Title: PSI 2018/2019 - Explorations in Quantum Information - Lecture 1

Speakers: Eduardo Martin-Martinez

Collection: PSI 2018/2019 - Explorations in Quantum Information (Martin-Martinez)

Date: April 15, 2019 - 9:00 AM

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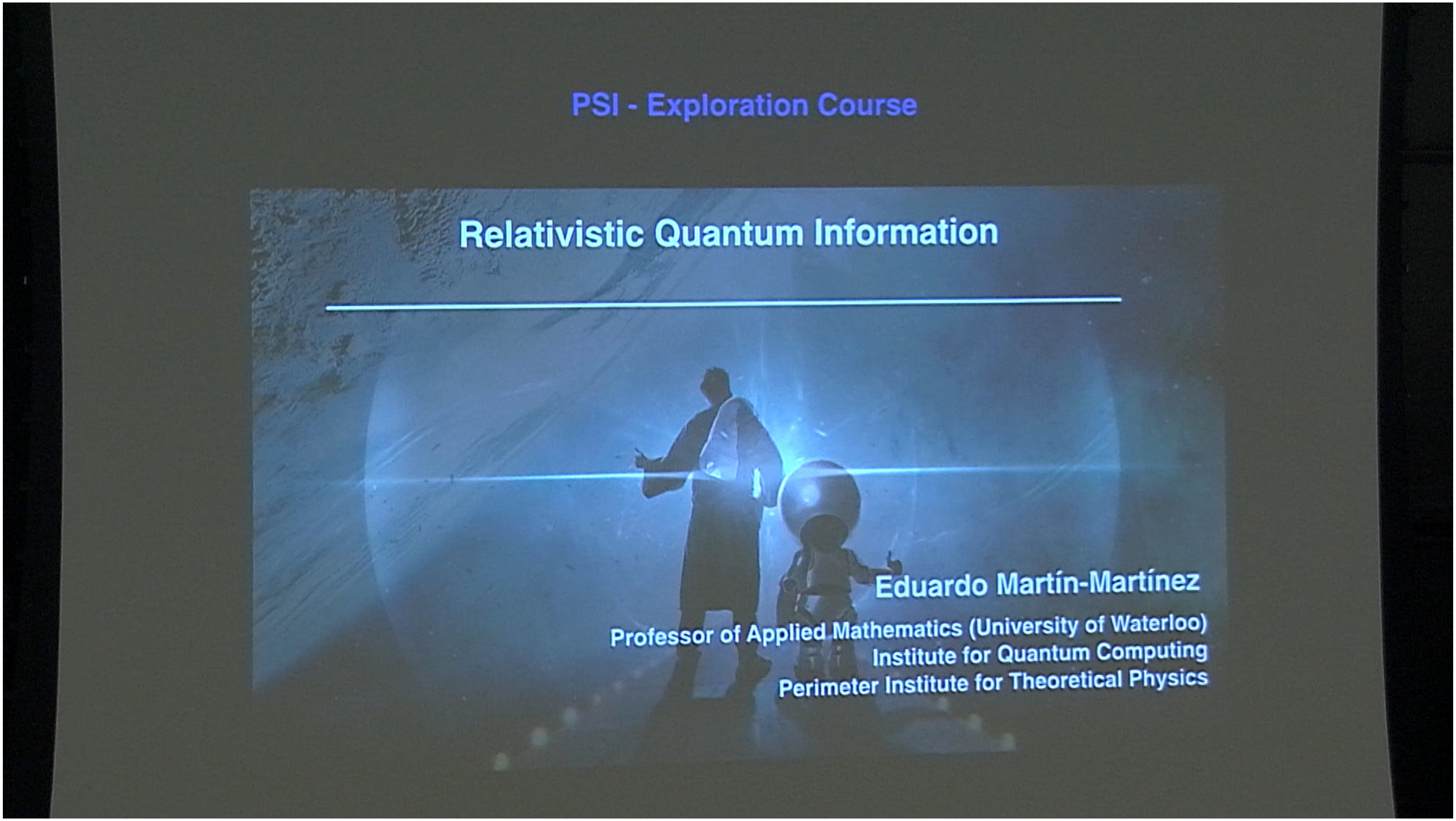
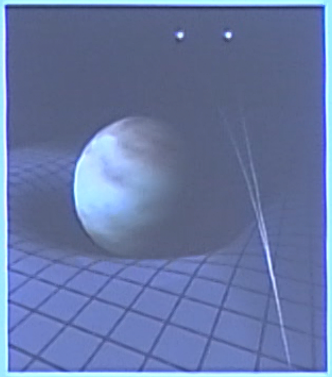
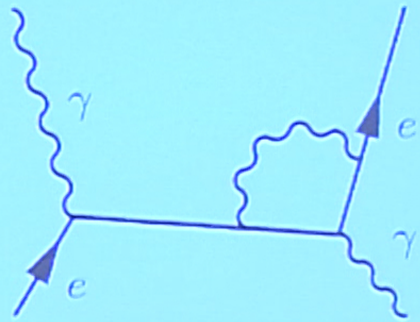

PSI - Exploration Course
Relativistic Quantum Information
Eduardo Martín-Martínez
Professor of Applied Mathematics (University of Waterloo)
Institute for Quantum Computing
Perimeter Institute for Theoretical Physics

Relativistic Quantum Information



General relativity

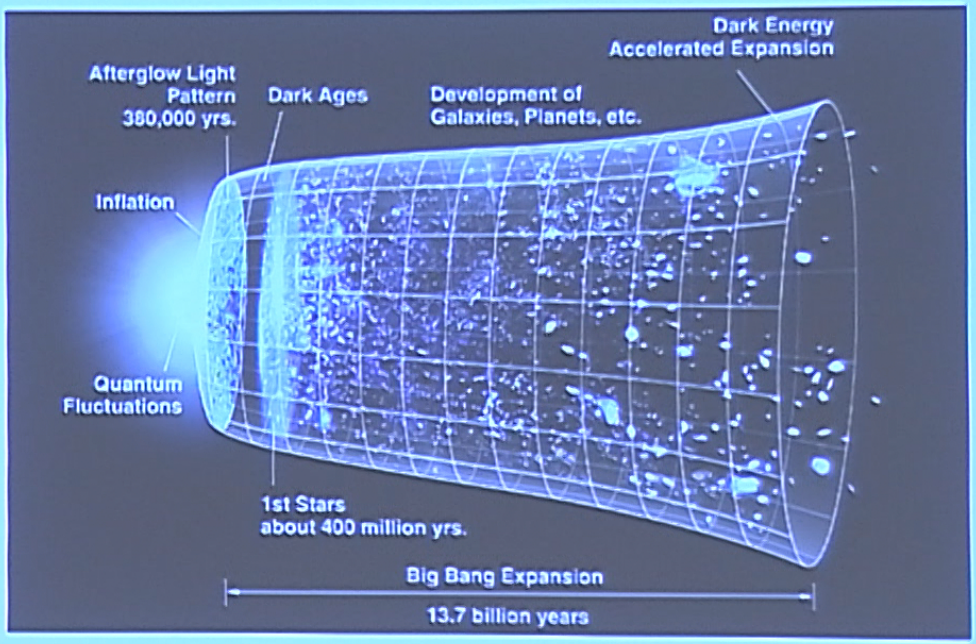


Quantum field theory

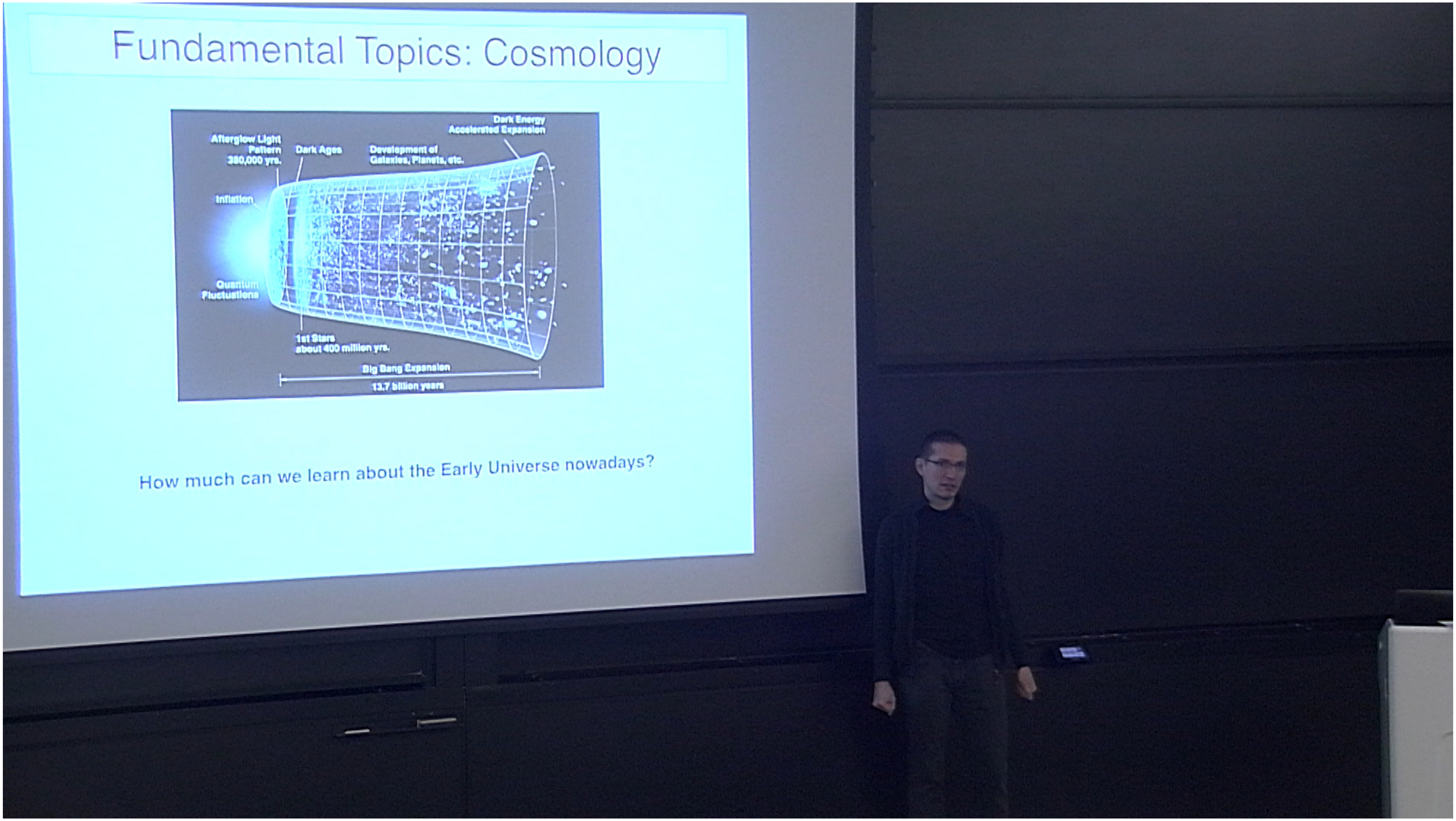
Quantum information

- 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

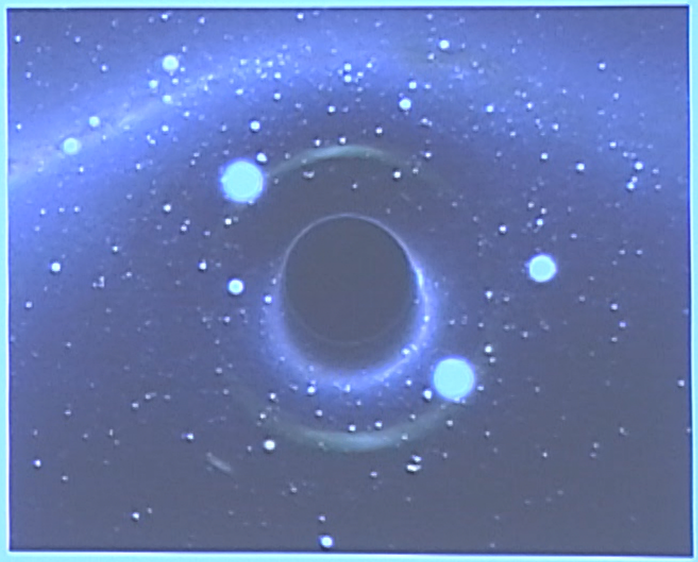
Fundamental Topics: Cosmology



How much can we learn about the Early Universe nowadays?


