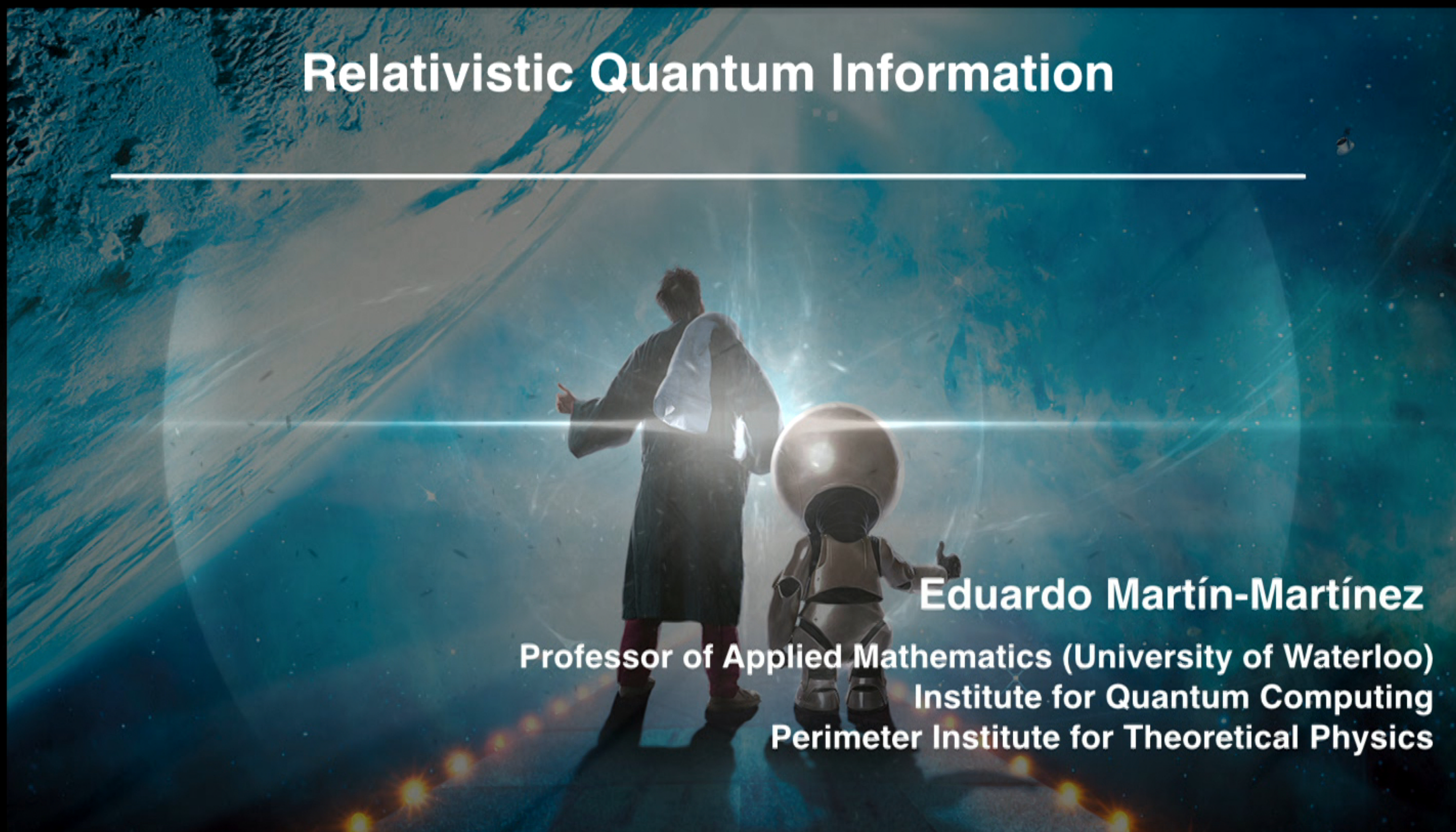
Title: PSI 2017/2018 - Relativistic Quantum Information - Lecture 1

Date: Mar 19, 2018 09:00 AM

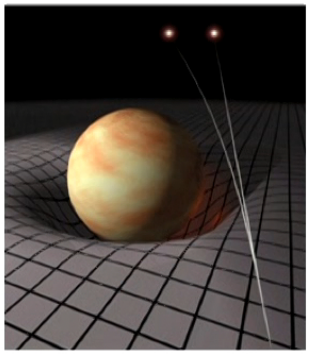
URL: http://pirsa.org/18030028

Abstract:

