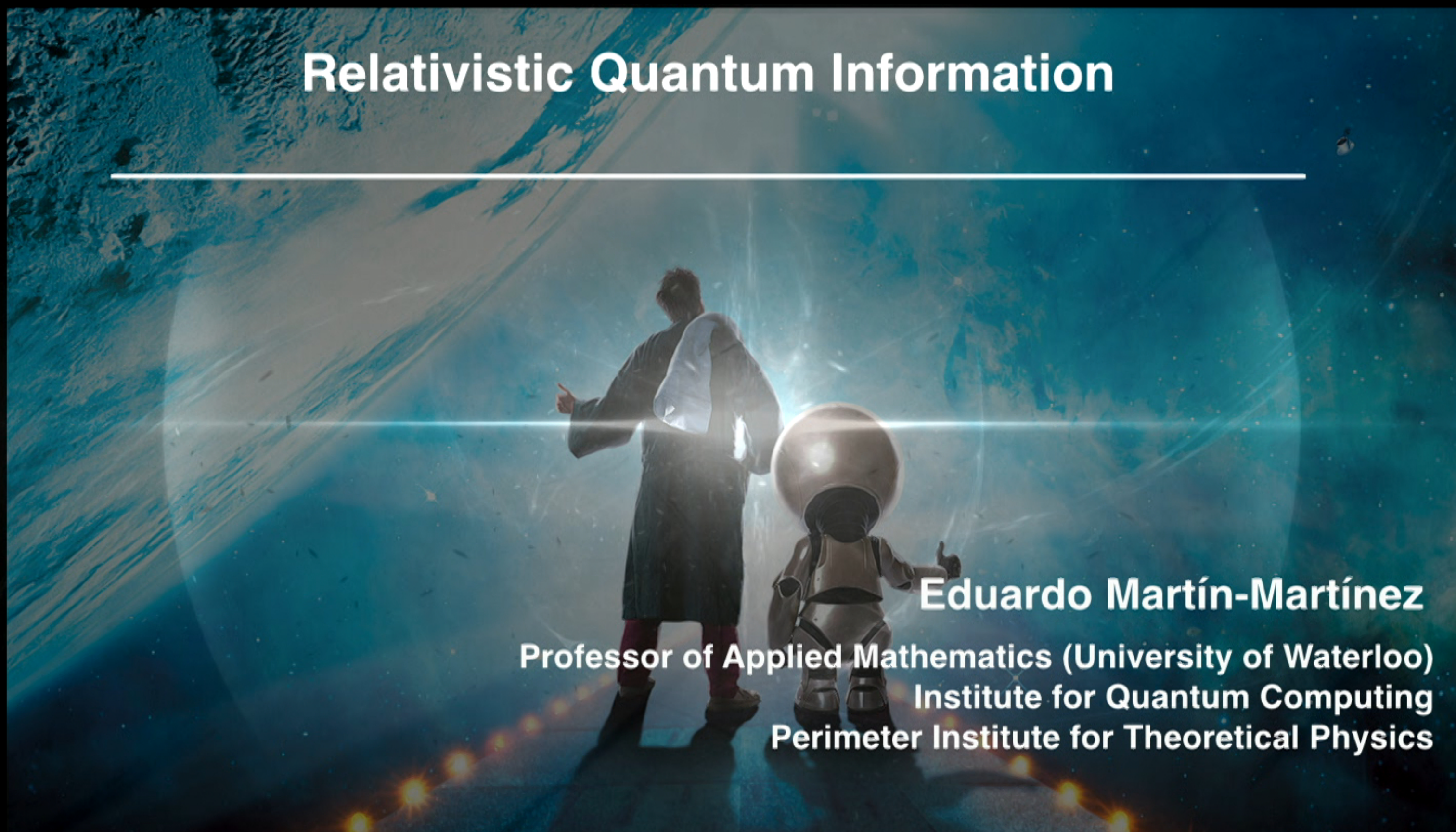
Title: PSI 2016/2017 Quantum Information (Review) - Lecture 9 (Eduardo Martin-Martinez)