Fundamental Topics: Cosmology
Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
How much can we learn about the Early Universe nowadays?

Fundamental Topics: Black Hole Information Loss Problem



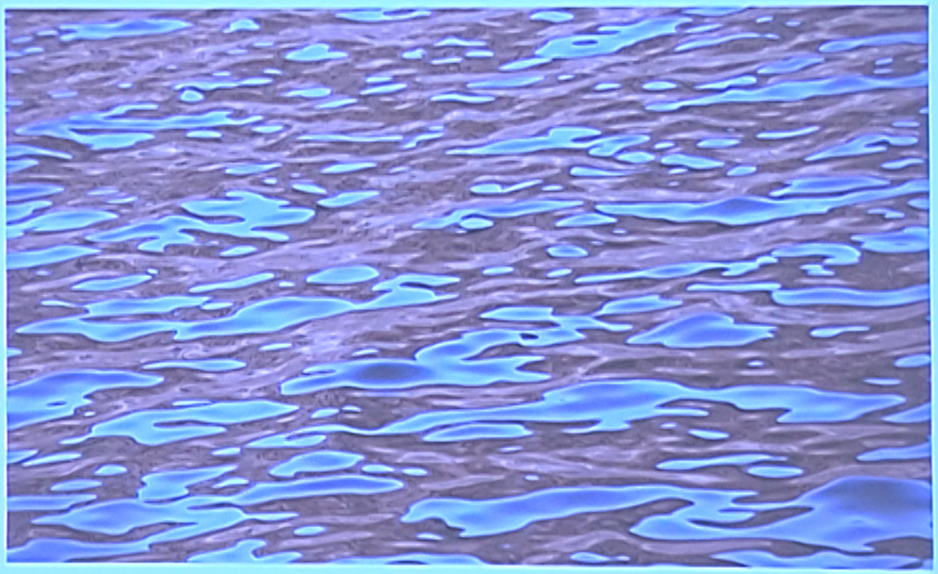
Quantum Mechanics preserves information.

Black Holes: Does Nature destroy information?

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


ng Radiation?

Fundamental Topics: Vacuum Fluctuations

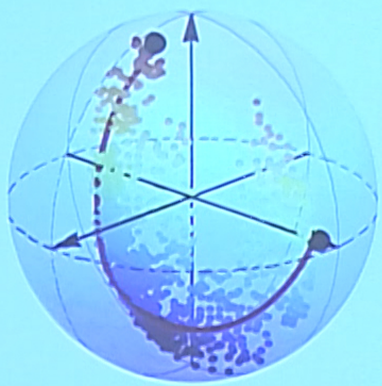


In Nature, the vacuum is not empty. Only on average.

Vacuum Fluctuations contain Information about curvature of spacetime.

Quantum noise is special: It can assist communication!

Fundamental Topics:
Quantum Measurements and Localization



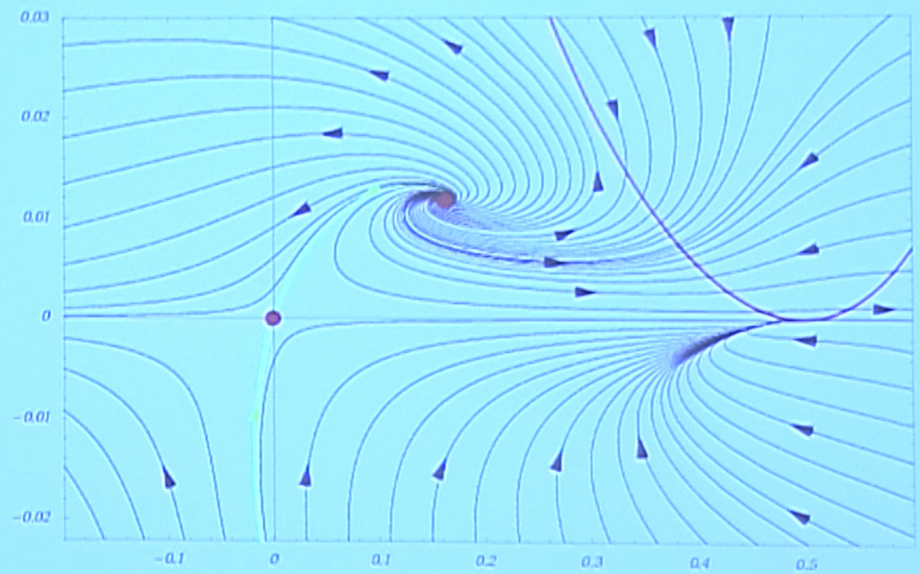
Quantum Theory is a probabilistic theory.

The measurement problem in QFT.

Quantum-to-Classical transition.

Relativistic considerations in the localization of Information

Fundamental Topics: Thermodynamics in QFT



The problem of equilibration in Quantum Theory and in Gravity.

Quantum Thermodynamics.

Fundamental Topics:
Quantum Gravity

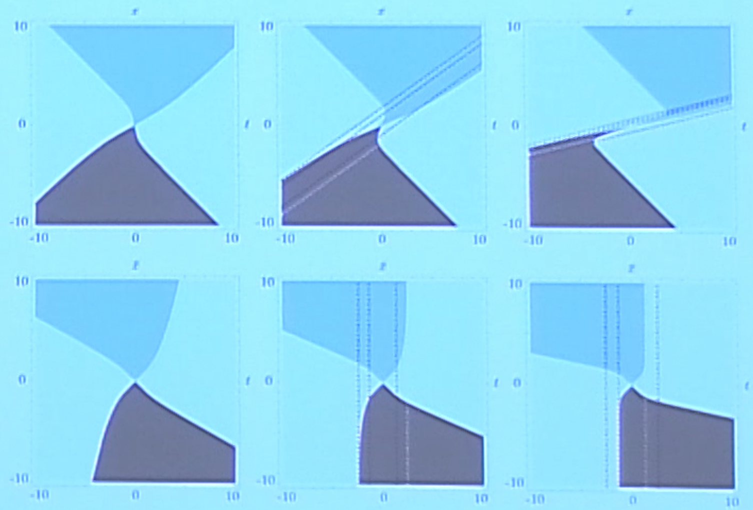
One of the most important challenges of modern Mathematical Physics:

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

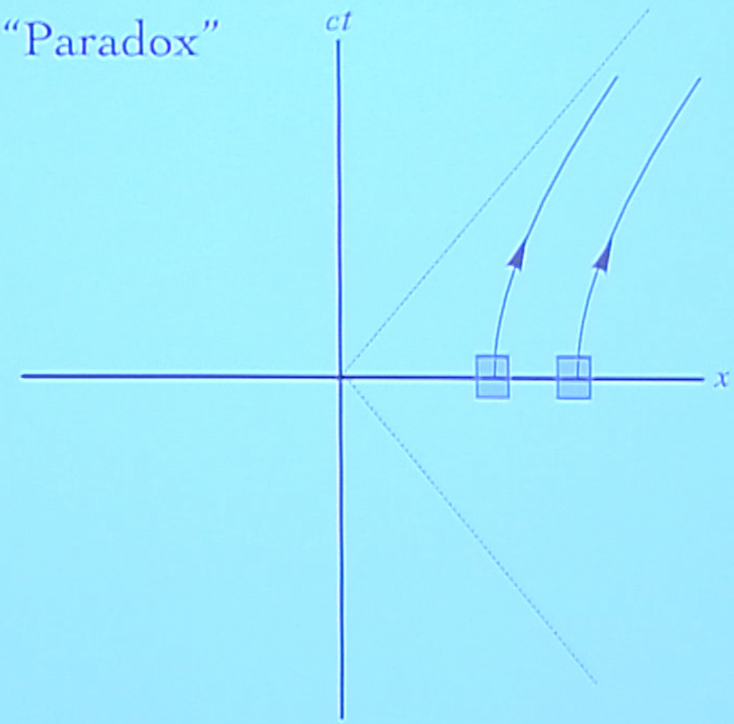
Bell Rocket "Paradox"

Does the rope break or not??

Why??