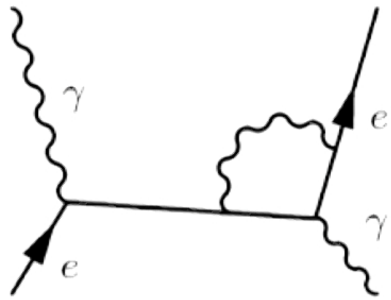
# PSI - Exploration Course



# Relativistic Quantum Information



General relativity

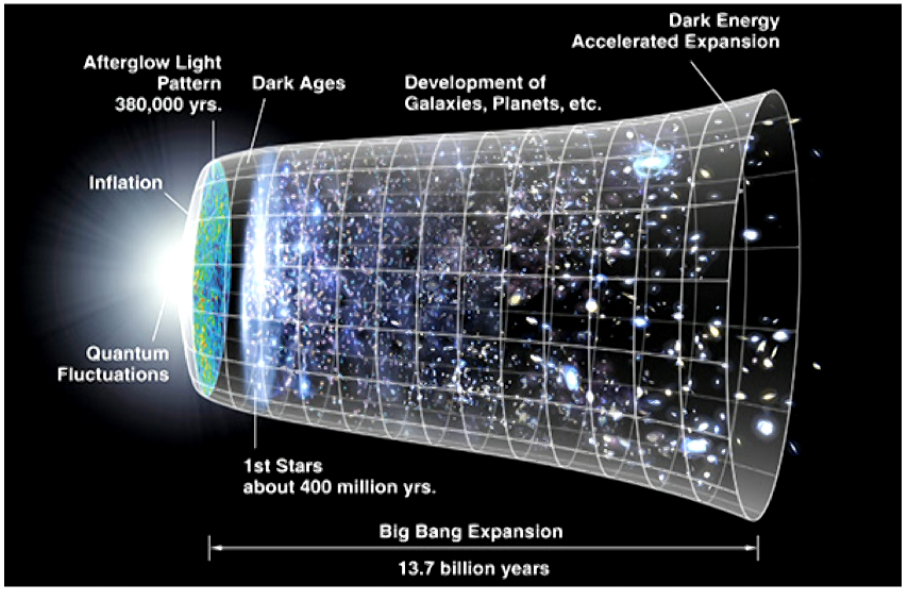



Quantum field theory


Quantum information

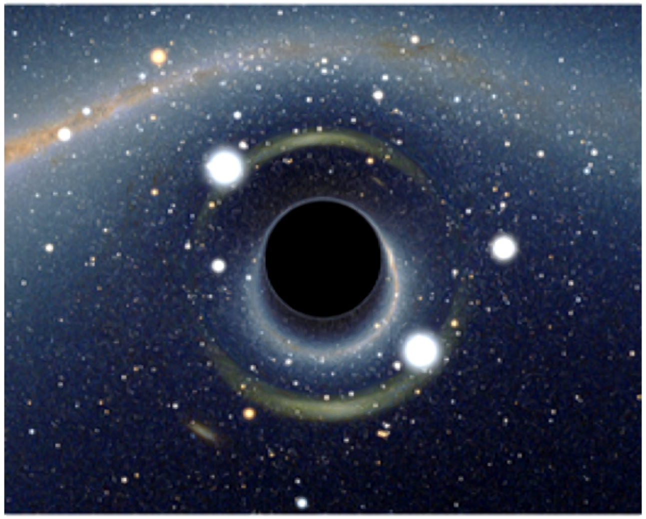
- Harness relativistic approaches to "do more" in quantum information processing.
- Study the structure of spacetime and the quantum nature of gravity via quantum informational tools

# Fundamental Topics: Cosmology




**How much can we learn about the Early Universe nowadays?**

# Fundamental Topics:
# Black Hole Information Loss Problem

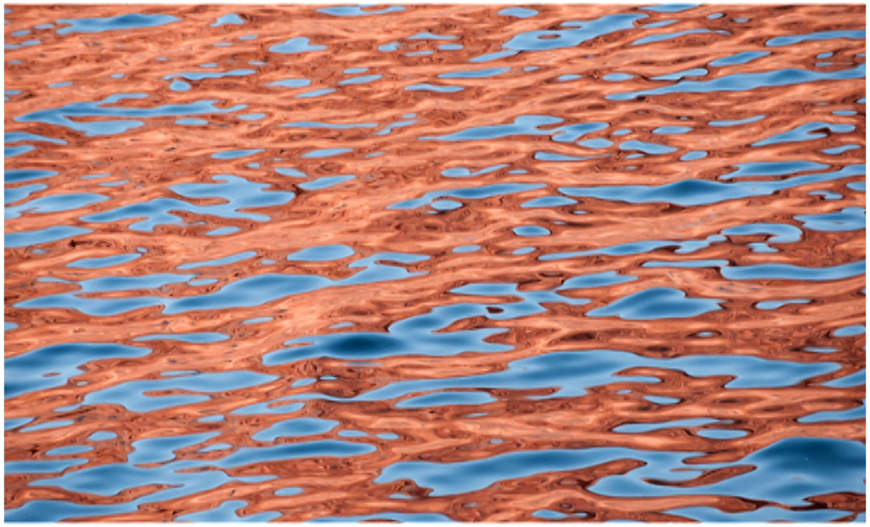


**Quantum Mechanics preserves information.**

**Black Holes: Does Nature destroy information?**

**Or does the information escape in the form of Hawking Radiation?**

# Fundamental Topics: Vacuum Fluctuations

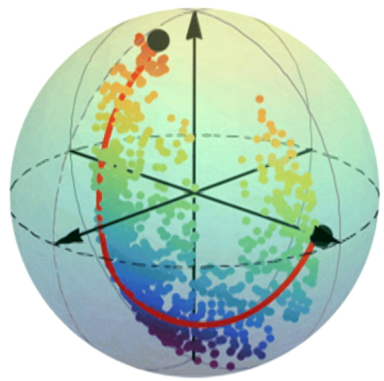


In Nature, the vacuum is not empty. Only on average.

Vacuum Fluctuations contain Information about curvature of spacetime.

Quantum noise is special: It can assist communication!