Date: Mar 06, 2017 09:00 AM

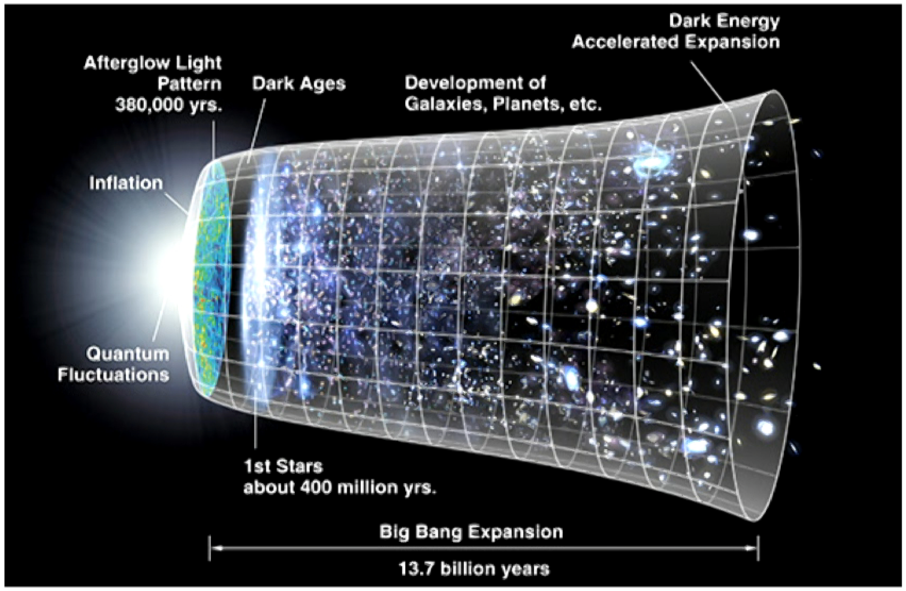
URL: http://pirsa.org/17030033

Abstract:

March 5-6th 2017 PSI

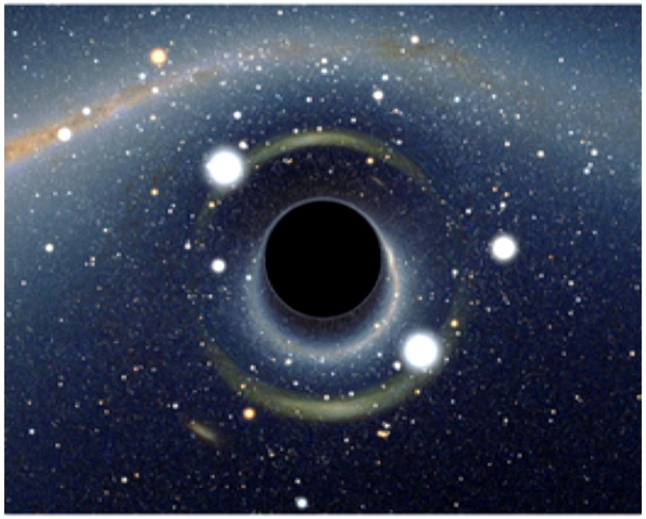


Fundamental Topics: Cosmology



How much can we learn about the Early Universe nowadays?

Fundamental Topics: Black Hole Information Loss Problem

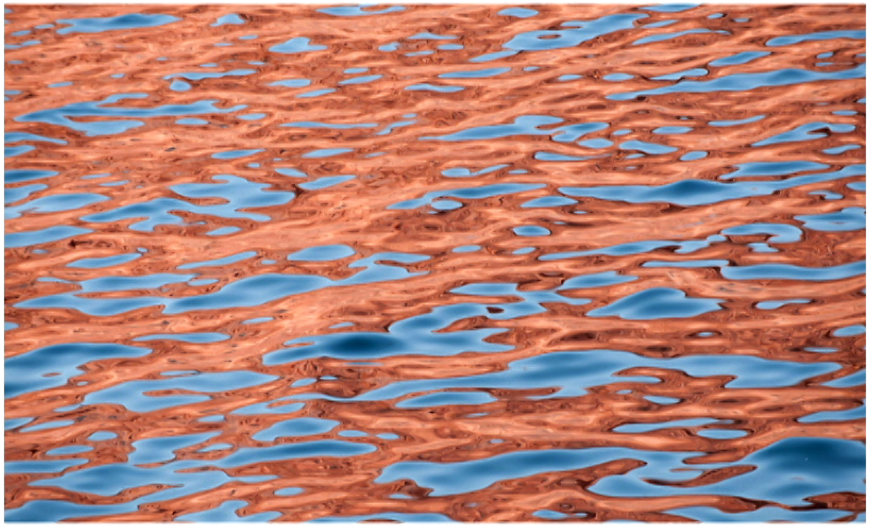


Quantum Mechanics preserves information.