Same Physics, Different Descriptions

Bell Rocket "Paradox"



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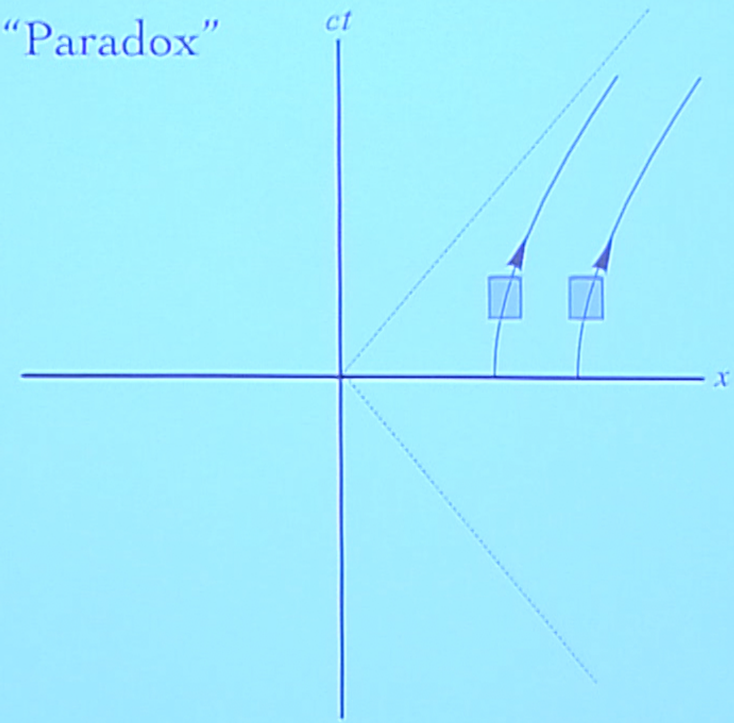

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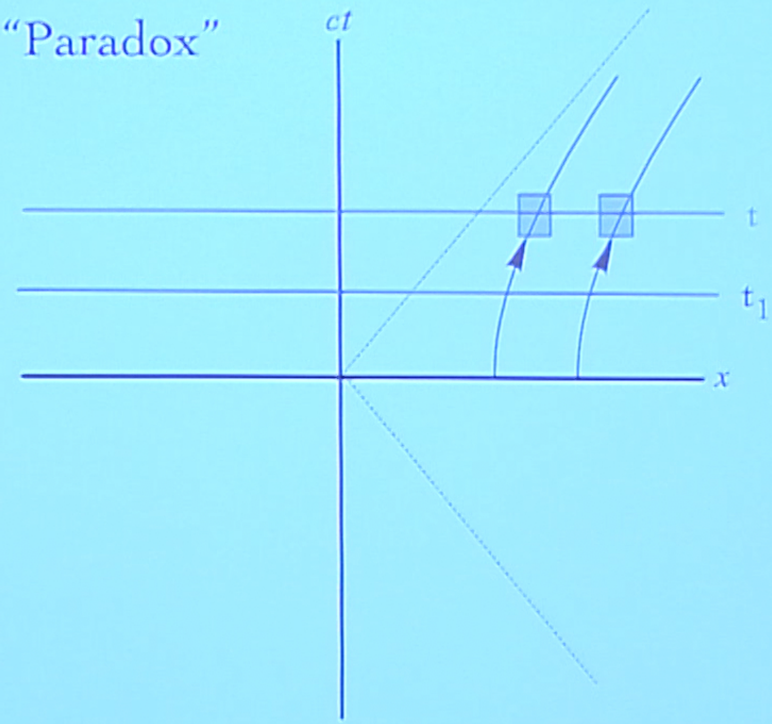

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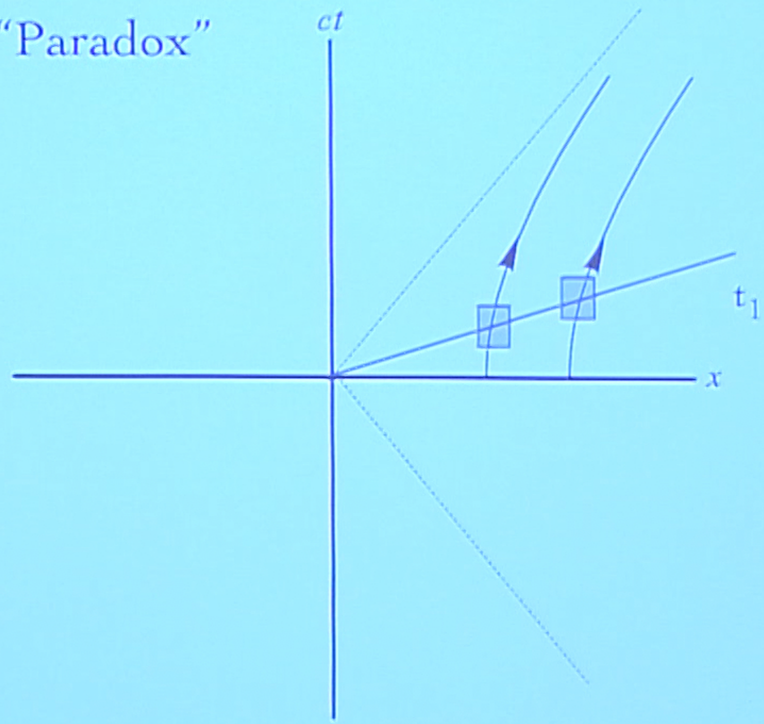

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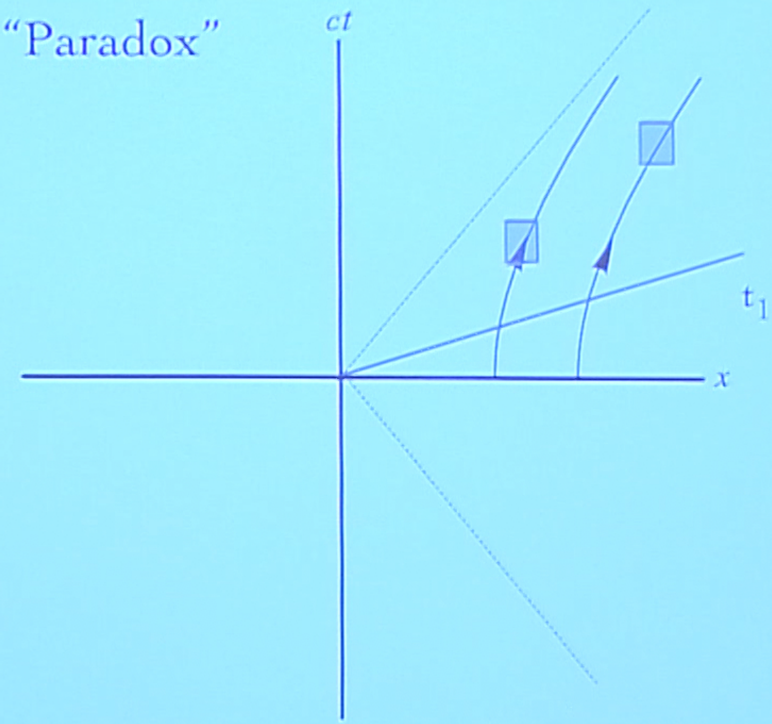


Does the rope break or not??

Why??

Same Physics, Different Descriptions

PHYSICS:

The rope breaks, all right!

Same Physics, Different Descriptions

PHYSICS:

The rope breaks, all right!

PHENOMENOLOGY:

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

Same Physics, Different Descriptions

PHYSICS:

The rope breaks, all right!

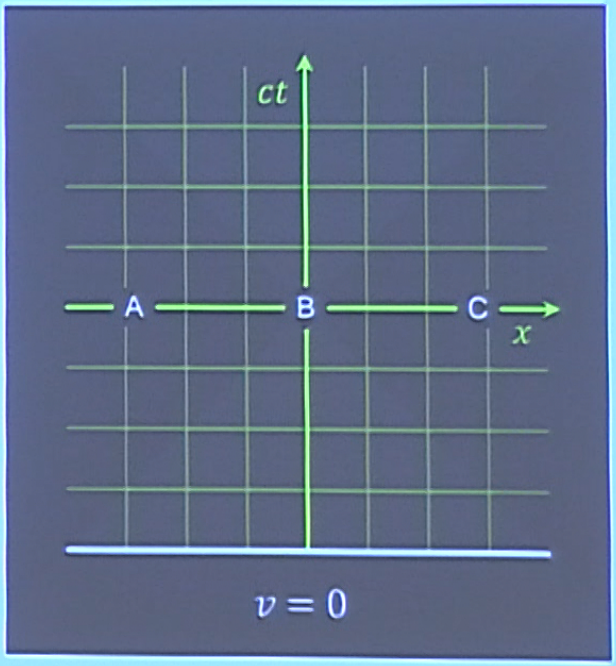
PHENOMENOLOGY:

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

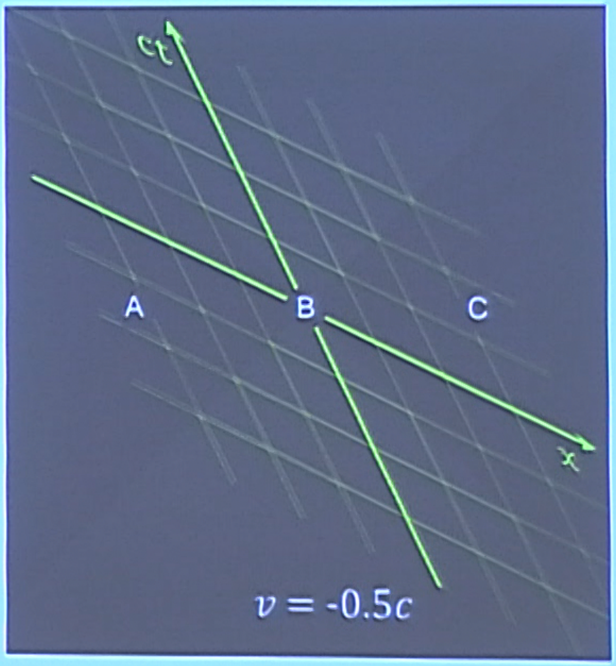
Simultaneity is Relative!



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

Getting Familiar with Spacetime

Simultaneity is Relative!



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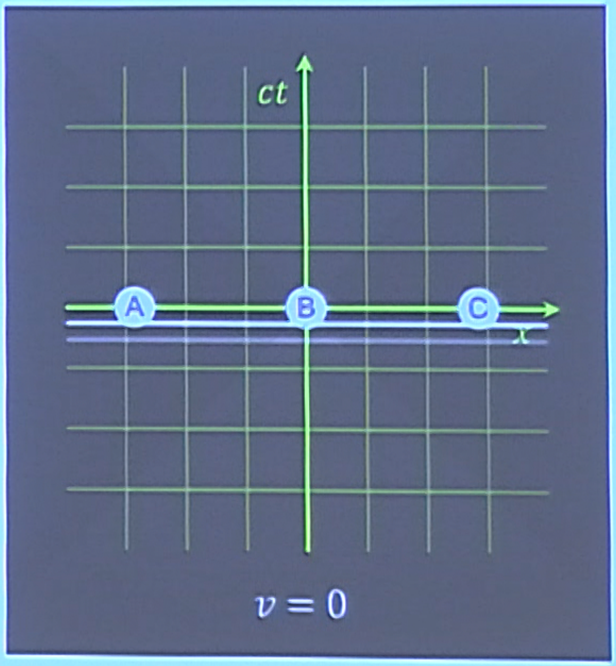

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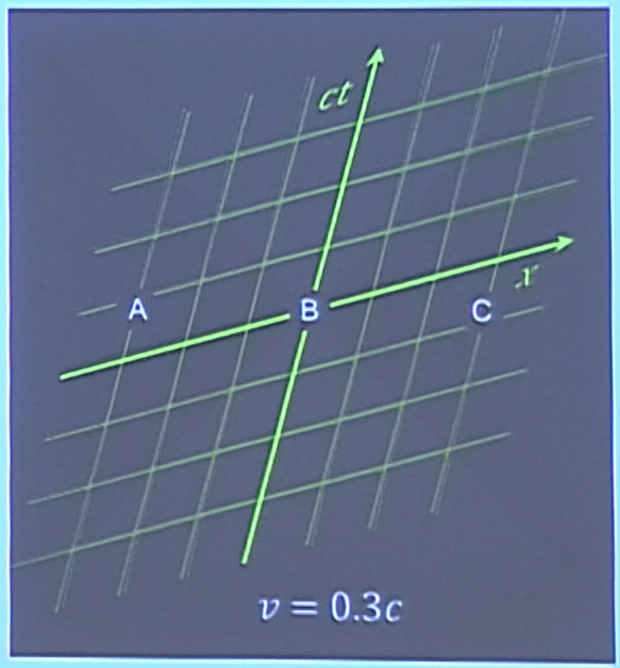