# Fundamental Topics:
# Quantum Measurements and Localization



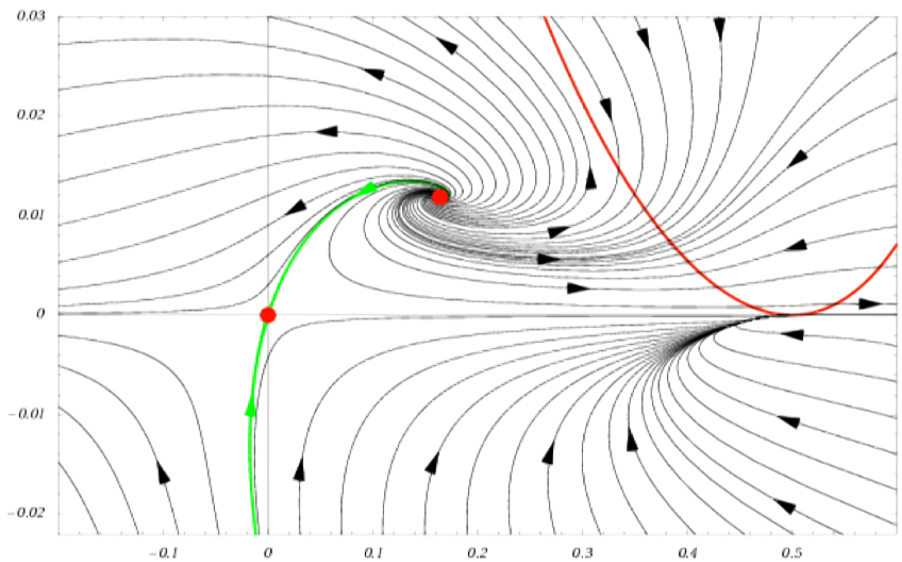

**Quantum Theory is a probabilistic theory.**

**The outcome of measurements is not deterministically predictable.**

**Quantum-to-Classical transition.**

**Relativistic considerations in the localization of Information**

# Fundamental Topics: Fixed points in Quantum evolution




**The problem of equilibration in Quantum Theory and in Gravity.**

**Quantum Thermodynamics.**

**Quantum Control.**

# Fundamental Topics:
# Quantum Gravity

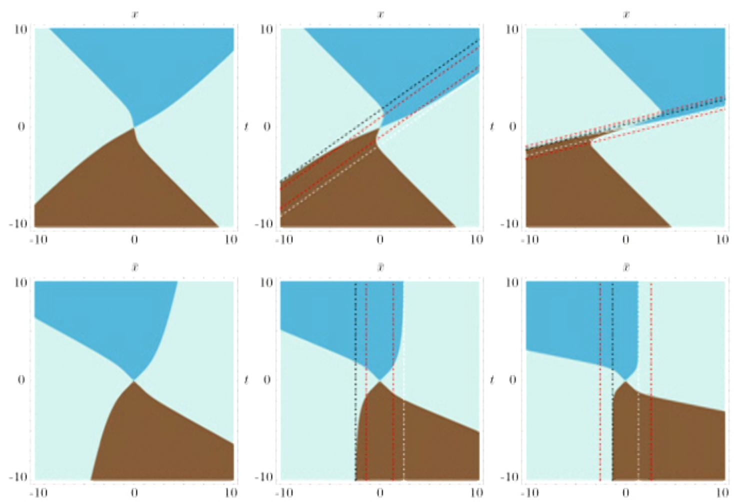

**One of the most important challenges of modern Mathematical Physics:**

**Quantum Theory for Gravitation**

# Fundamental Topics: "Spacetime Engineering"

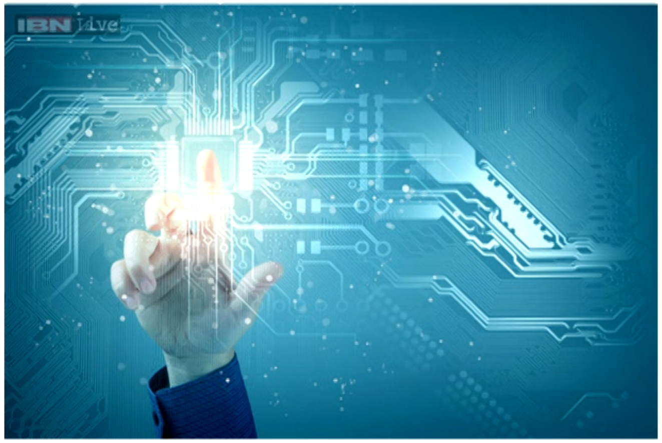
**Consequences of Violation of energy conditions:**

**-Warp drives?**
**-Wormholes?**



# Applications

**Development of Mathematical tools that can be applied to experiments and technologies:**




**-Quantum Entanglement and Quantum Resources**

**-Communication**

**-Metrology**

**-Quantum Control and Simulations**

# Getting Familiar with Spacetime

Relativity Matters for Quantum Information

# Same Physics, Different Descriptions

Bell Rocket "Paradox"

# Same Physics, Different Descriptions

Bell Rocket "Paradox"


Does the rope break or not??

# Same Physics, Different Descriptions

Bell Rocket "Paradox"


Does the rope break or not??

Why??

# Same Physics, Different Descriptions

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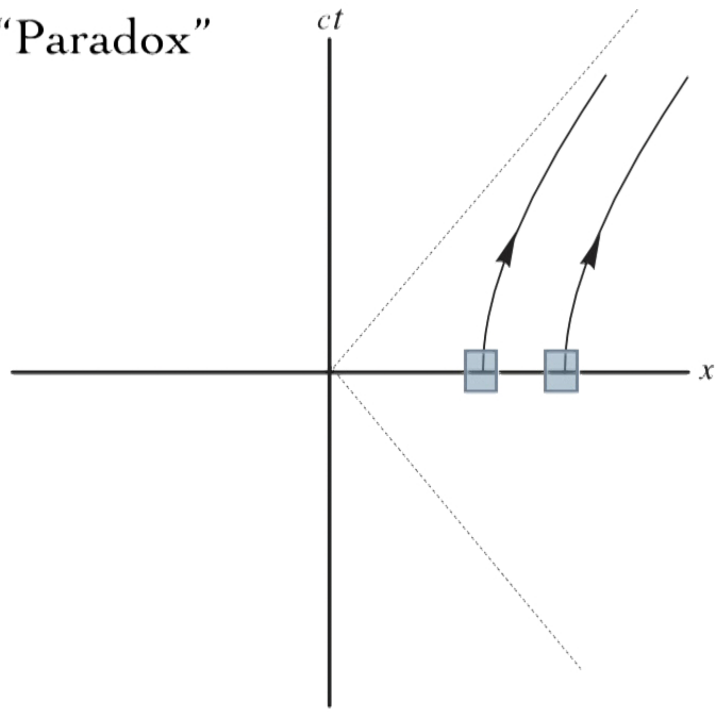


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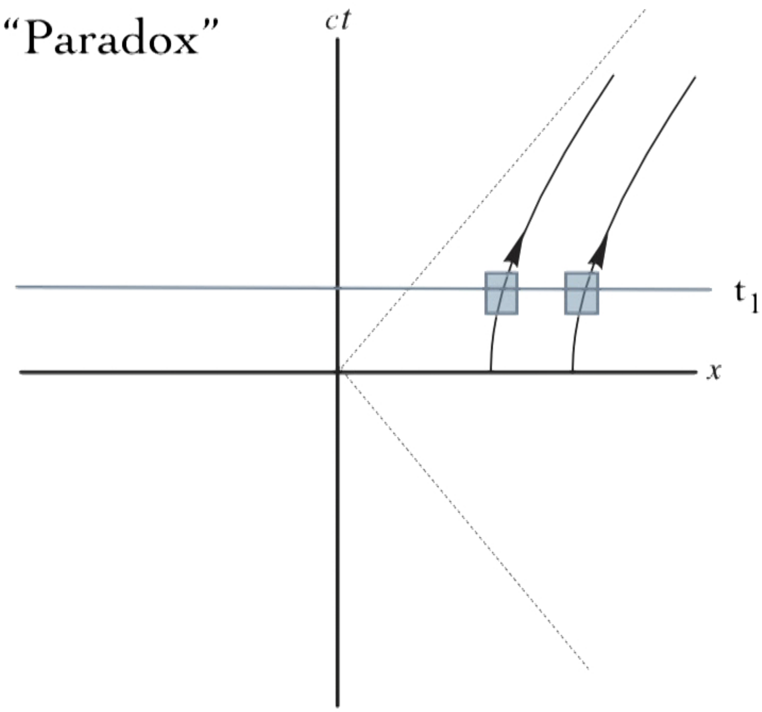