Black Holes: Does Nature destroy information?

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

Fundamental Topics: Vacuum Fluctuations

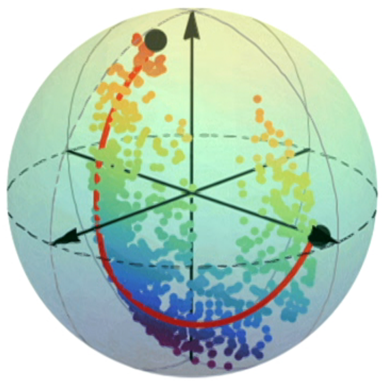


In Nature, the vacuum is not empty. Only on average.

Vacuum Fluctuations contain Information about curvature of spacetime.

Quantum noise is special: It can assist communication!

Fundamental Topics: Quantum Measurements and Localization



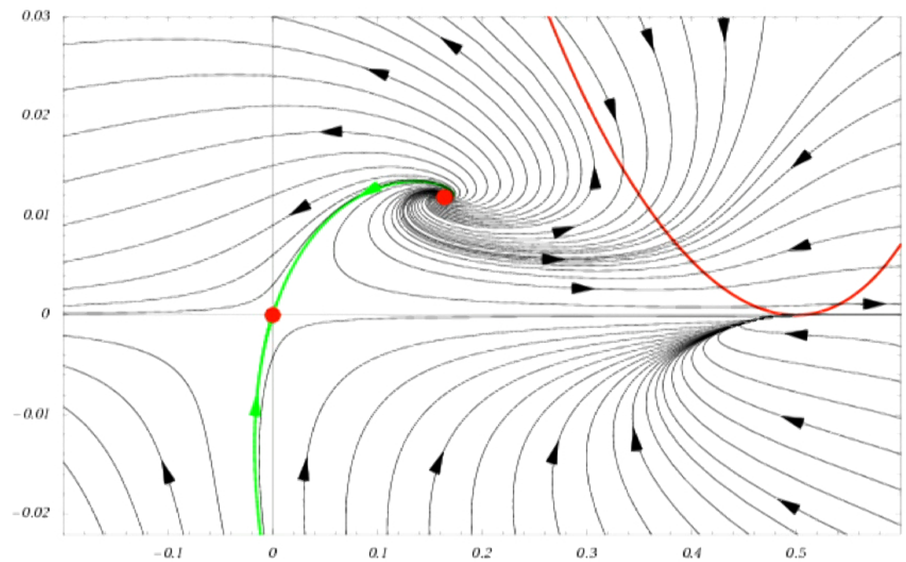
Quantum Theory is a probabilistic theory.

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

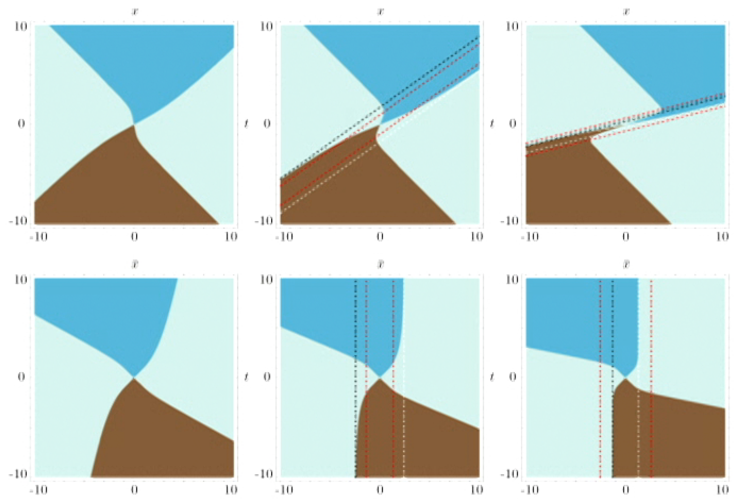
One of the most important challenges of modern Mathematical Physics:

Quantum Theory for Gravitation

Fundamental Topics: "Spacetime Engineering"

Violate energy conditions:

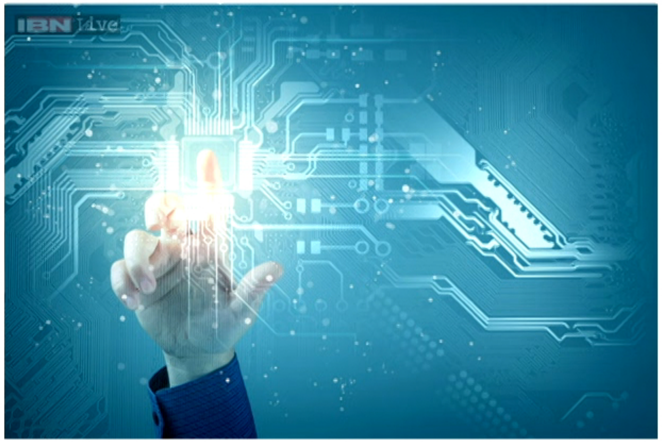
-Warp drives?
-Wormholes?



For more info: N.Funai, E. martin-Martinez: arXiv:1701.03805

Technological 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

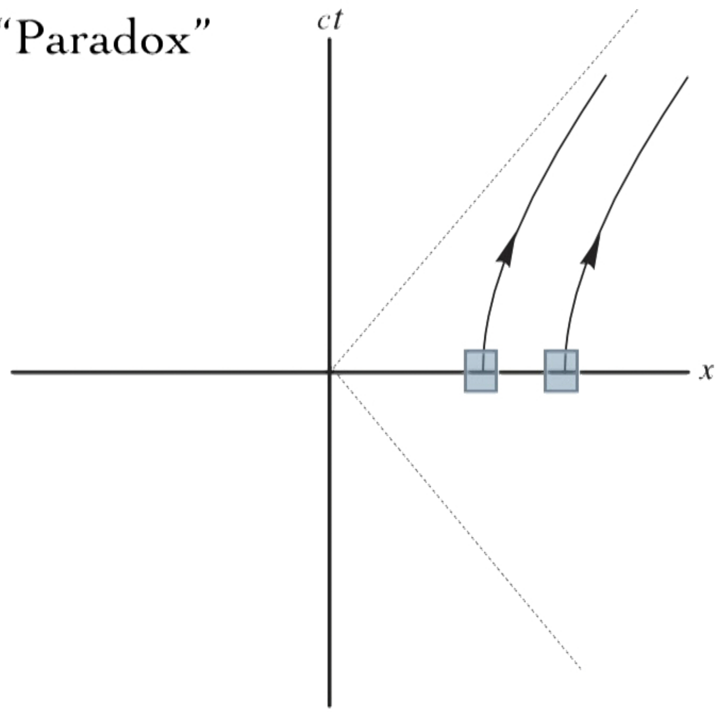
Relativity Matters for Quantum Information

Same Physics, Different Descriptions

Bell Rocket "Paradox"

Same Physics, Different Descriptions

Bell Rocket "Paradox"