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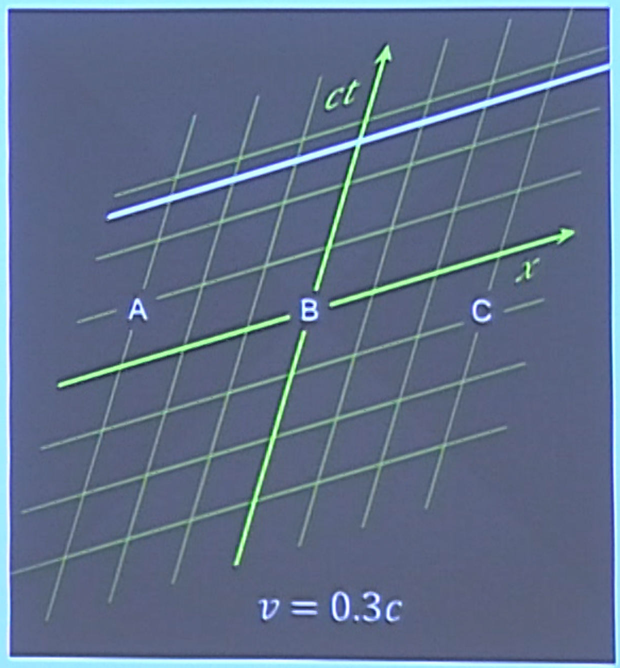

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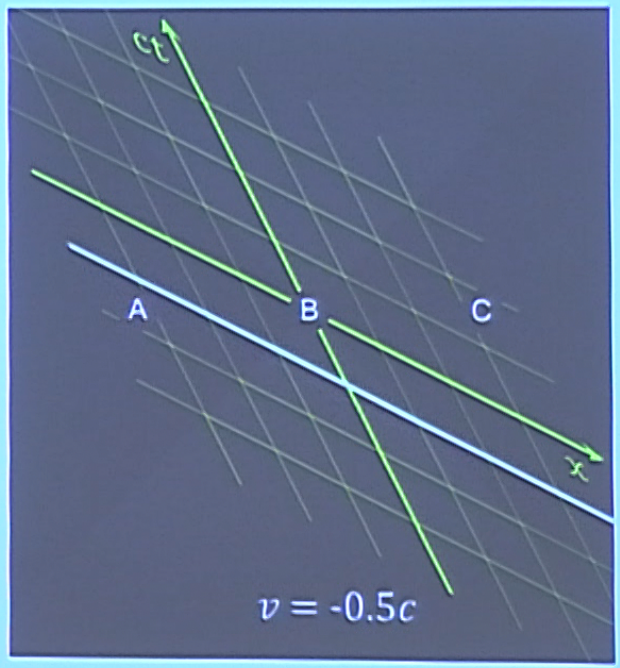

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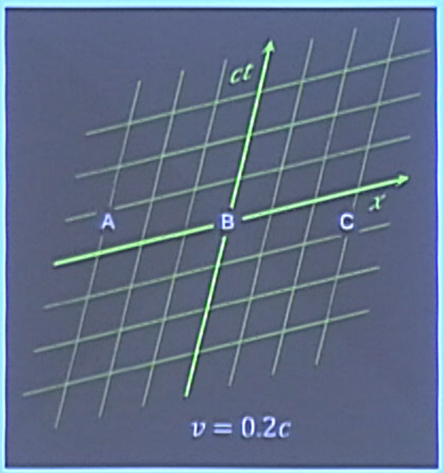
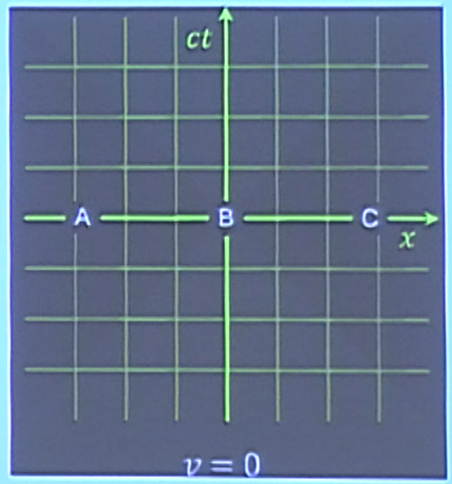
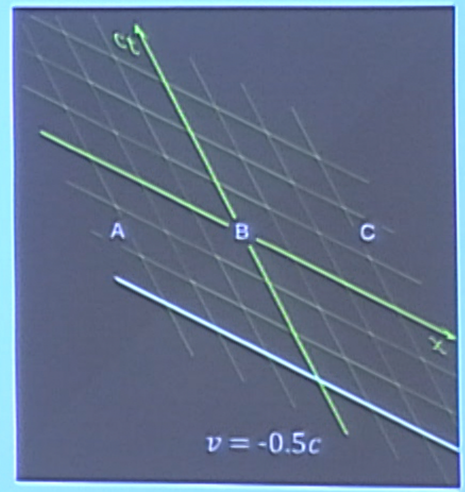


A happens after C



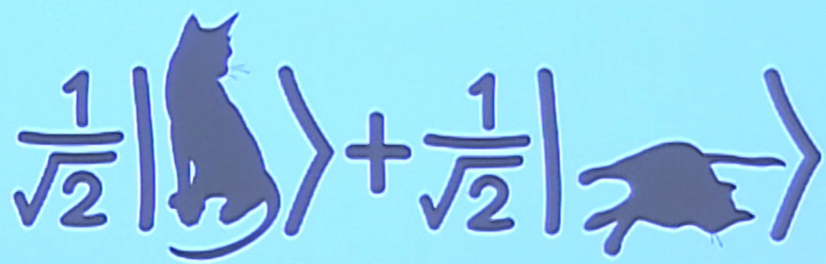
A and C are simultaneous



A happens before C

Getting Familiar with Quantum Mechanics

Schrödinger's cat



Quantum Entanglement

The New York Times.

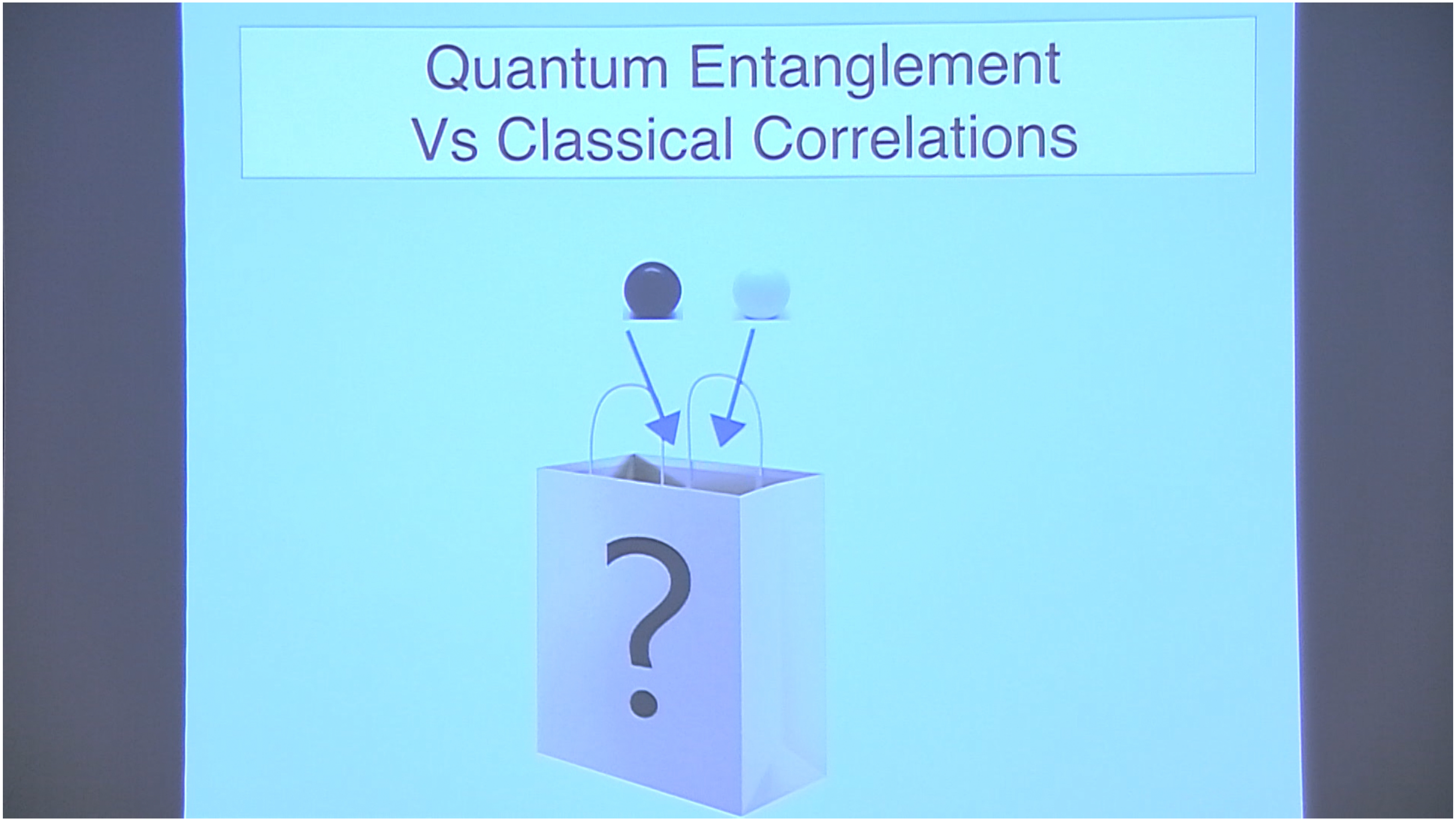
NEW YORK, SATURDAY, MAY 4, 1935. TWO CENTS

