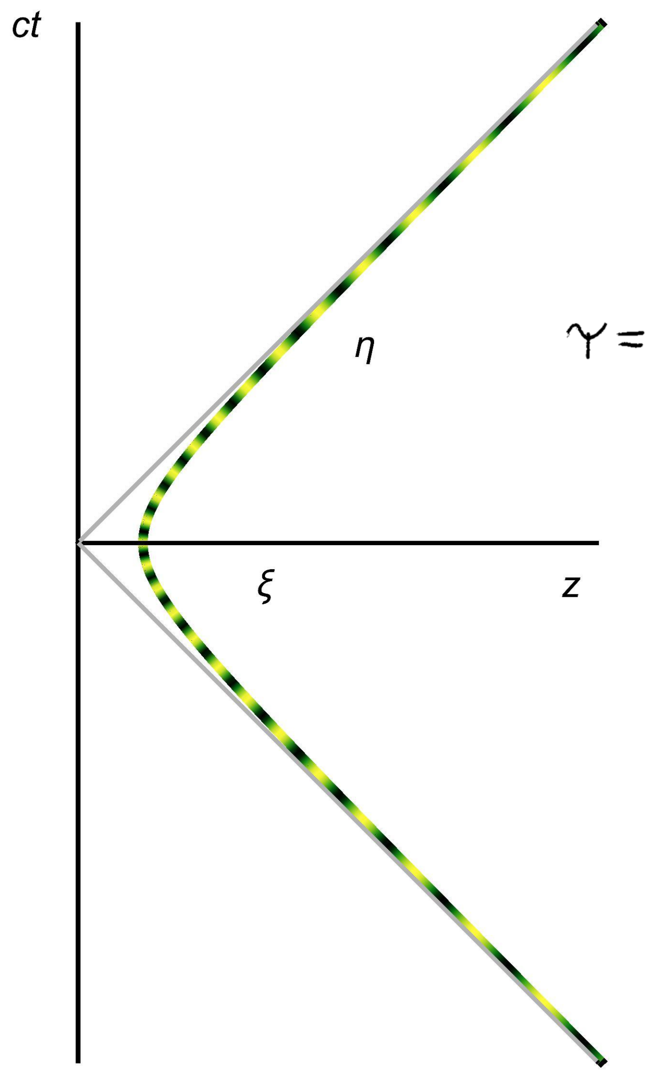


Accelerated observer: Rindler diagram



$$\xi = \frac{c^2}{\alpha}$$

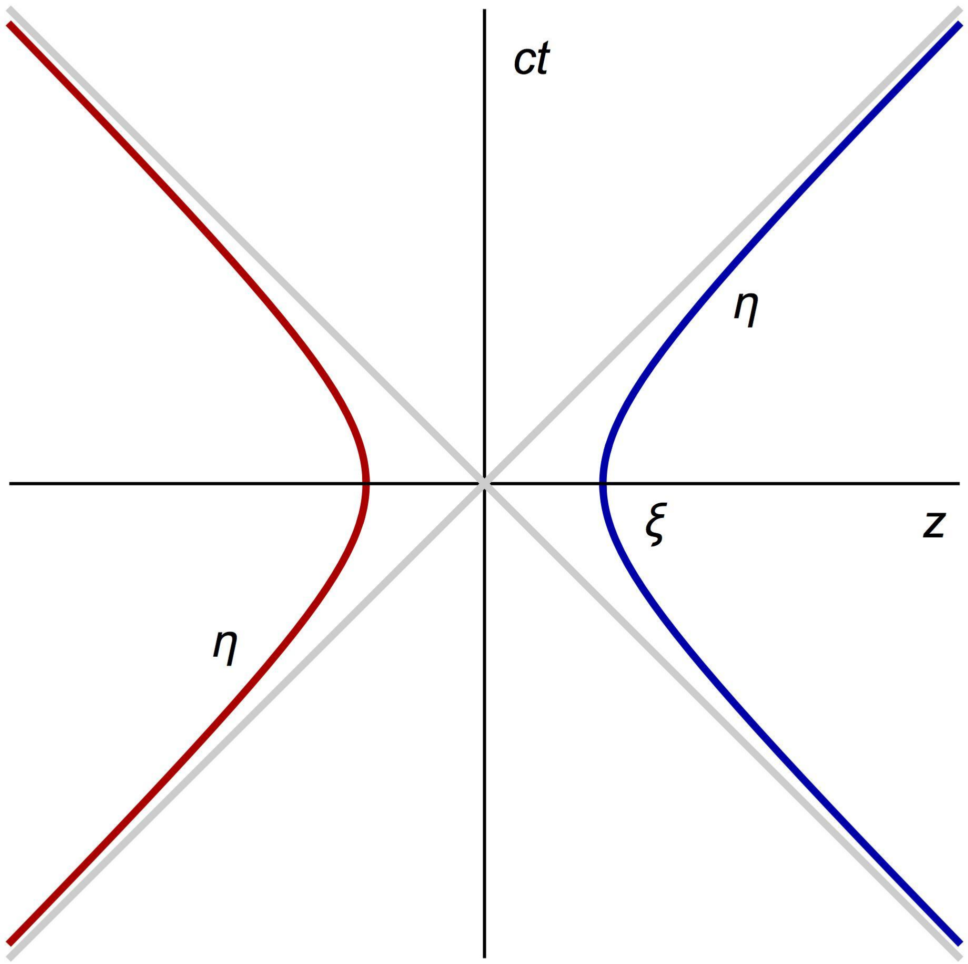
Accelerated observer: exponential time dilation