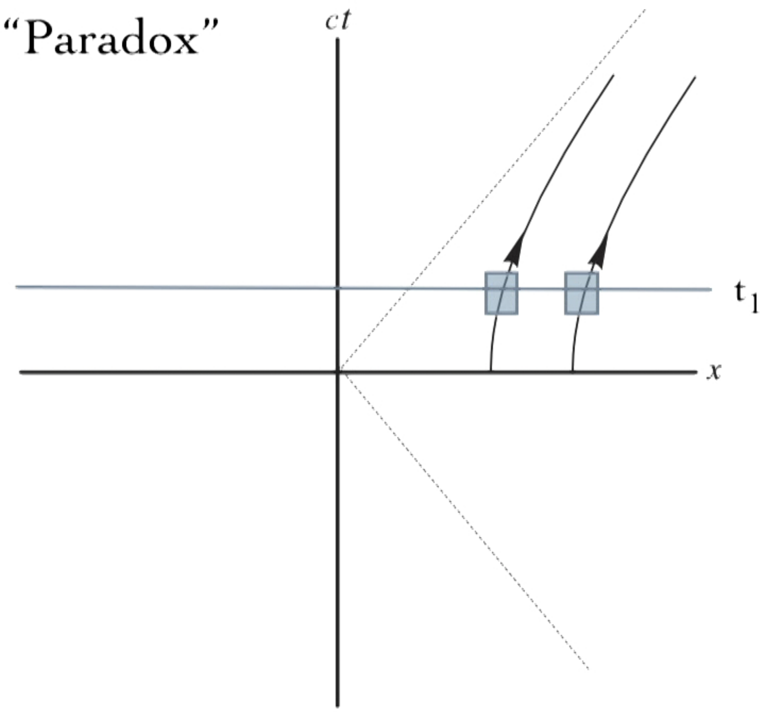


Does the rope break or not??

Why??

Same Physics, Different Descriptions

Bell Rocket "Paradox"



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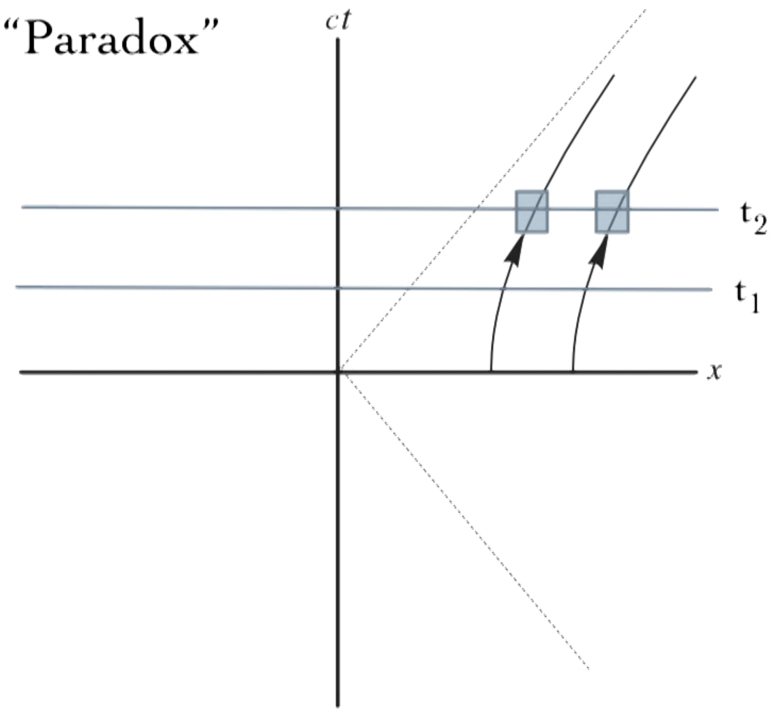

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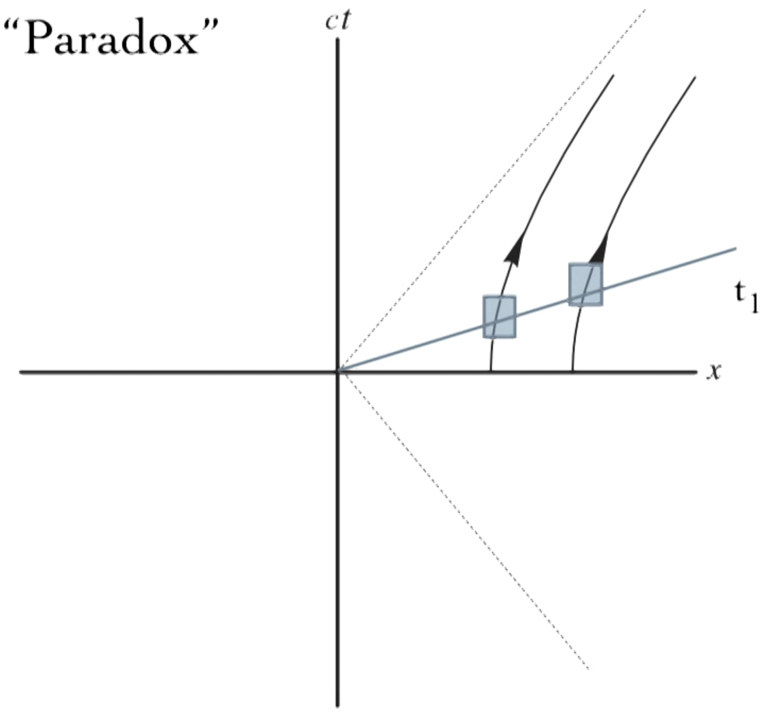