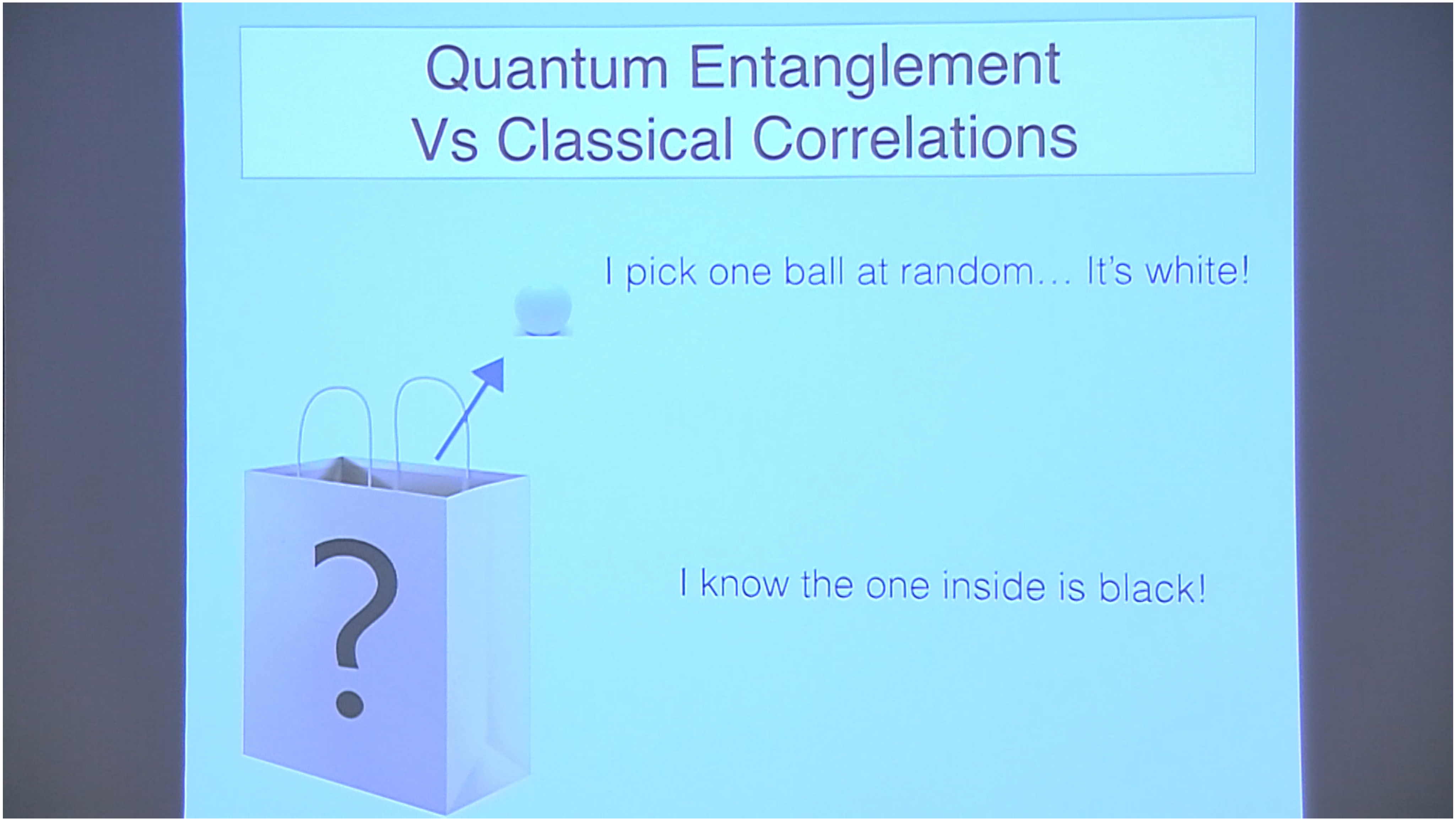
EINSTEIN ATTACKS QUANTUM THEORY

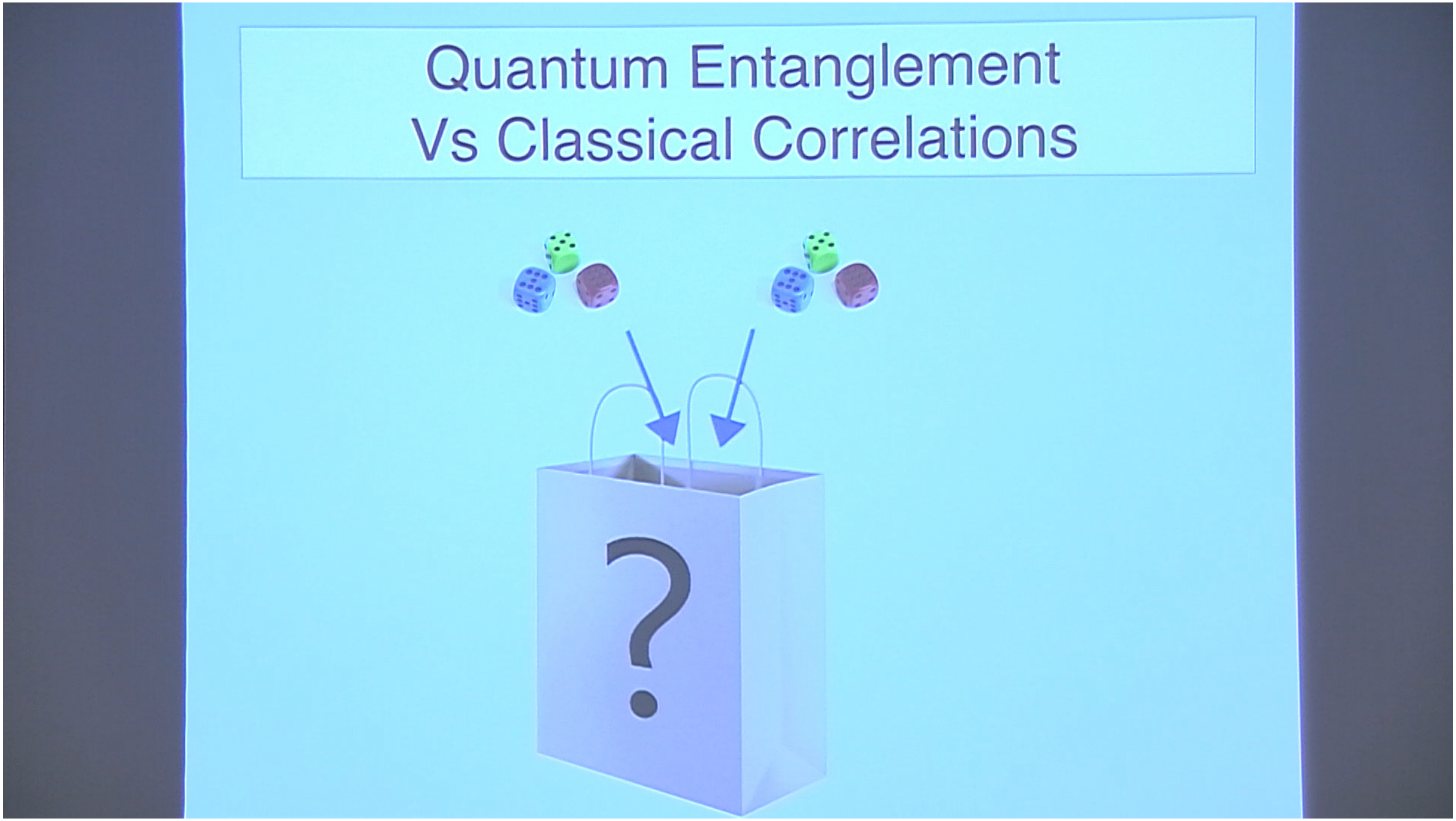
Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

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
?

What entanglement is not

POPULAR SCIENCE

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

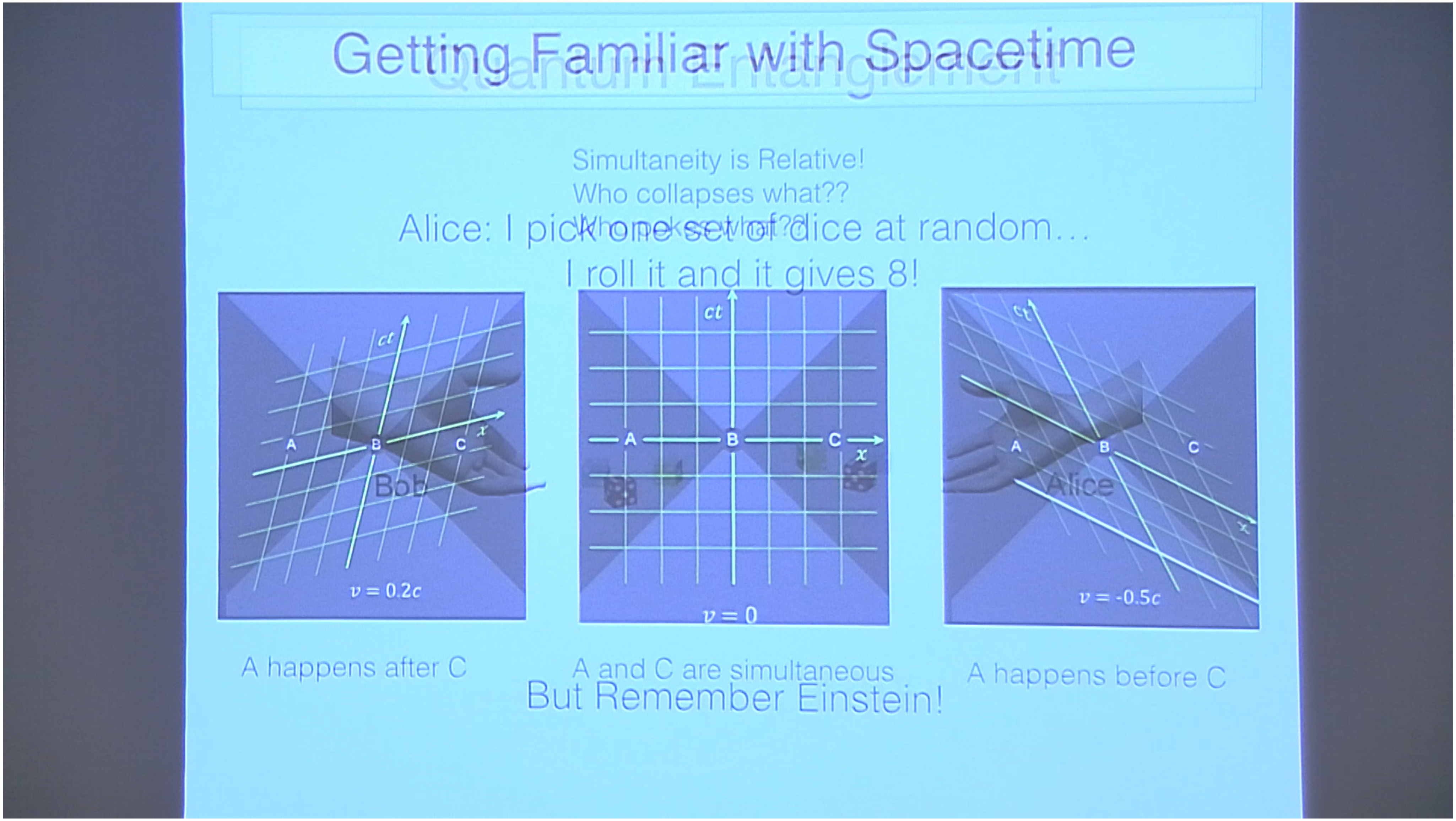
Entanglement breakthrough could lead to unhackable Internet

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.