$$\xi = \frac{c^2}{a}$$

$$\tau = \frac{c}{a}\eta \qquad \text{proper time}$$

A tale of two observers

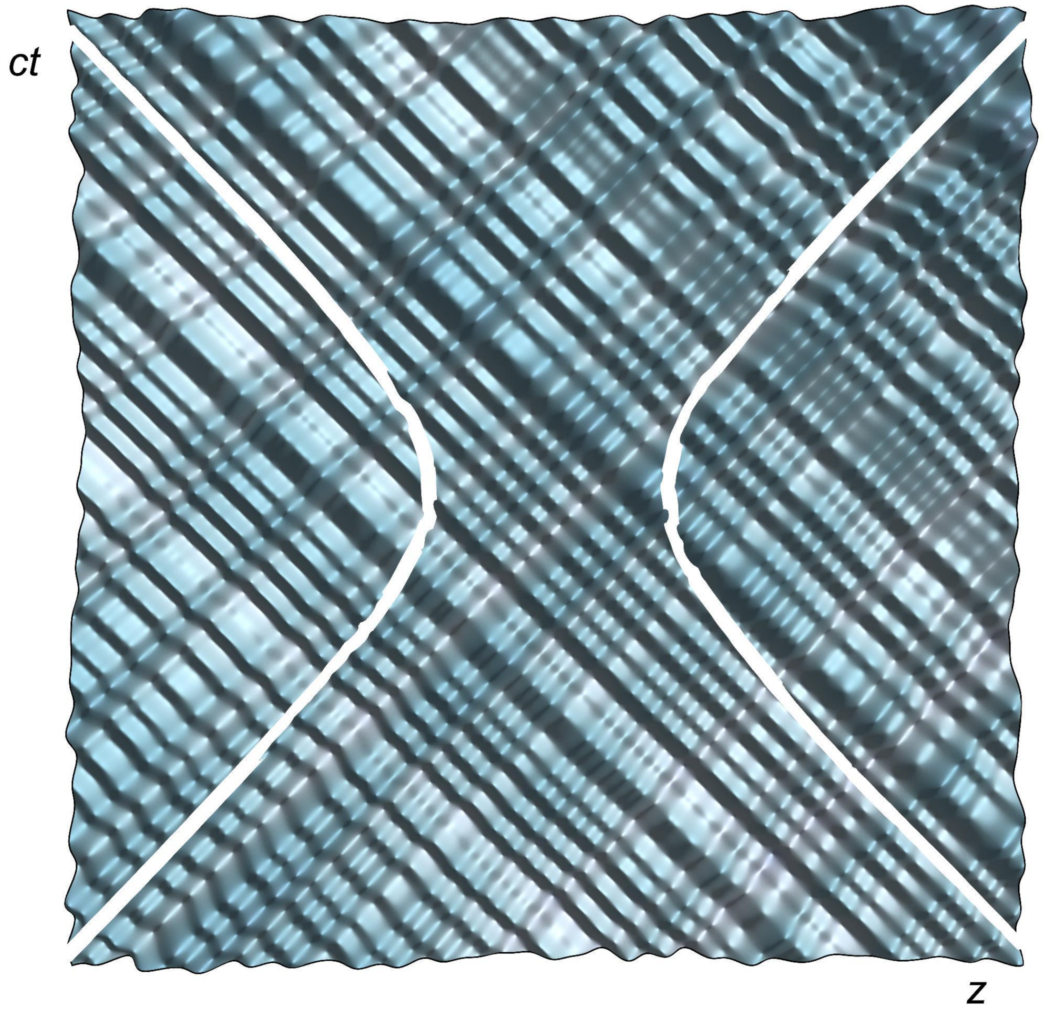


$$k_B T = \frac{\hbar a}{2\pi c}$$

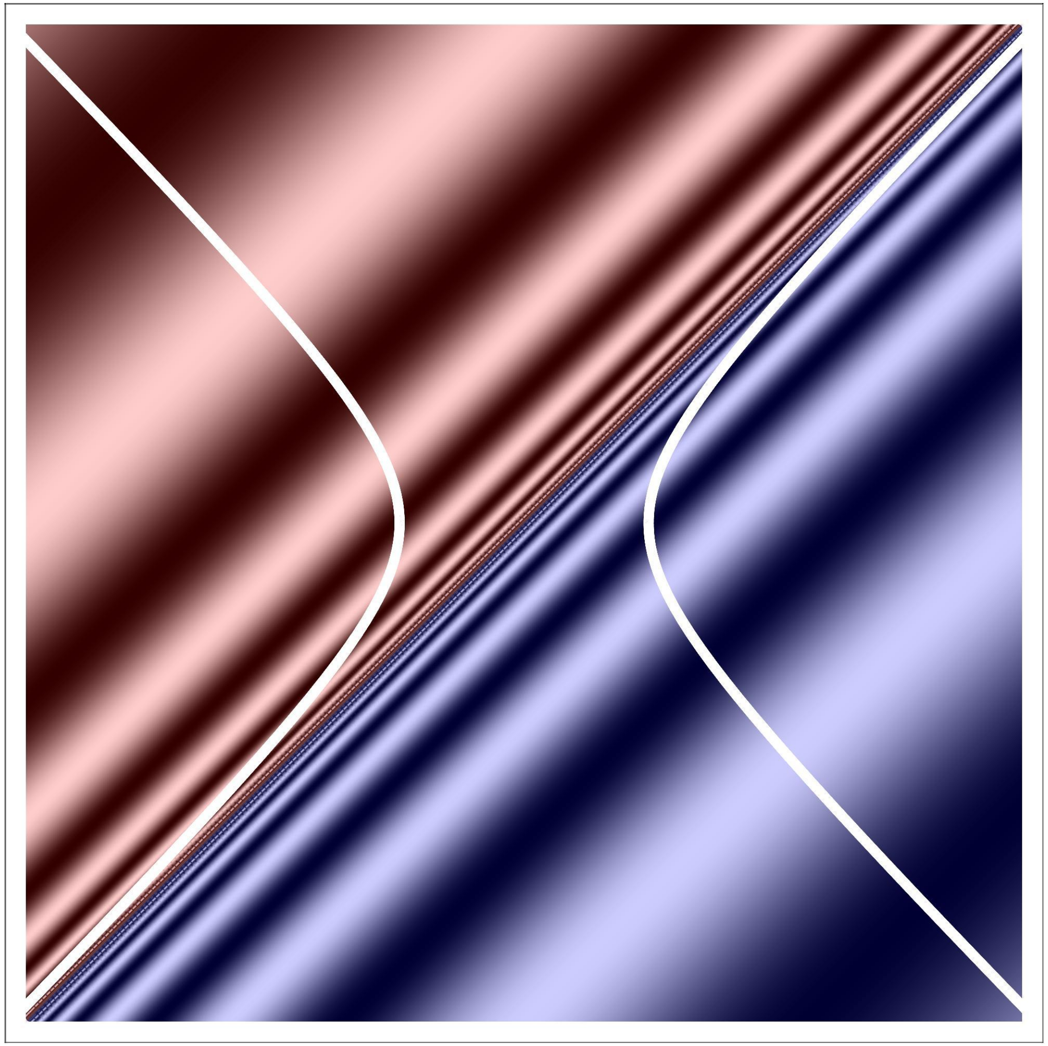
$$\xi = \frac{c^2}{a}$$

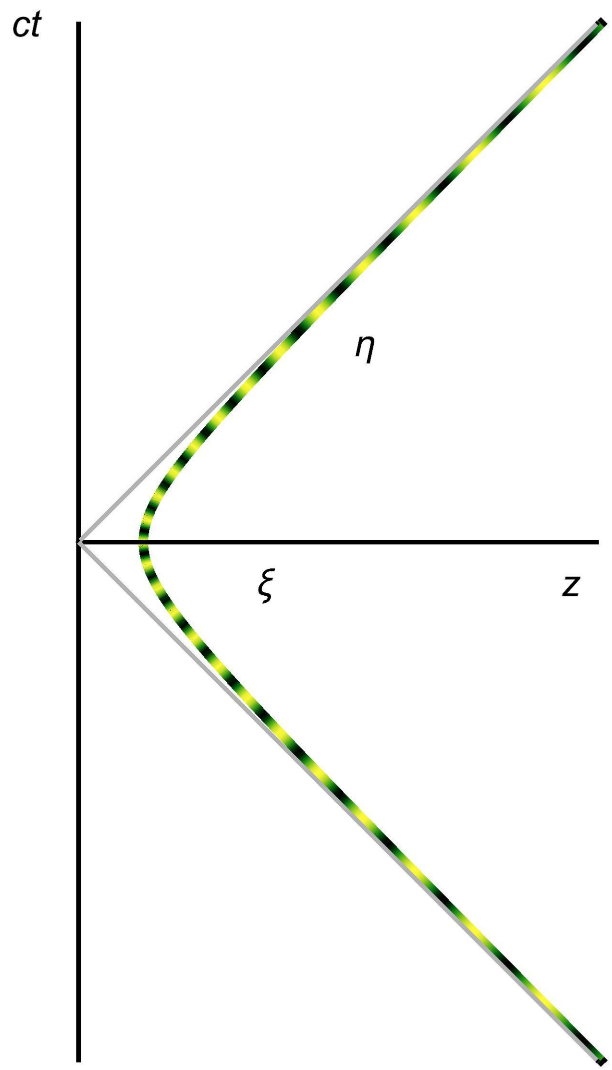