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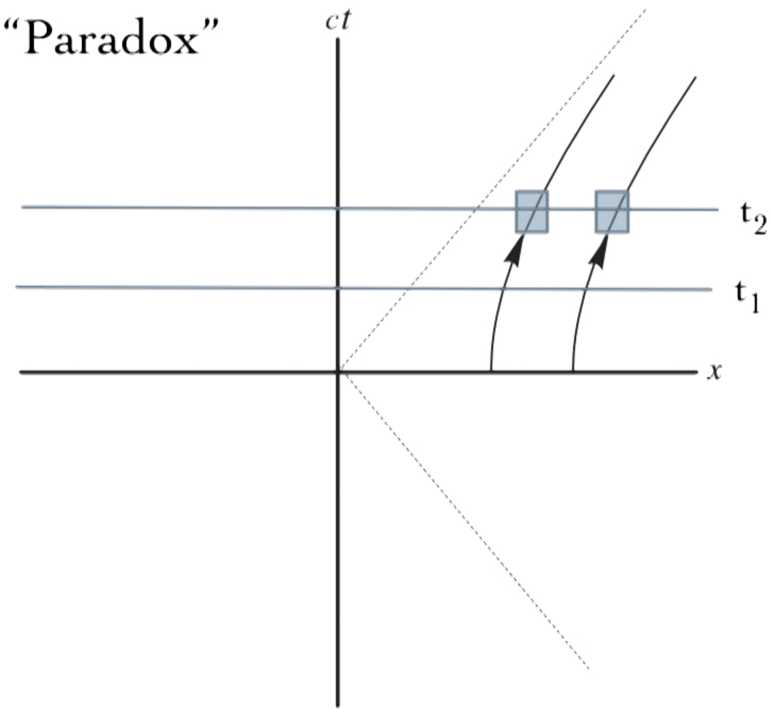


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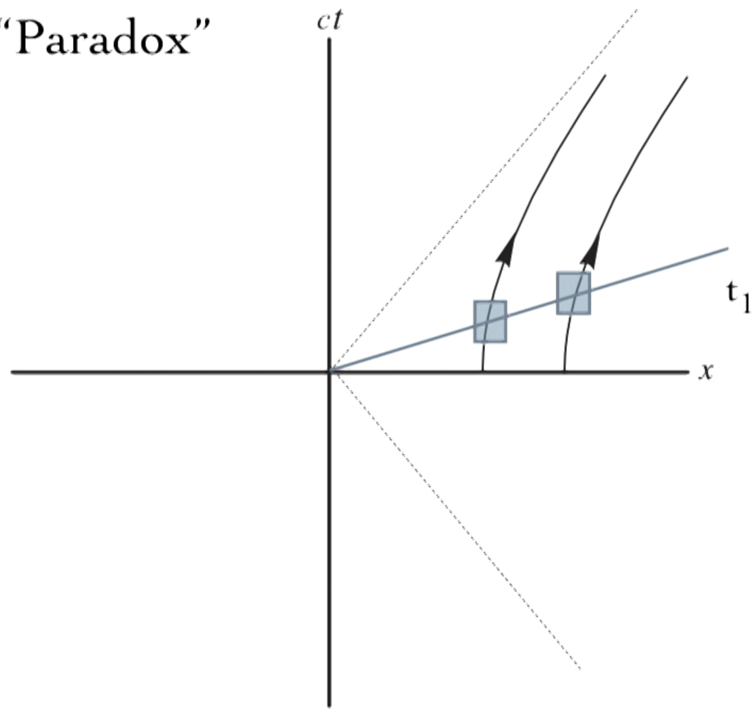


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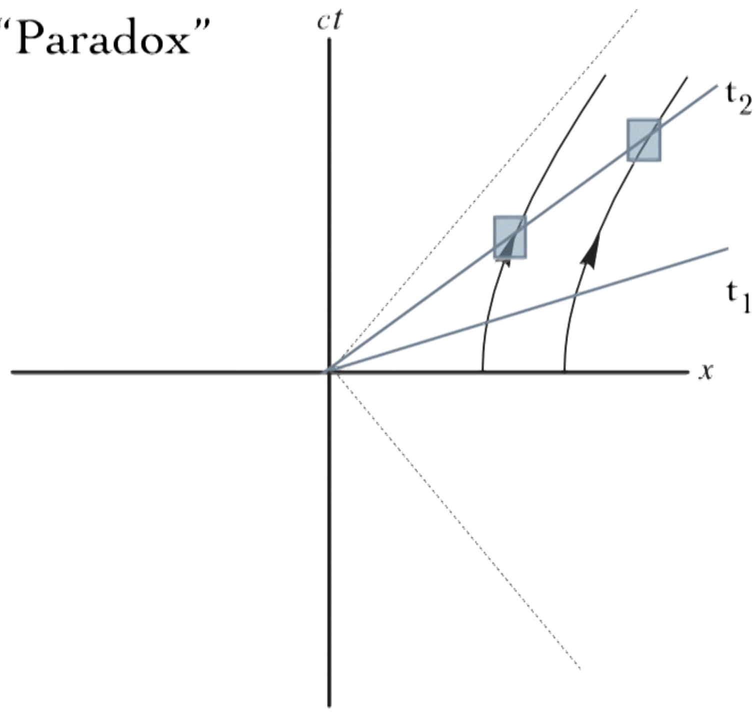


Does the rope break or not??