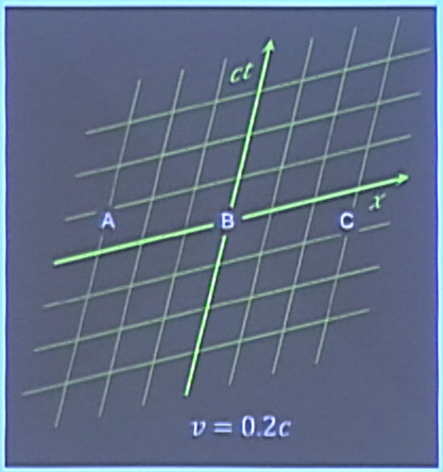
From http://www.popsci.com



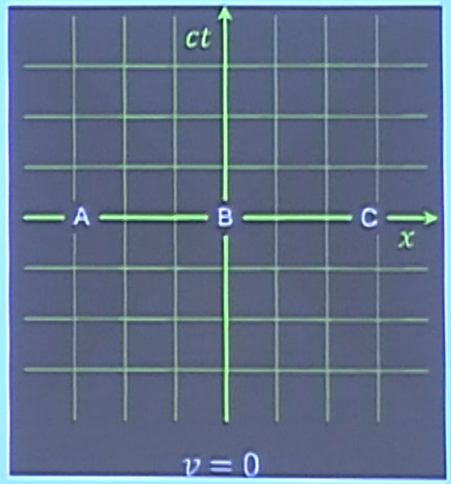
Getting Familiar with Spacetime
Quantum Entanglement
Simultaneity is Relative!
Who collapses what??
Alice: I pick one set of dice at random…
I roll it and it gives 8!
ct
x
A
B
C
Bob
Alice
$v = 0.2c$
$v = 0$
$v = -0.5c$
A happens after C
A and C are simultaneous
A happens before C
But Remember Einstein!

Getting Familiar with Spacetime

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



A happens after C



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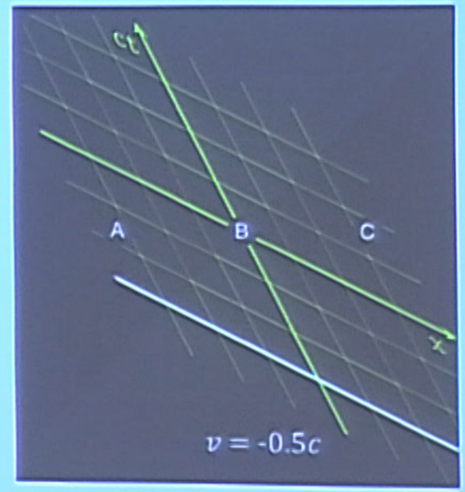
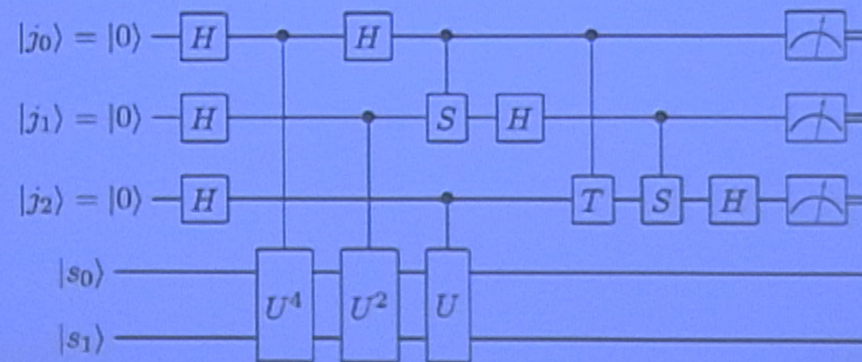


A happens before C

Effects on quantum information

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



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

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:

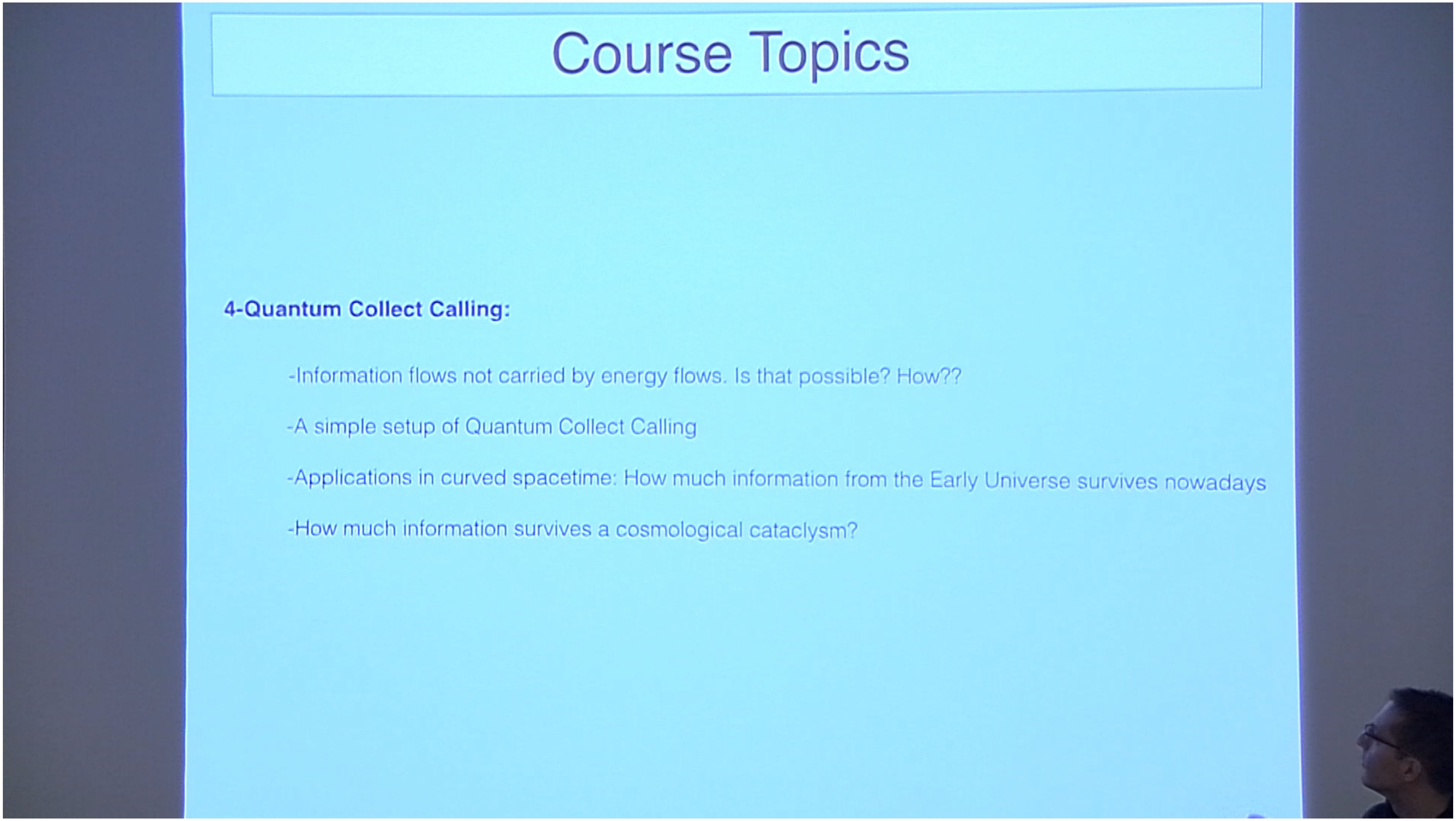
-Entangling spacelike separated systems: Is that possible? How??

-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?