$$\tau = \frac{c}{a}\eta$$

Wave noise is correlated in space-time

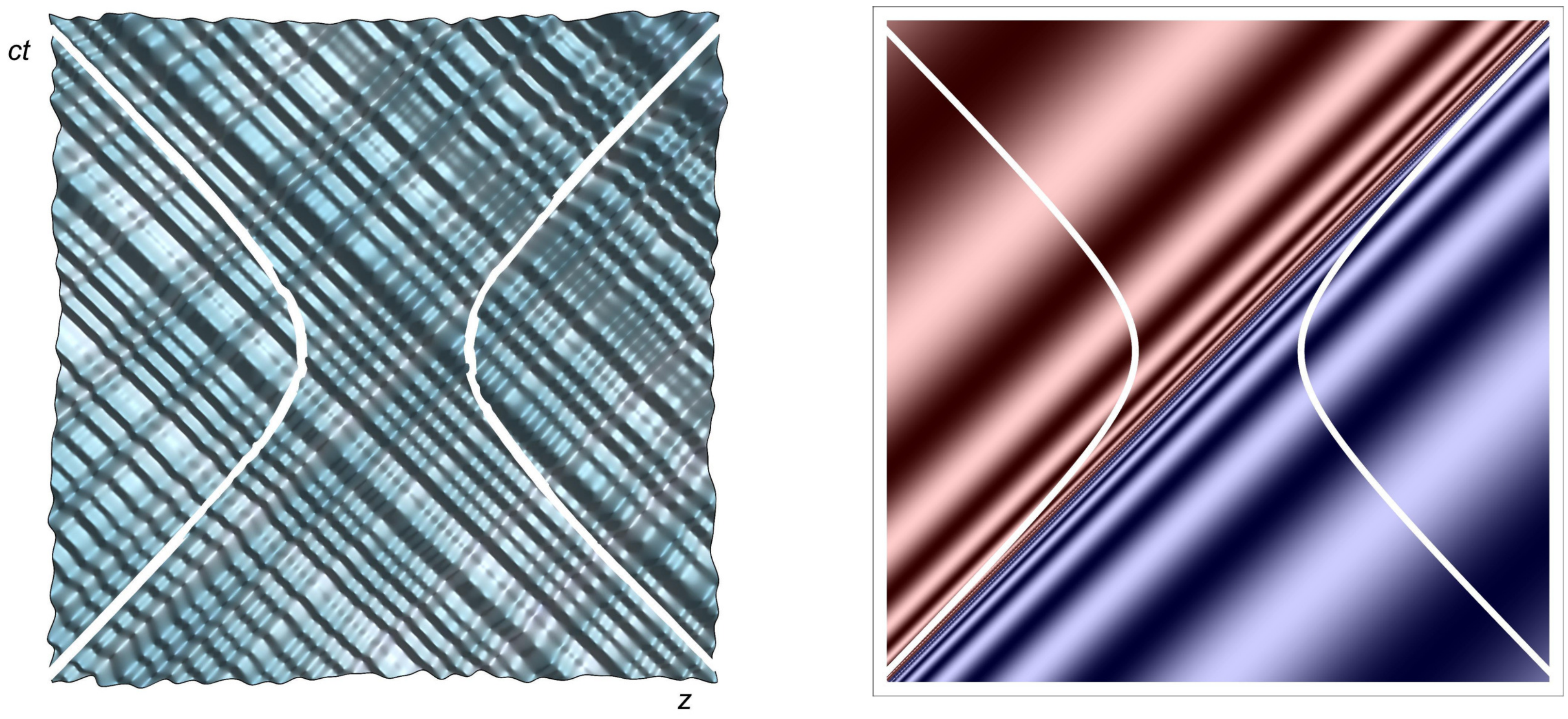


Rindler waves:
monochromatic to the two accelerated observers





Unruh effect: Minkowski noise seen by Rindler waves



PHYSICAL REVIEW A **98**, 022118 (2018)