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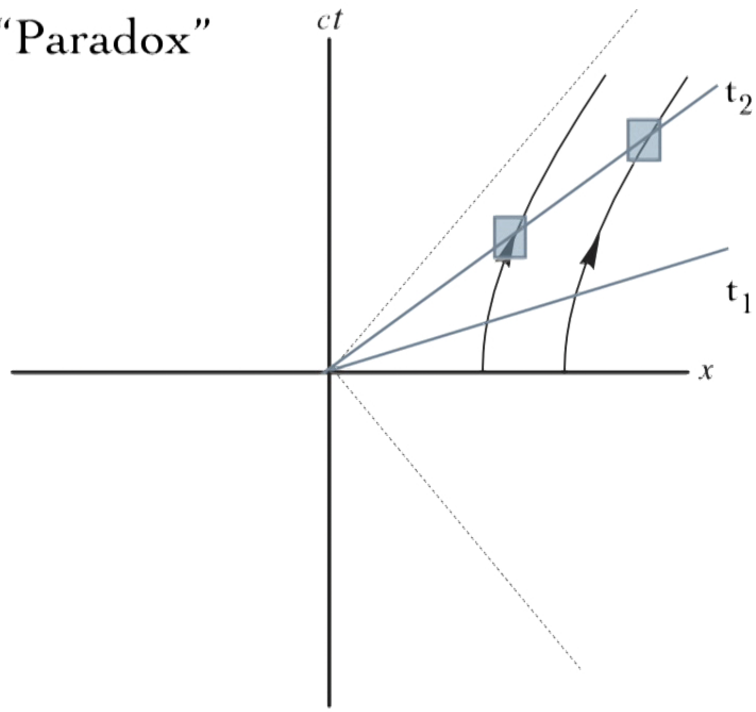



Does the rope break or not??

Why??

# Same Physics, Different Descriptions

PHYSICS:

The rope breaks, all right!

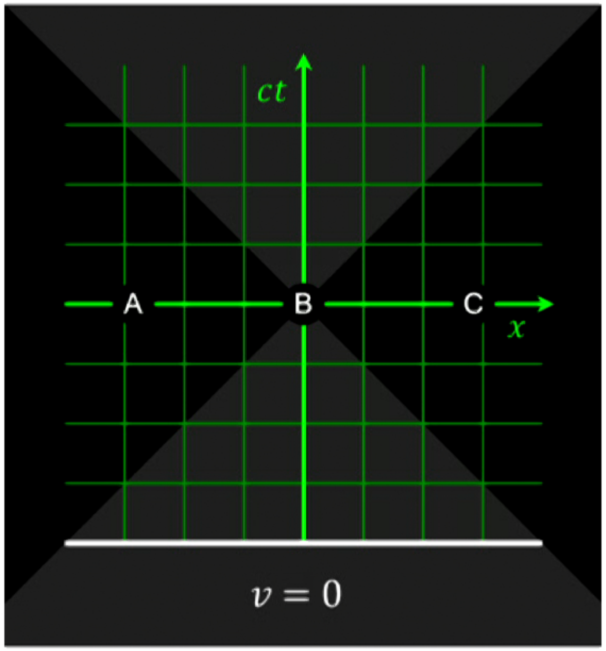
PHENOMENOLOGY:

For the accelerated observer A: Because rocket B is faster than us!

For the observer on the ground: Because both rockets go equally faster and faster, the length of the rope Lorentz-contracts!

# Getting Familiar with Spacetime

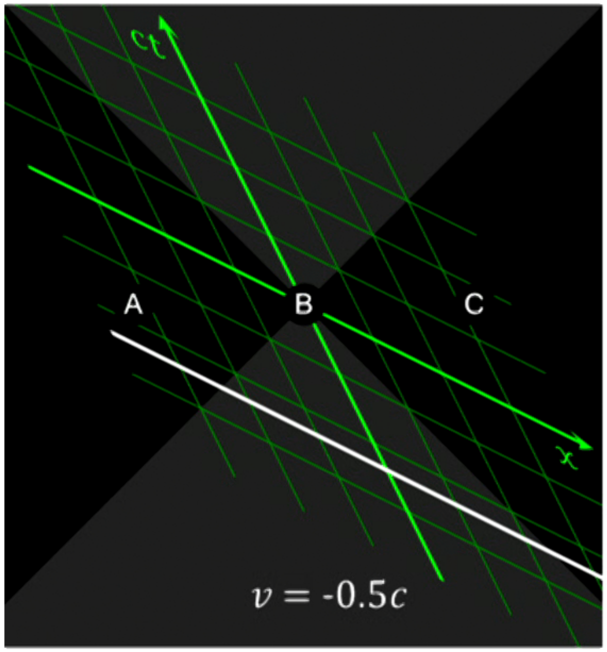
Simultaneity is Relative!




Two observers in different states of motion would not agree about what happens first

# Getting Familiar with Spacetime

Simultaneity is Relative!