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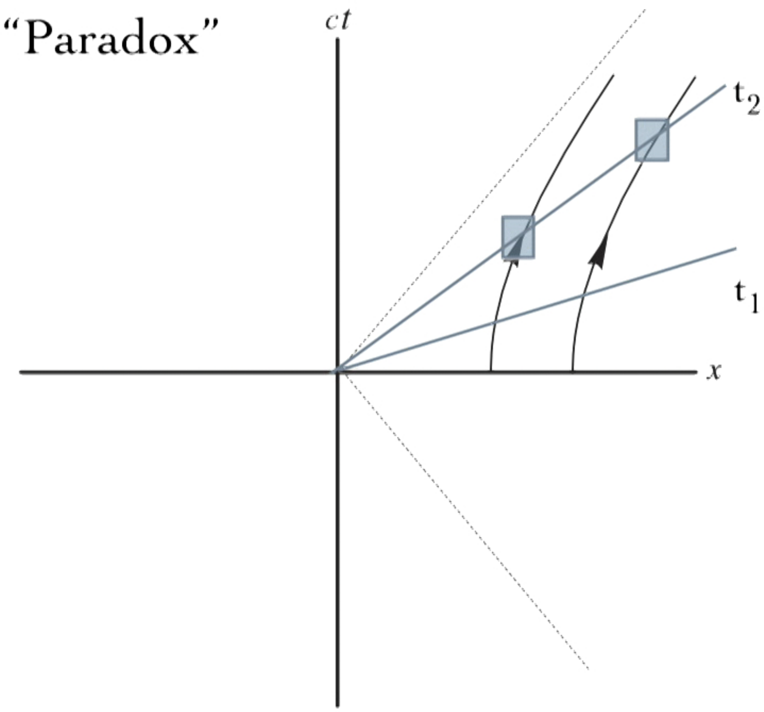


Does the rope break or not??

Why??

Same Physics, Different Descriptions

PHYSICS:

The rope breaks, all right!

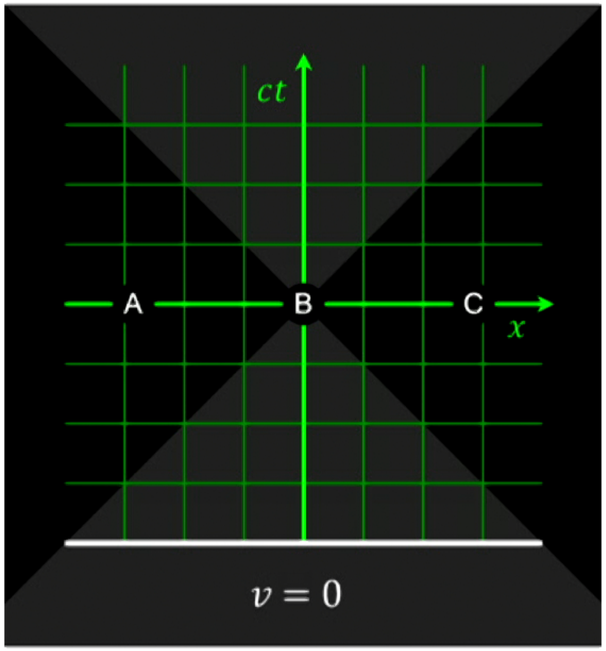
PHENOMENOLOGY:

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

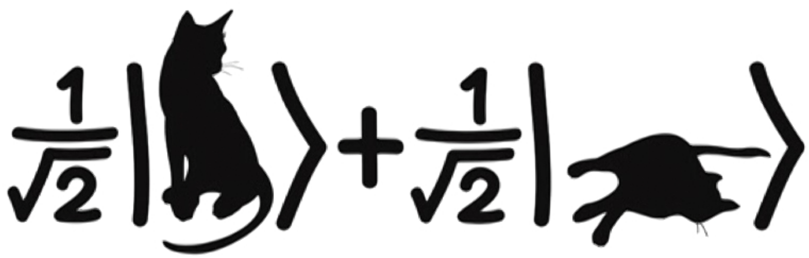
Simultaneity is Relative!