Classical analog of the Unruh effect

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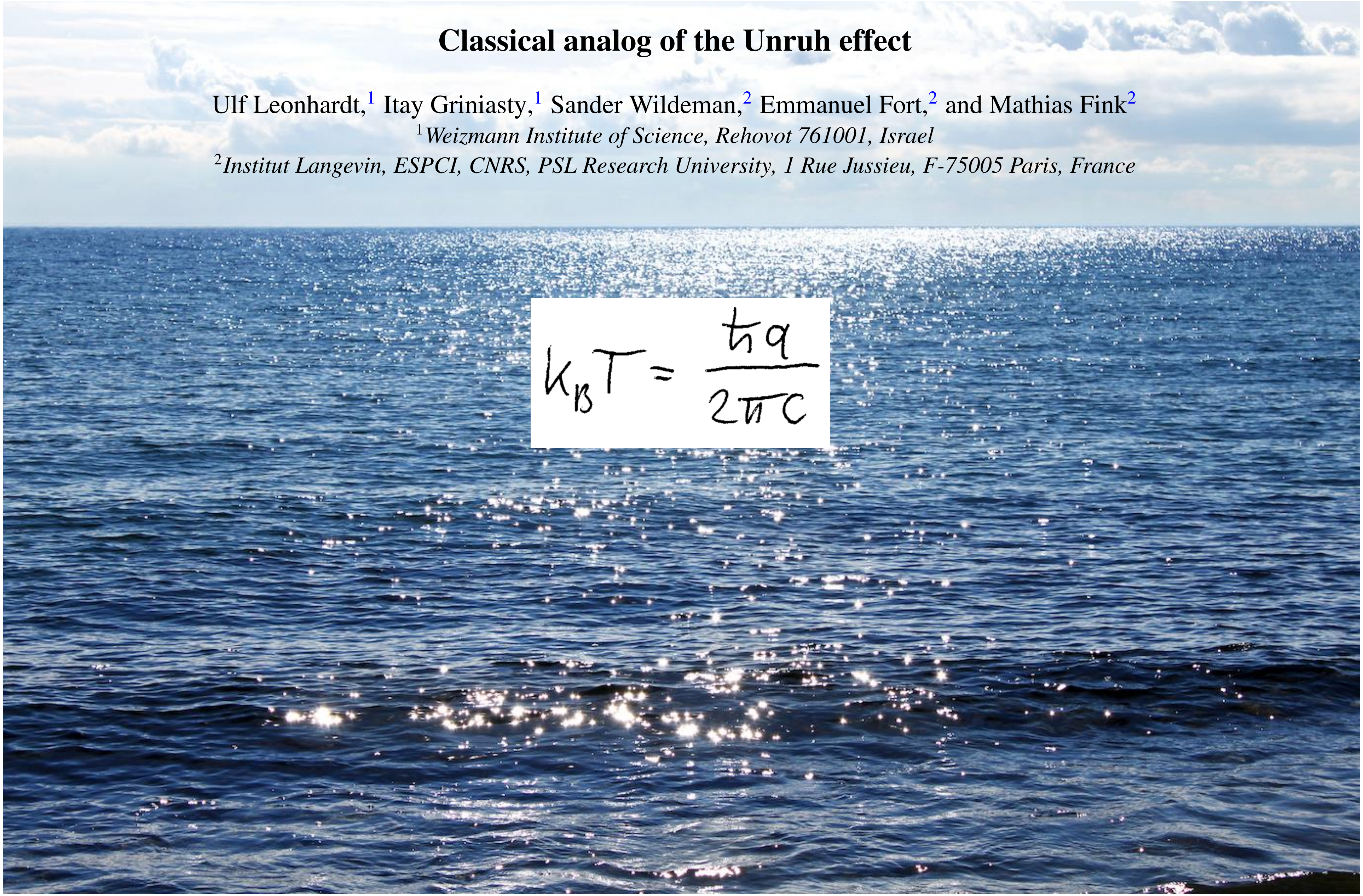
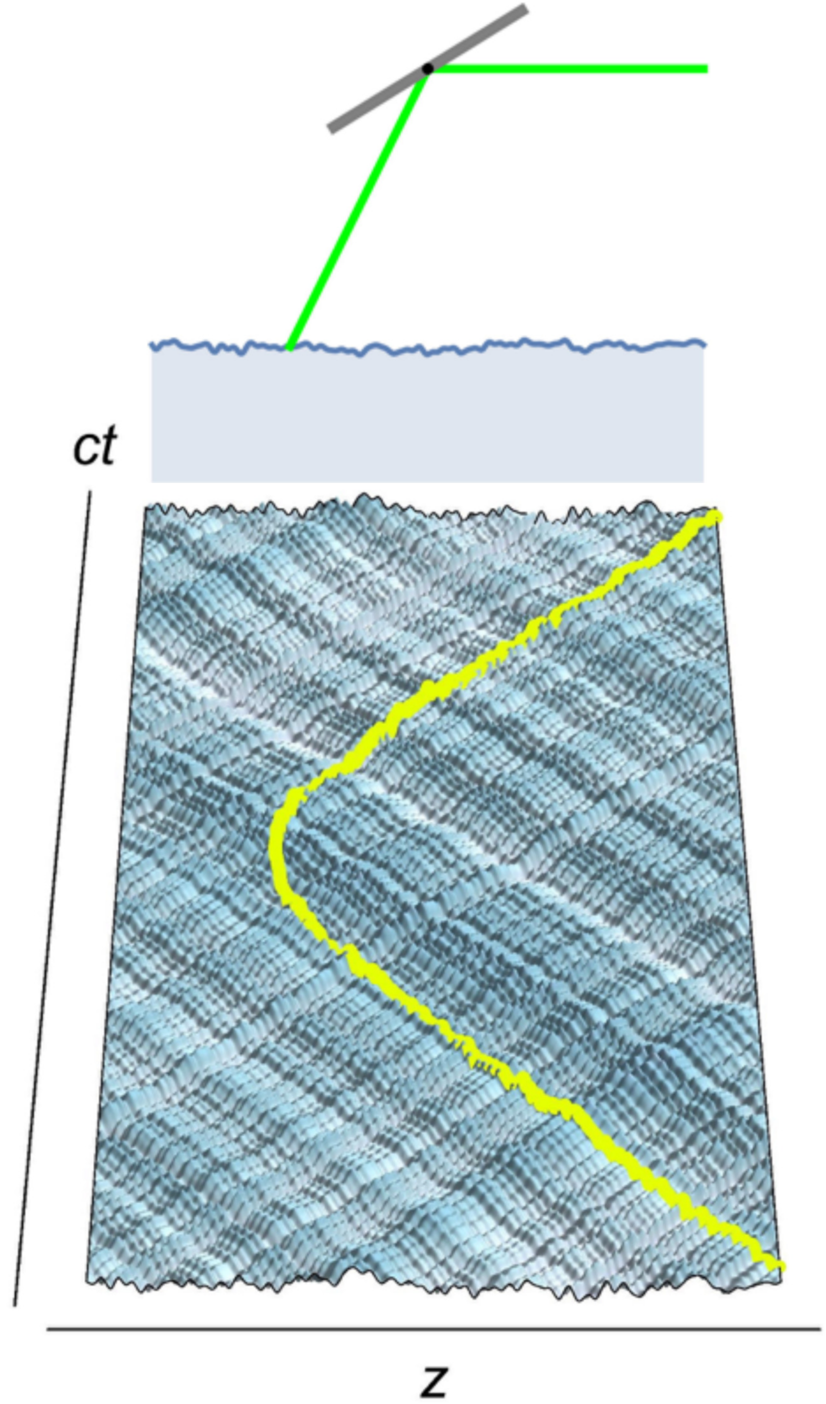