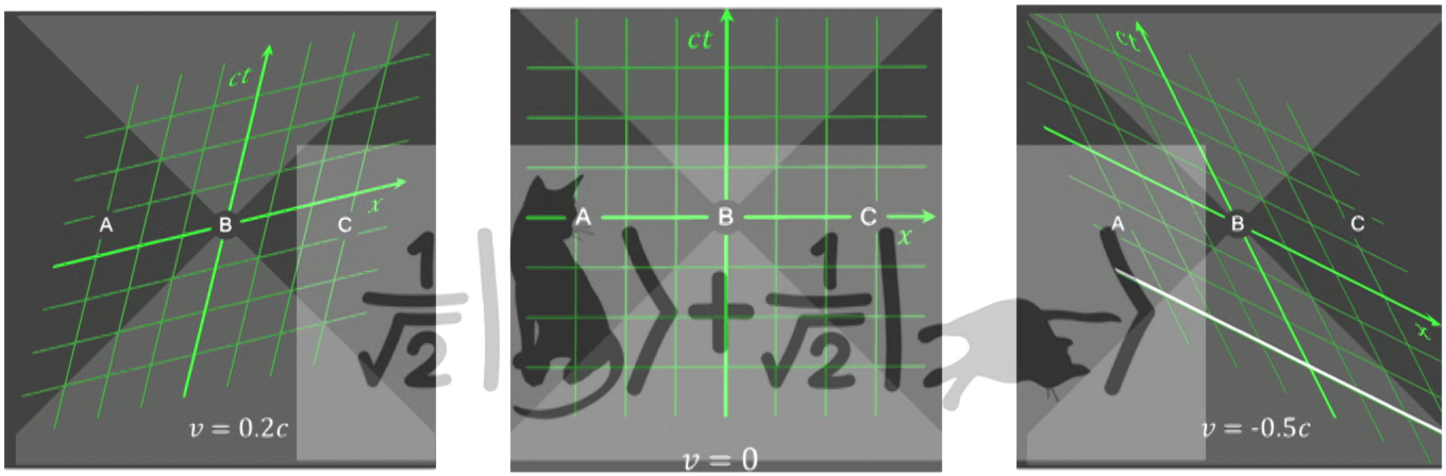

Two observers in different states of motion would not agree about what happens first

# Getting Familiar with Spacetime

# Getting Familiar with Quantum Mechanics

Simultaneity is Relative!

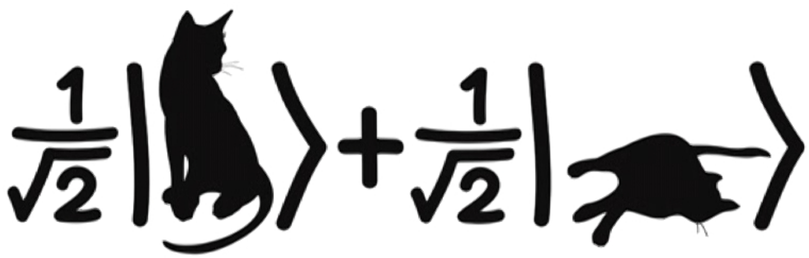
Schrödinger's cat




A happens after C | A and C are simultaneous | A happens before C

# Getting Familiar with Quantum Mechanics

Schrödinger's cat



# Quantum Entanglement

**The New York Times.**

NEW YORK, SATURDAY, MAY 4, 1935. TWO CENTS

## EINSTEIN ATTACKS QUANTUM THEORY

**Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'**

**SEE FULLER ONE POSSIBLE**

**Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.**

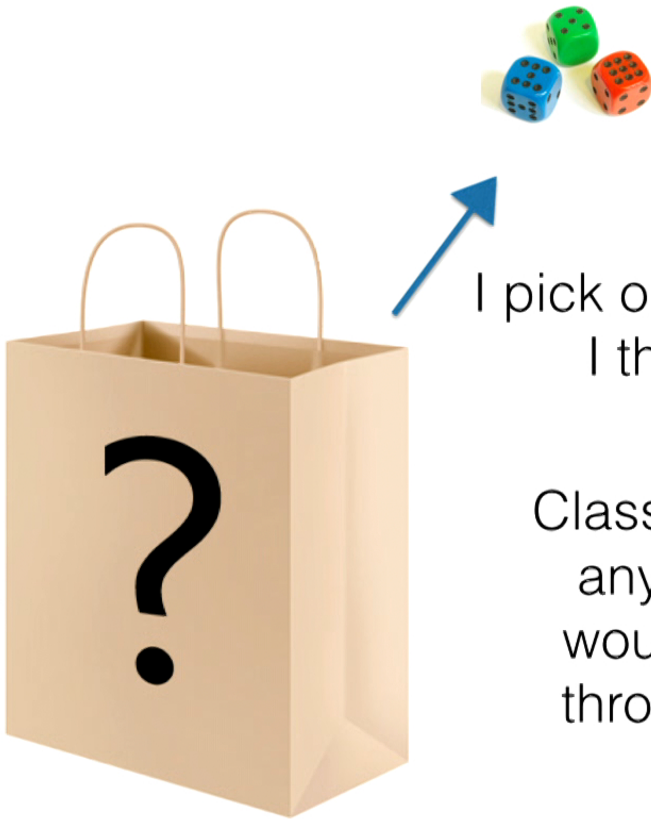
# Quantum Entanglement
# Vs Classical Correlations

# Quantum Entanglement Vs Classical Correlations


I pick one ball at random… It's white!

I know the one inside is black!

# Quantum Entanglement Vs Classical Correlations




I pick one set of dice at random…
I throw it and it gives 10!

Classically: I don't know anything about what would be the result of throwing the other set

# Quantum Entanglement

What if the dice are in an entangled state?

Alice: I pick one set of dice at random…
I roll it and it gives 8!


I know what Bob's roll is going to be! (or was)

# What entanglement is not

POPULAR SCIENCE SUBSCRIBE

## The Race To Prove 'Spooky' Quantum Connection May Have a Winner

**Entanglement breakthrough could lead to unhackable Internet**

By **Devin Powell** August 29, 2015

Particles don't obey the same rules as people. Poke a particle, and another one far away can instantly respond the touch -- without any messages passing through the space between, as if the two particles were one. "Entanglement" is what quantum physics calls the intimate connection.

Einstein called it "spooky." To his dying day, he refused to believe that nature could be so unreasonable.