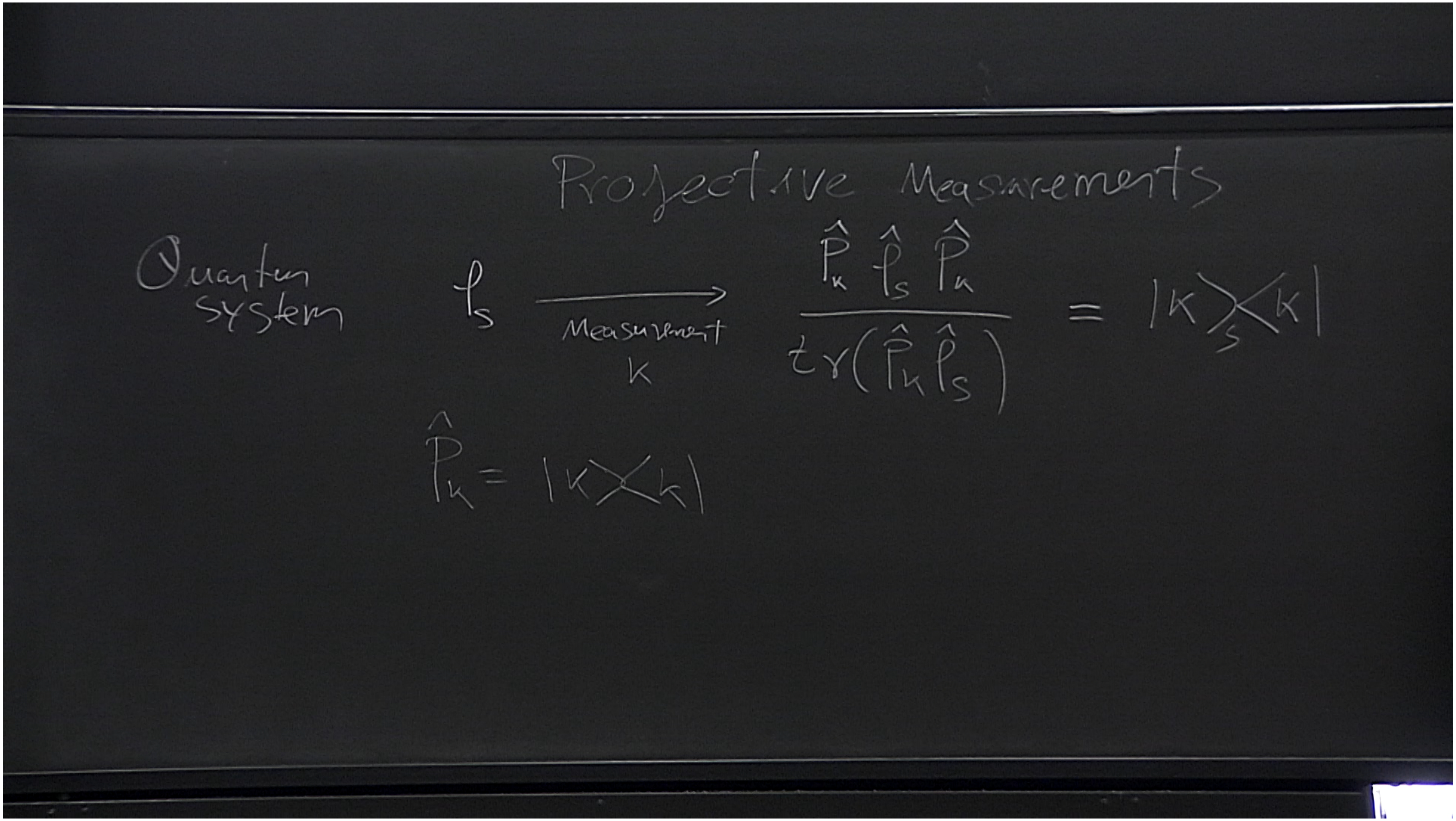
Course Topics

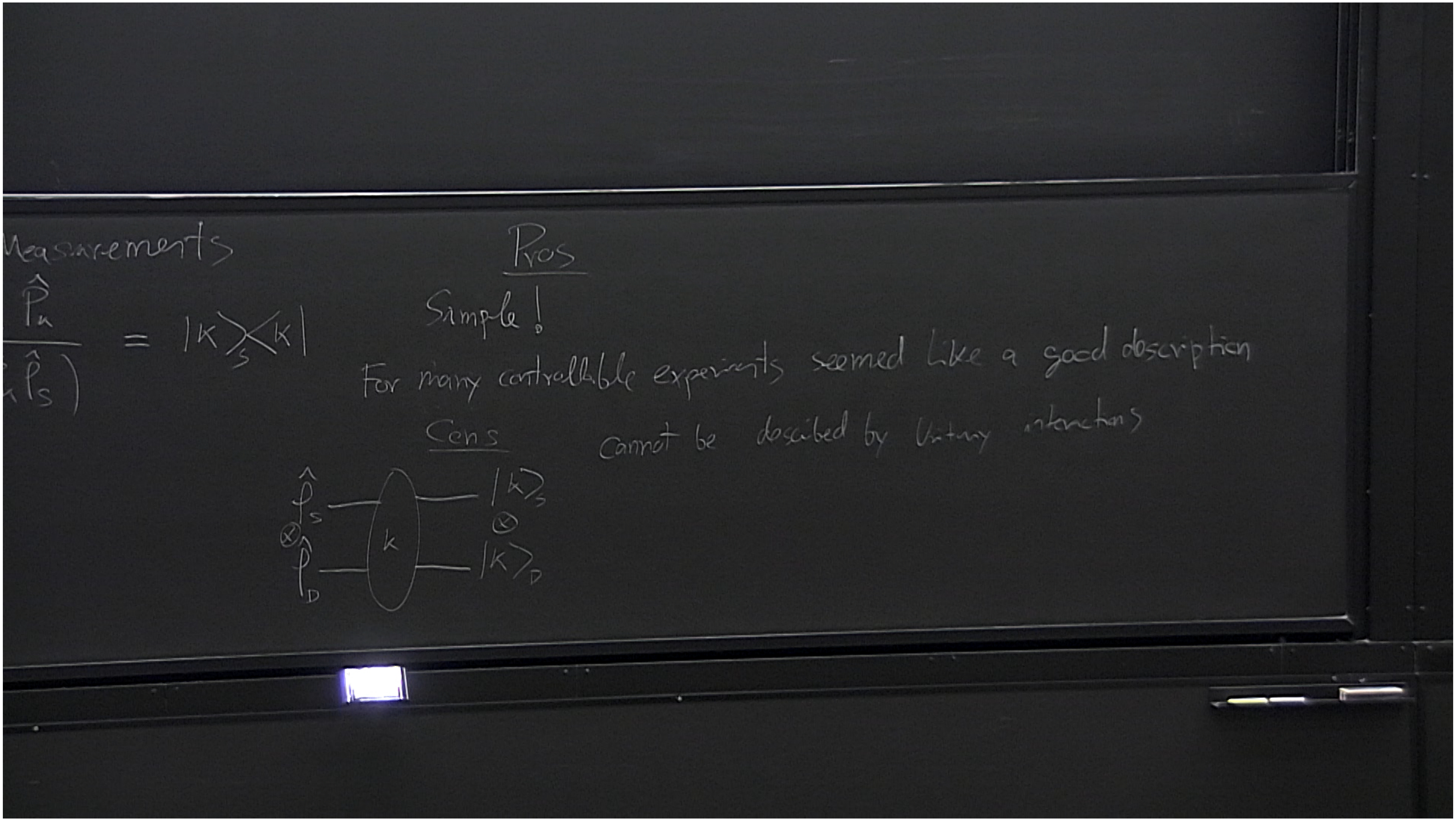
5-Quantum Energy Teleportation:

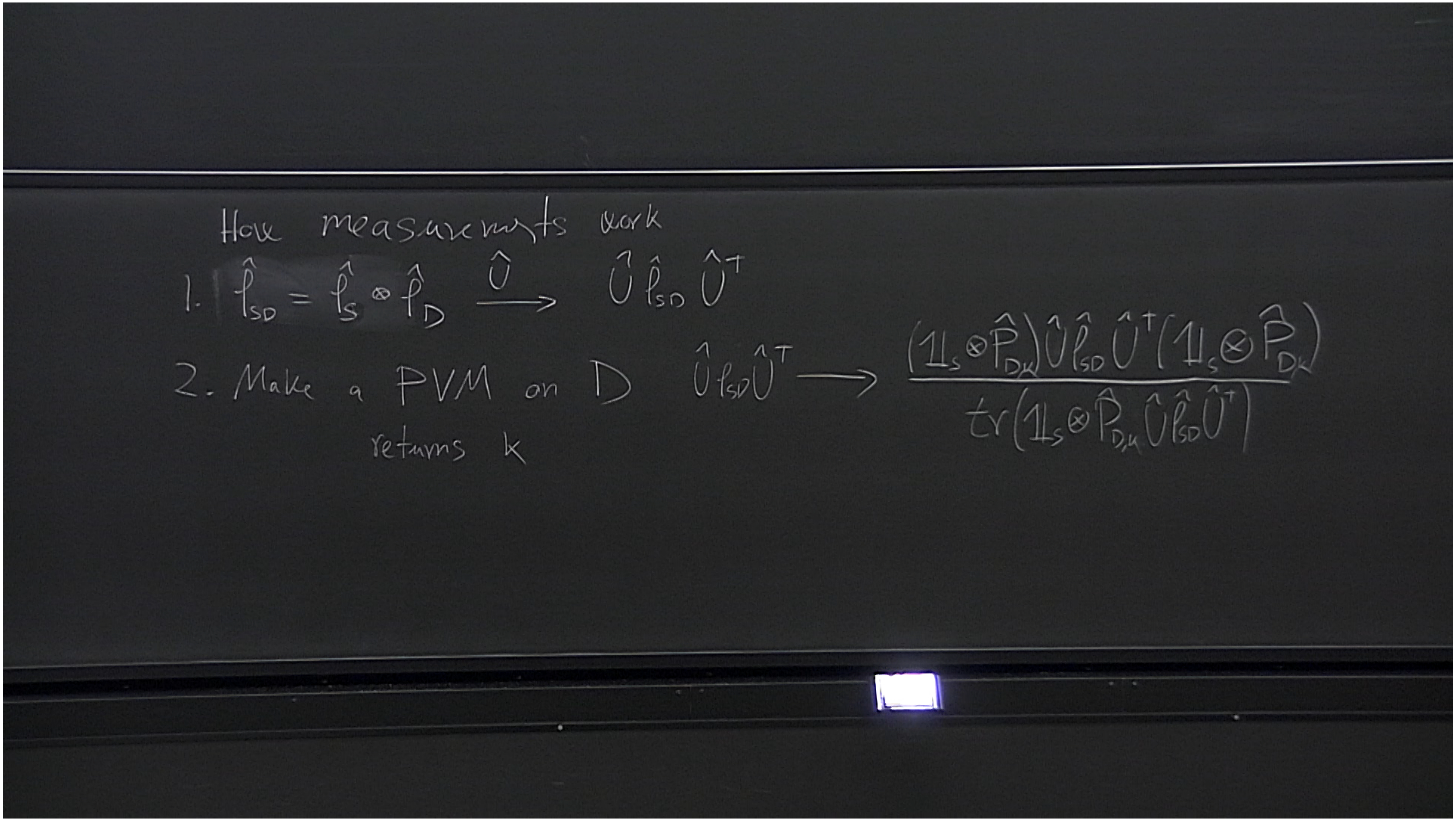
-Minimal QET model: transmitting energy without energy travelling from sender to receiver

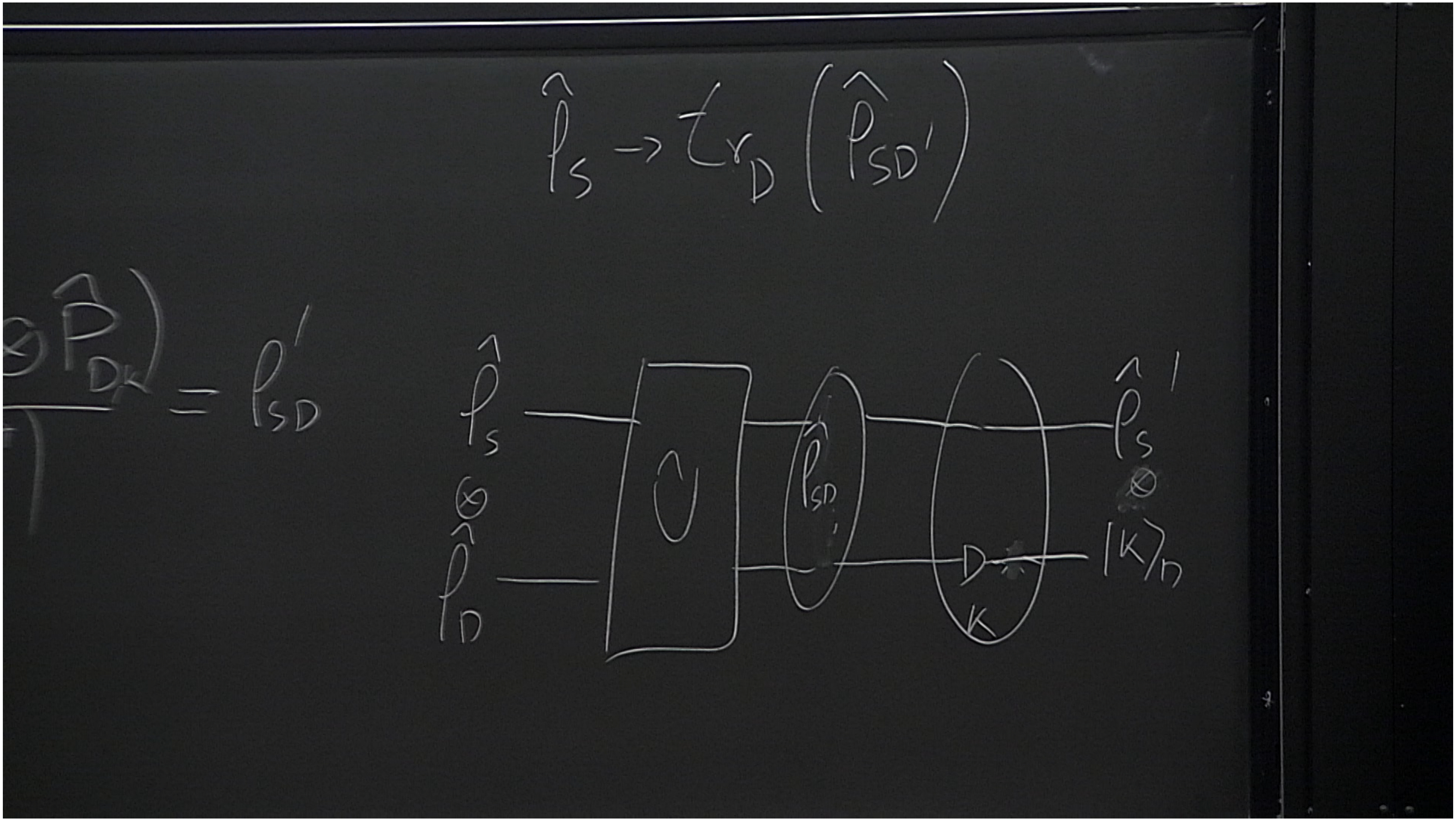
-A bit of quantum thermodynamics: Breaking Strong Local Passivity.