Classical analogue with water waves

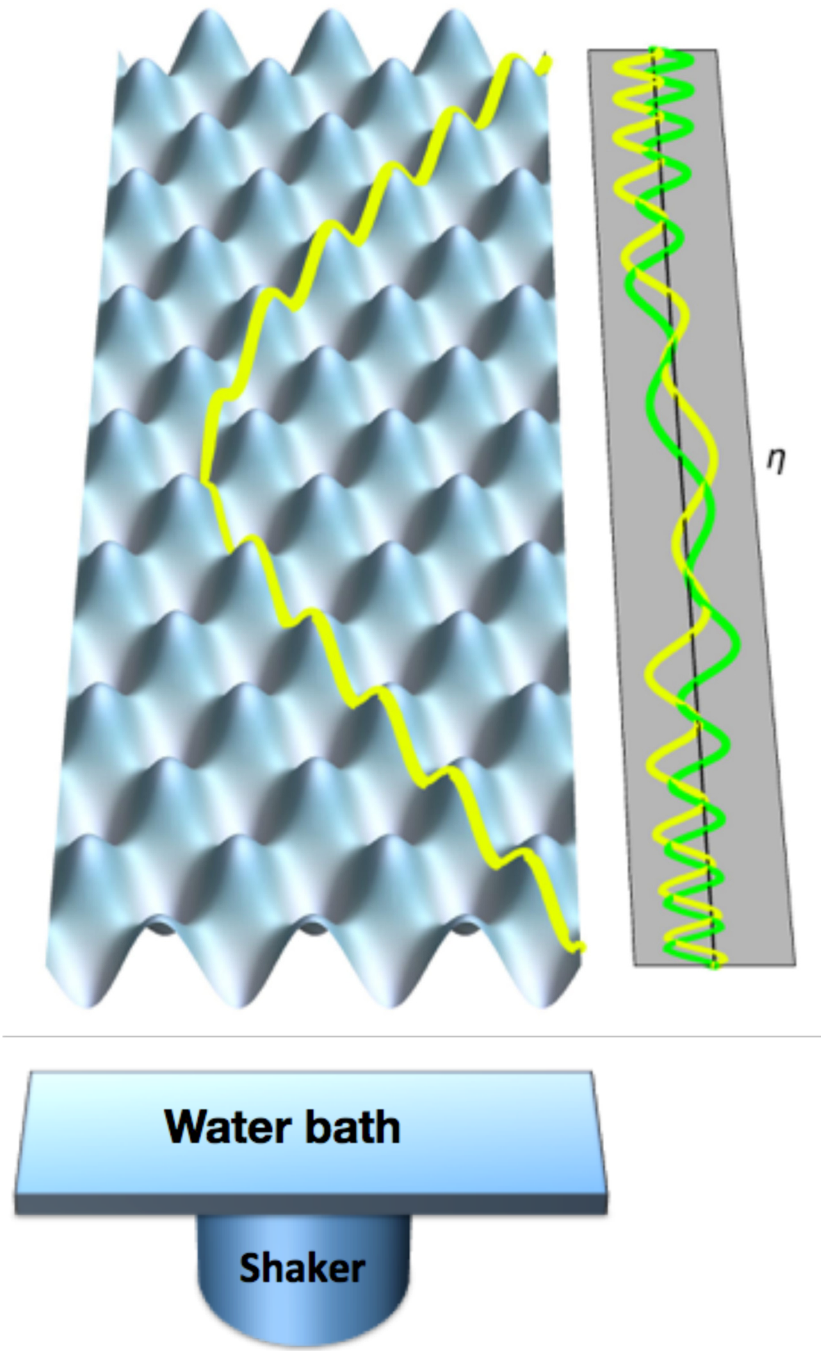
$$k_B T = \frac{\hbar a}{2\pi c}$$

- Waves – quanta
- Classical noise
- Water – light

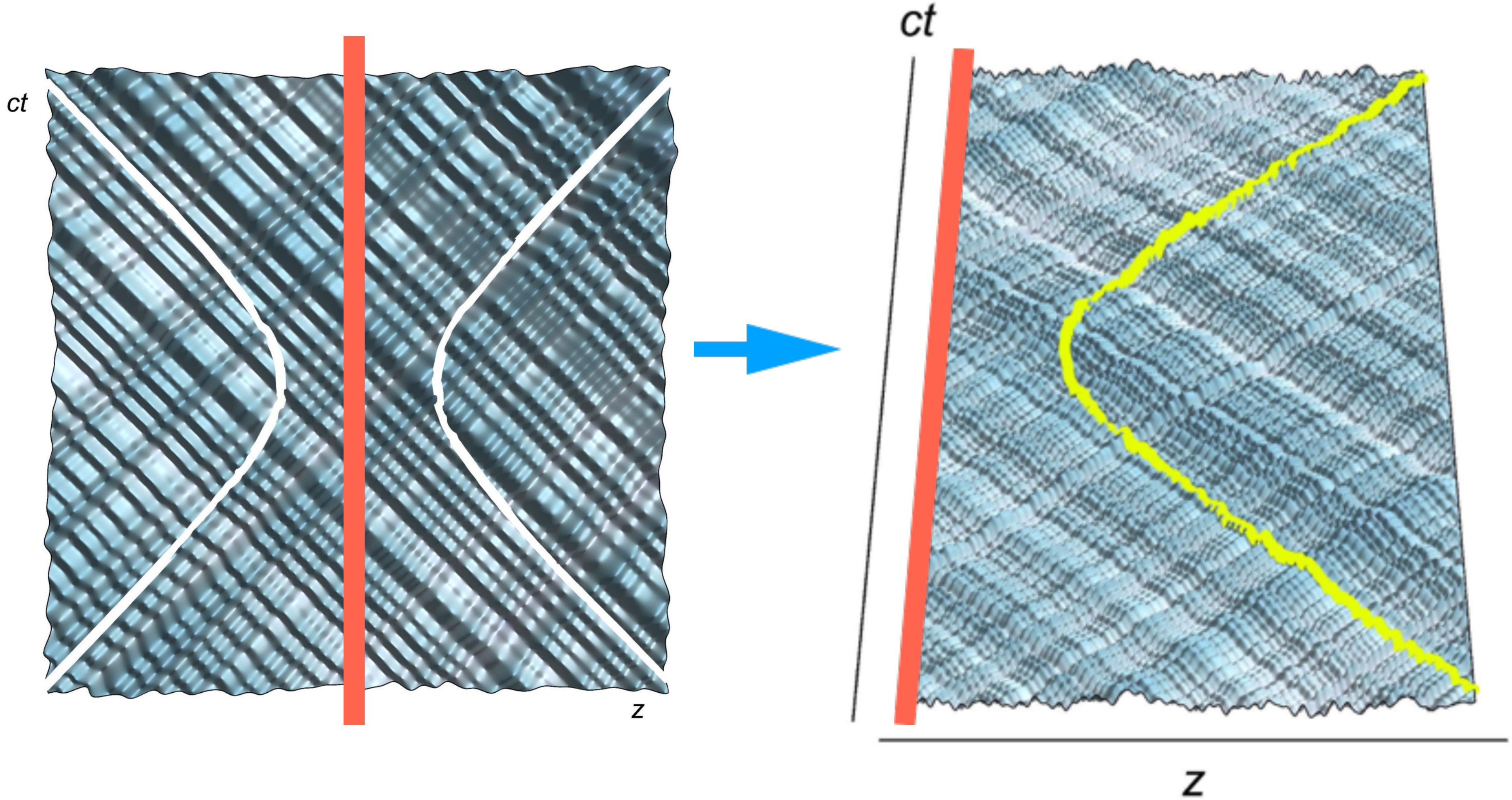


Classical analogue with water waves