From http://www.popsci.com

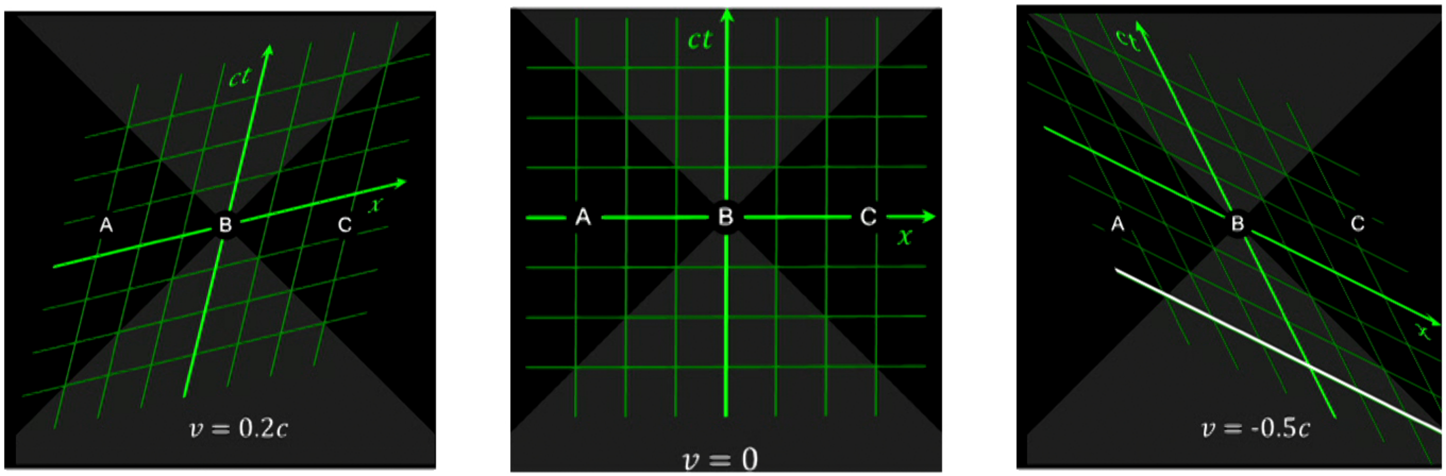
# Quantum Entanglement

Alice: I pick one set of dice at random…
I roll it and it gives 8!


But Remember Einstein!

# Getting Familiar with Spacetime

Simultaneity is Relative!
Who collapses what??
Who pokes what??




A happens after C

A and C are simultaneous

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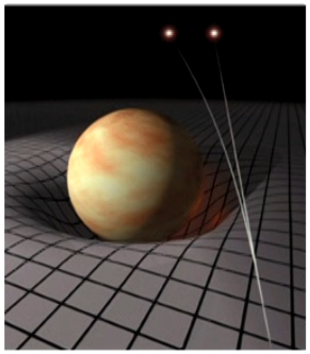
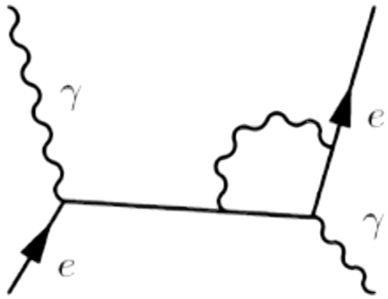
# Relativistic Quantum Information



General relativity




Quantum field theory


Quantum information

- Harness relativistic approaches to "do more" in quantum information processing.
- Study the structure of spacetime and the quantum nature of gravity via quantum informational tools

# Quantum Information and Relativity

**Can we take advantage of relativistic effects to do better in Quantum information?**

-Quantum information processing.

-Generation of Quantum resources.

-Quantum Communication.

-Quantum non-demolition measurements. Relativistic Quantum Metrology.

-Quantum simulations.

**Can we learn something about spacetime using quantum informational approaches?**

-The Early Universe and Cosmology

-QFT in curved spacetimes: Unruh and Hawking radiation. Black hole information paradox.

-Quantum correlations and the structure of spacetime.

-Relativistic Quantum Foundations: The Casimir effect, The problem of localization, measurement…

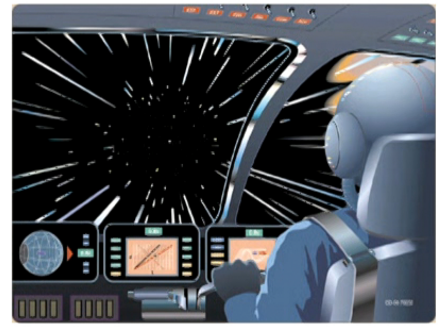
-Quantum Gravity. Causal Structure.

# Effects on quantum information

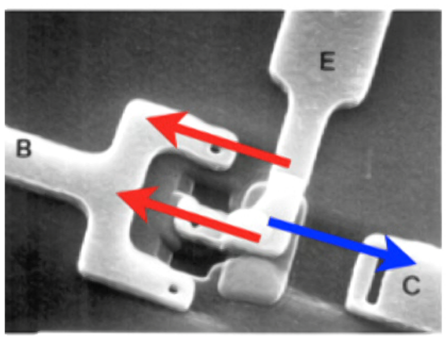
Particle detectors and QI

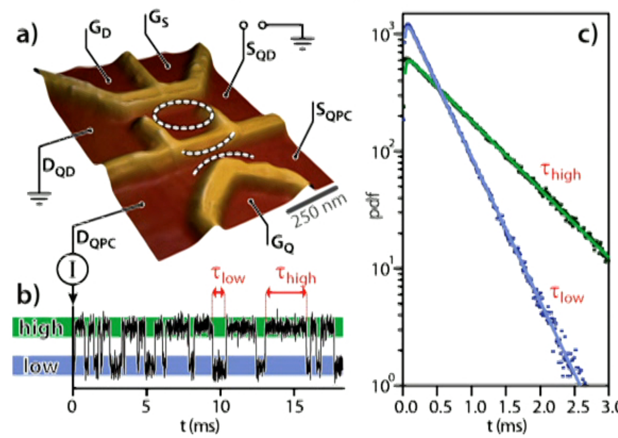
Standard view: Acceleration/gravity introduces noise

A. G. S. Landulfo and G. E. A. Matsas, Phys. Rev. A, 80, 032315 (2009)
L. C. Céleri, A. G. S. Landulfo, R. M. Serra, and G. E. A. Matsas, Phys. Rev. A, 81, 062130 (2010).