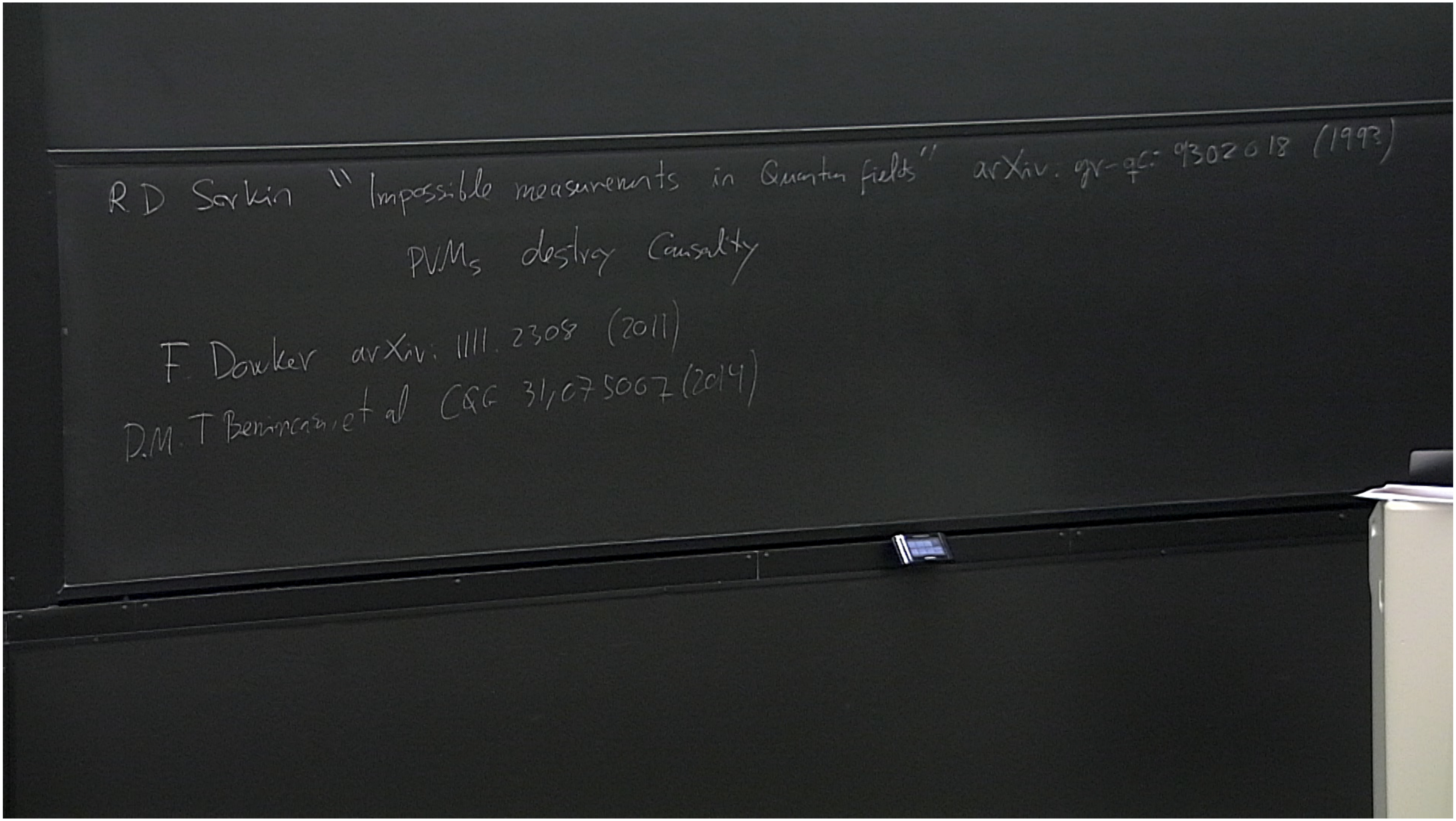
-QET in quantum fields: designing negative stress-energy densities.

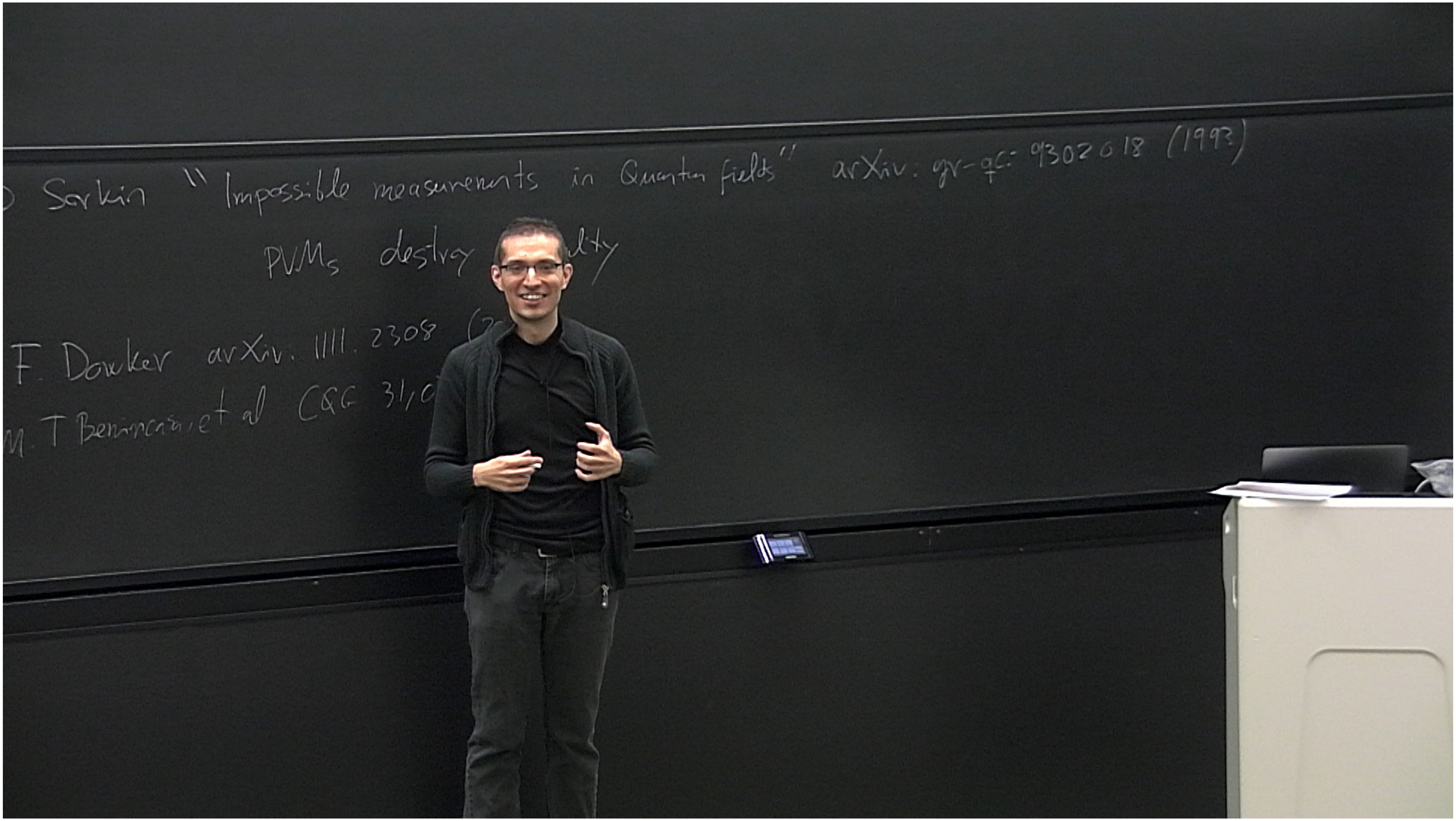

Projective Measurements
Quantum system
$\rho_s \xrightarrow[\text{Measurement } k]{} \frac{\hat{P}_k \hat{\rho}_s \hat{P}_k}{tr(\hat{P}_k \hat{\rho}_s)} = |k\rangle_s\langle k|$
$\hat{P}_k = |k\rangle\langle k|$


Measurements
Pros
Simple!
For many controllable experiments seemed like a good description
Cons
Cannot be described by Unitary interactions


How measurements work
1. $\hat{\rho}_{SD} = \hat{\rho}_S \otimes \hat{\rho}_D \xrightarrow{\hat{U}} \hat{U}\hat{\rho}_{SD}\hat{U}^\dagger$
2. Make a PVM on D $\hat{U}\hat{\rho}_{SD}\hat{U}^\dagger \longrightarrow \frac{(\mathbb{1}_S \otimes \hat{P}_{D,k})\hat{U}\hat{\rho}_{SD}\hat{U}^\dagger(\mathbb{1}_S \otimes \hat{P}_{D,k})}{tr(\mathbb{1}_S \otimes \hat{P}_{D,k}\hat{U}\hat{\rho}_{SD}\hat{U}^\dagger)}$
returns k


$\hat{\rho}_S \rightarrow tr_D(\hat{\rho}_{SD'})$
$\otimes \hat{P}_{DK}) = \rho'_{SD}$
$\hat{\rho}_S$
$\otimes$
$\hat{\rho}_D$
$\hat{U}$
$\hat{\rho}_{SD'}$
D
K
$\hat{\rho}_S'$
$\otimes$
$|K\rangle_D$


R D Sorkin "Impossible measurements in Quantum fields" arXiv: gr-qc: 9302018 (1993)
PVMs destroy Causality
F. Dowker arXiv: 1111.2308 (2011)
D.M.T Benincasa, et al CQG 31, 075007 (2014)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