- Video camera records surface height
- Accelerated trajectory traced in computer
- Shaker induces Faraday waves: standing waves
- Many runs with phase noise



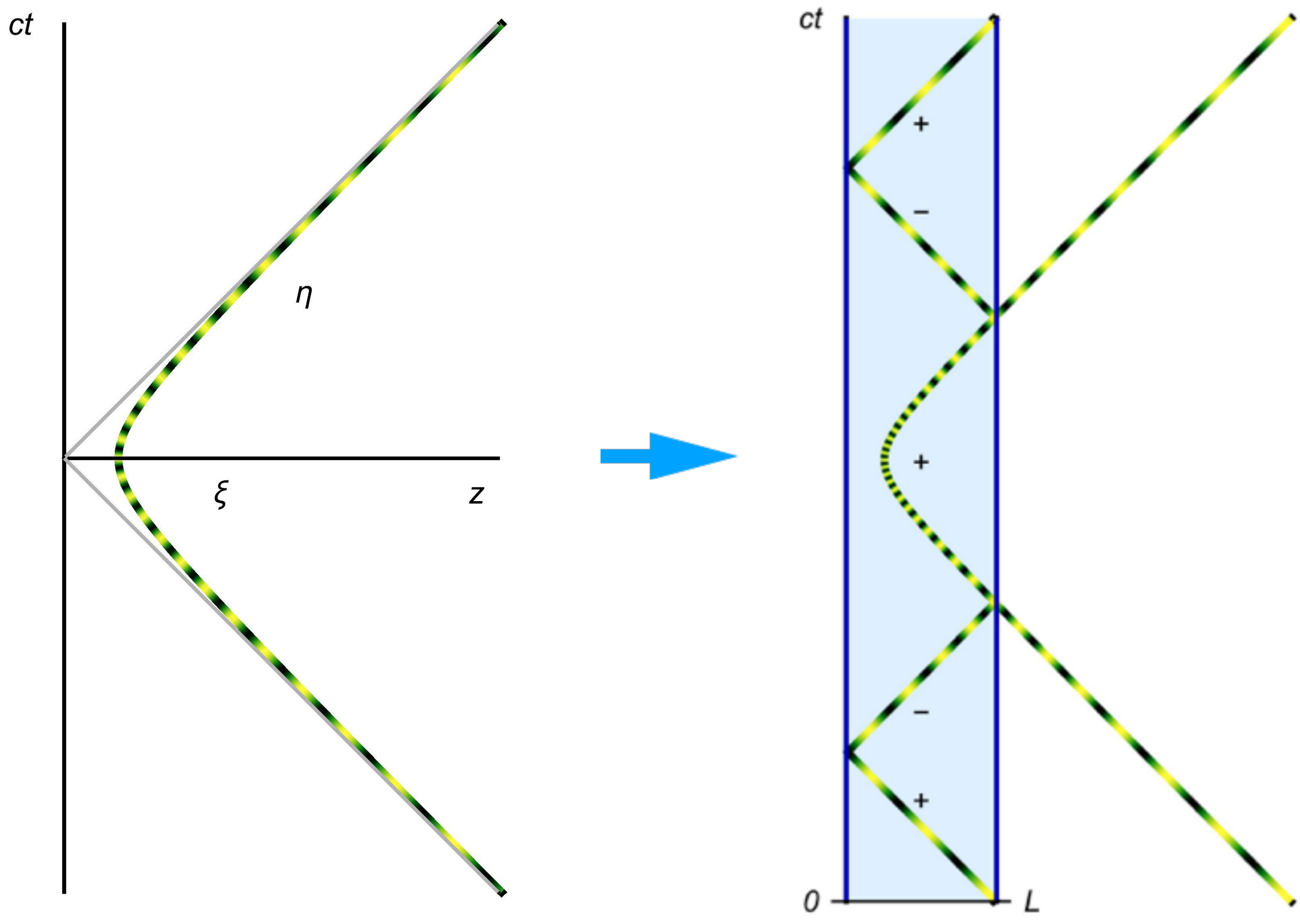
Mirror maps left observer into right observer