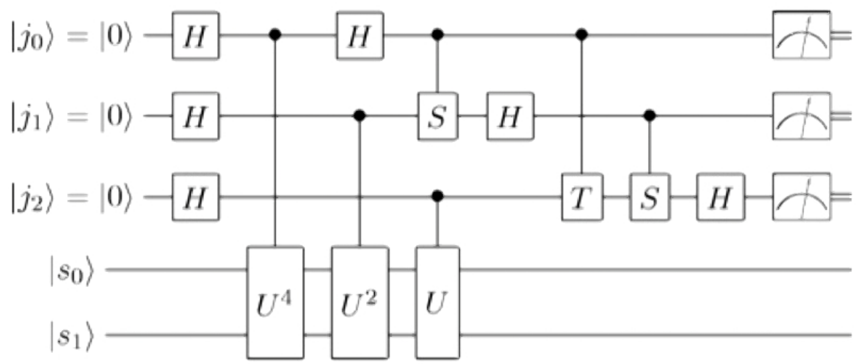
In the past the same arguments were used against quantum effects in classical computing



# Effects on quantum information

But now we take advantage of quantum effects to go beyond what classical computers can do

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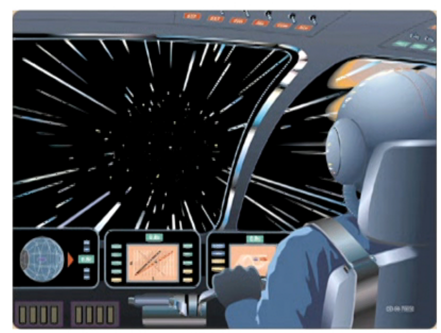

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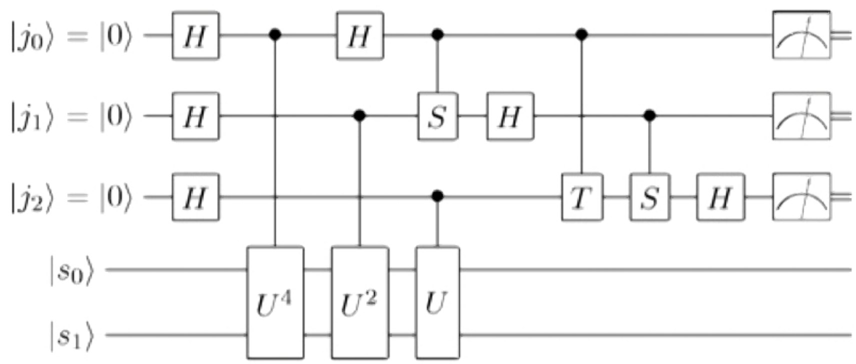
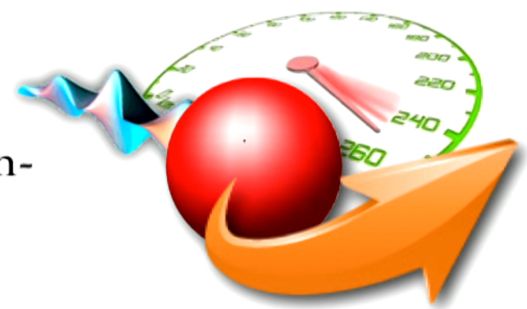



Can general relativistic effects be used to get computational advantage over non-relativistic settings?



# What people are doing

Accelerate (or shake) cavities:

D. E. Bruschi, A. Dragan, A. R. Lee, I. Fuentes, J. Louko Phys. Rev. Lett. 111, 090504 (2013)

Yields Gaussian gates between cavity field modes

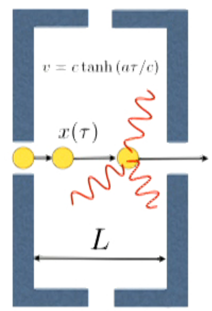
Gaussian gates, although useful, are not universal for quantum computing

# What I will talk about

Accelerate atoms longitudinally through cavities

Deflect atoms while flying transversally through cavities

E. Martín-Martínez, D. Aasen, A. Kempf. Phys. Rev. Lett. 110, 160501 (2013)




Yields Universal qubit Gates

Without relativistic accelerations you won't get universality

PRL **110**, 160501 (2013) PHYSICAL REVIEW LETTERS week ending 19 APRIL 2013

# Processing Quantum Information with Relativistic Motion of Atoms

Eduardo Martín-Martínez,[1,2,3] David Aasen,[2] and Achim Kempf[1,2,3,4]

We show that particle detectors, such as two-level atoms, in noninertial motion (or in gravitational fields) could be used to build quantum gates for the processing of quantum information. Concretely, we show that through suitably chosen noninertial trajectories of the detectors the interaction Hamiltonian's time dependence can be modulated to yield arbitrary rotations in the Bloch sphere due to relativistic quantum effects.

Physics Letters B 739 (2014) 74–82

# Quantum gates via relativistic remote control

CrossMark

Eduardo Martín-Martínez[a,b,c,*], Chris Sutherland[a]

[a] *Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada*
[b] *Dept. Applied Math., University of Waterloo, Ontario, N2L 3G1, Canada*
[c] *Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada*

ARTICLE INFO

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Editor: S. Dodelson

ABSTRACT

We harness relativistic effects to gain quantum control on a stationary qubit in an optical cavity by controlling the non-inertial motion of a different probe atom. Furthermore, we show that by considering relativistic trajectories of the probe, we enhance the efficiency of the quantum control. We explore the possible use of these relativistic techniques to build 1-qubit quantum gates.

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# Course Topics

**1-Relativistic Quantum Optics:**

-How do we measure quantum fields?

-Light-Matter interaction and particle detectors: when (textbook) quantum optics is not enough

-Measuring quantum fields: When waving your hands is dangerous.

-The Unruh-Dewitt Model from the Dipole coupling.

-Signalling and causality with detector models.

# Course Topics

**2-The Unruh effect and the Hawking effect: A Quantum Information perspective**

-The Unruh effect and the Hawking effect: What's common, what's not common

-A brief discussion of the information loss problem

-Vacuum entanglement structure.

# Course Topics

**3-Entanglement harvesting:**

-Entangling spacelike separated systems: Is that possible? How??

-A simple setup on entanglement harvesting: Harvesting entanglement from a scalar field.

-Some comments on harvesting entanglement from electromagnetic vacuum.

-Entanglement Farming: Growing entanglement from the vacuum

-“Quantum seismology”: How to reverse engineer entanglement farming for metrology.

# Course Topics

**4-Quantum Collect Calling:**

-Information flows not carried by energy flows. Is that possible? How??

-A simple setup of Quantum Collect Calling

-Applications in curved spacetime: How much information from the Early Universe survives nowadays

-How much information survives a cosmological cataclysm?

# Course Topics

**5-Quantum Energy Teleportation:**

-Minimal QET model: transmitting energy without energy travelling from sender to receiver

-A bit of quantum thermodynamics: Breaking Strong Local Passivity.

-QET in quantum fields: designing negative stress-energy densities.