Two mode correlation

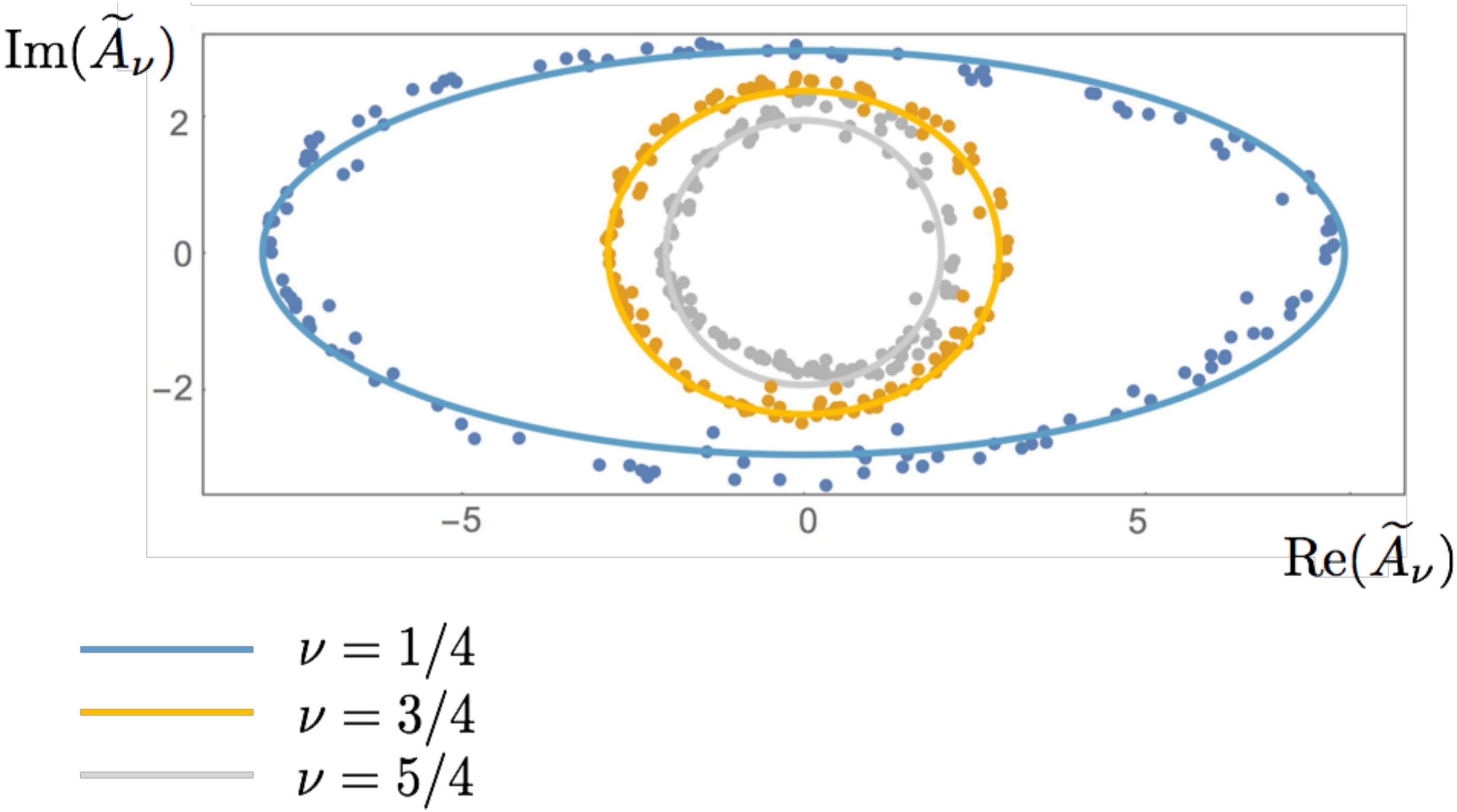
Single mode correlation

Second mirror maps everything into finite lab space



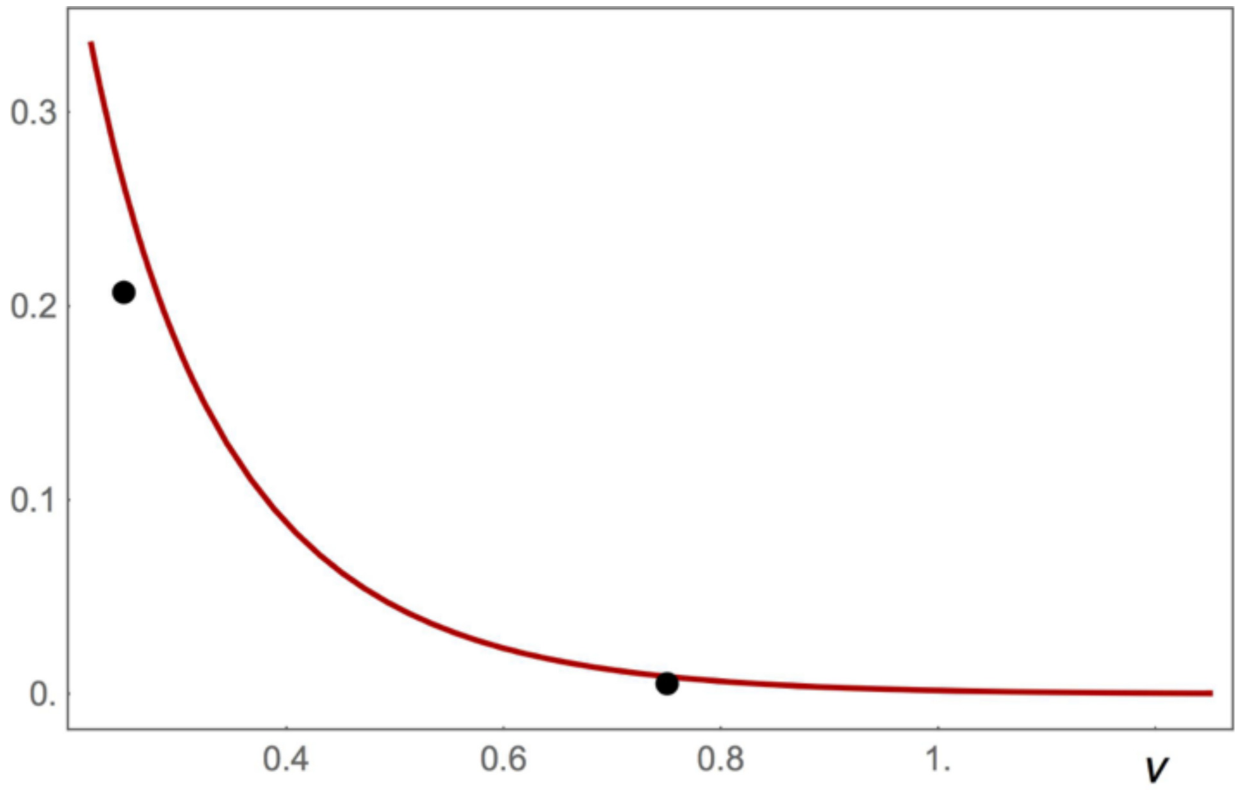
Experimental results

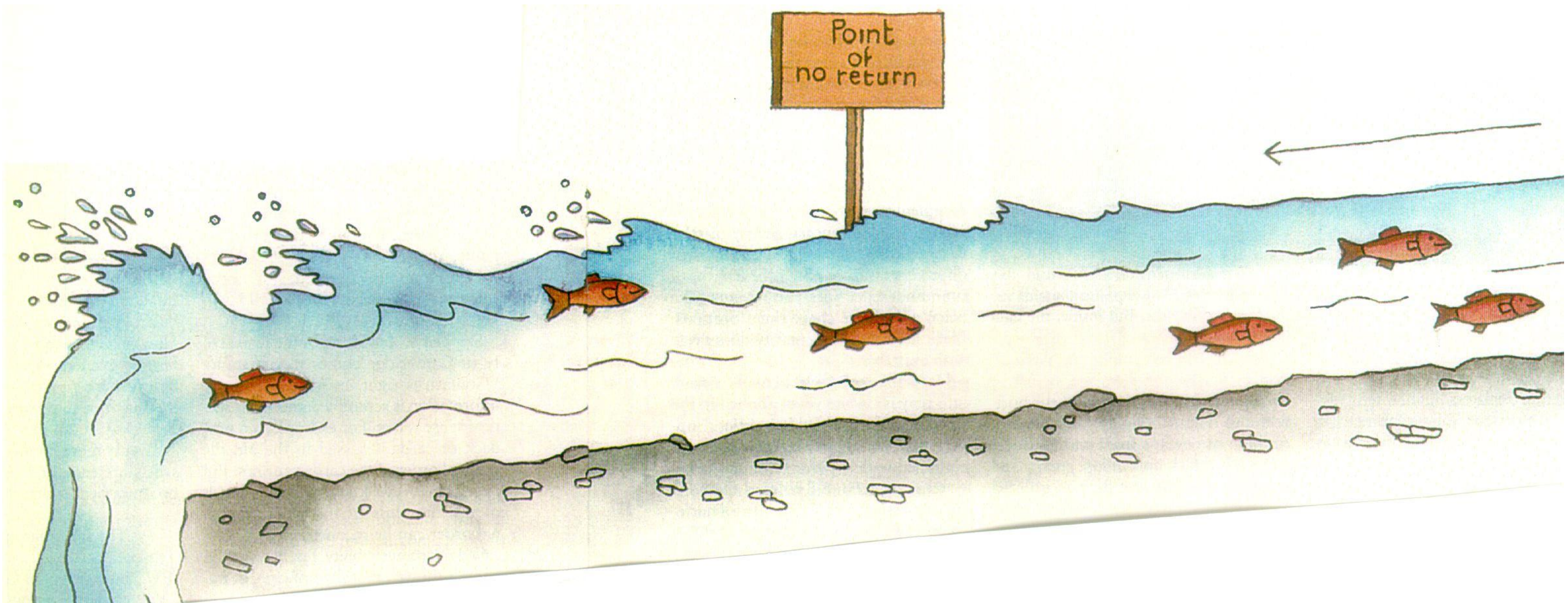
Single mode squeezing

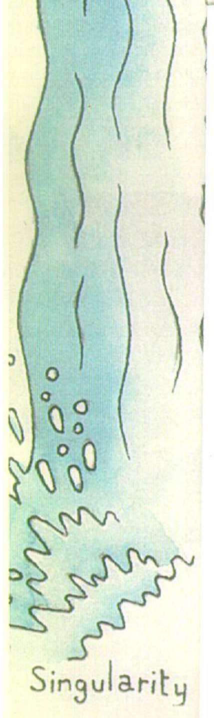


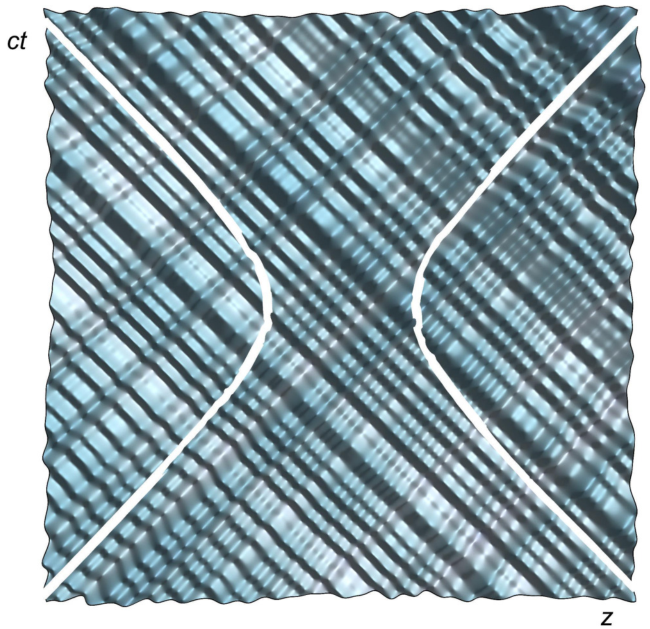
Experimental results

Correlation energy compared with Planck spectrum




Point of no return


Singularity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