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

Getting Familiar with 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

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

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

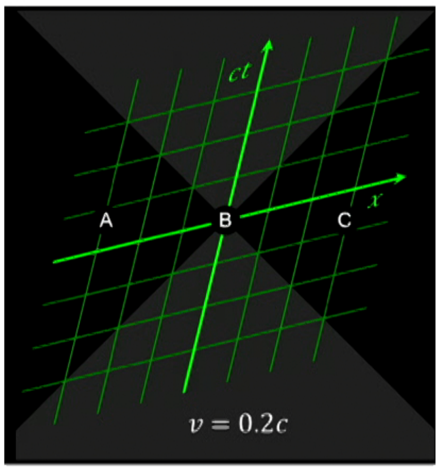
Particles don't obey the same rules as people. Poke a particle, and another one far away can instantly respond the touch -- without any messages passing through the space between, as if the two particles were one. "Entanglement" is what quantum physics calls the intimate connection.

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

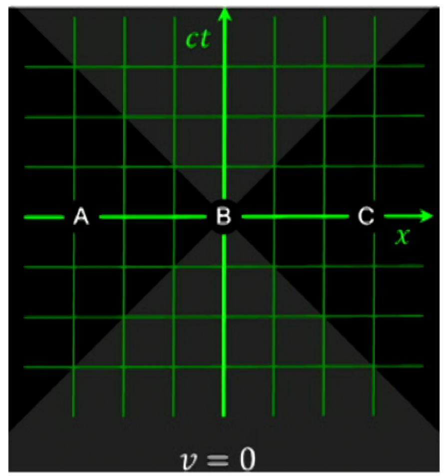
From http://www.popsci.com

Getting Familiar with Spacetime

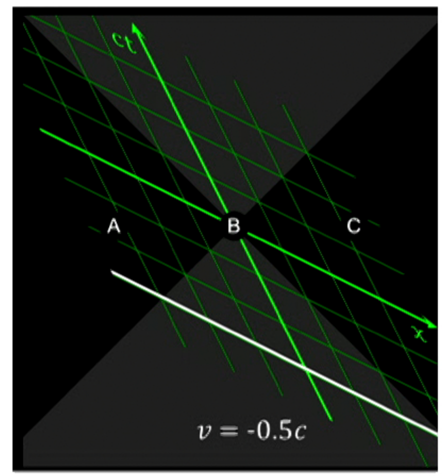
Simultaneity is Relative!
Who collapses what??
Who pokes what??



A happens after C

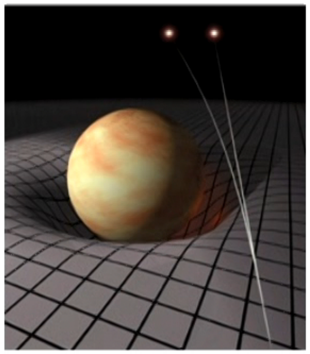


A and C are simultaneous

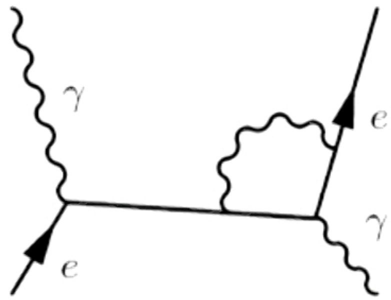


A happens before C

Relativistic Quantum Information



General relativity

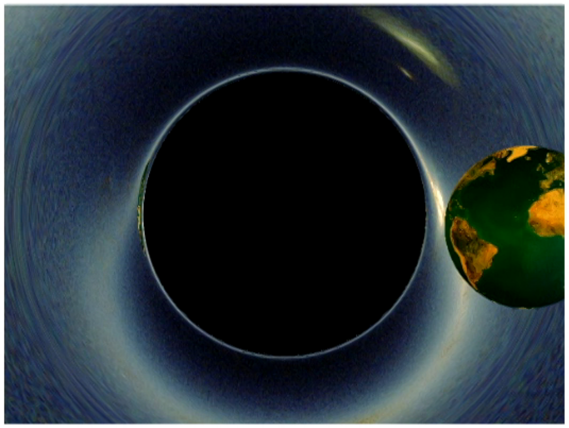


Quantum field theory

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

The Black Hole Information Paradox



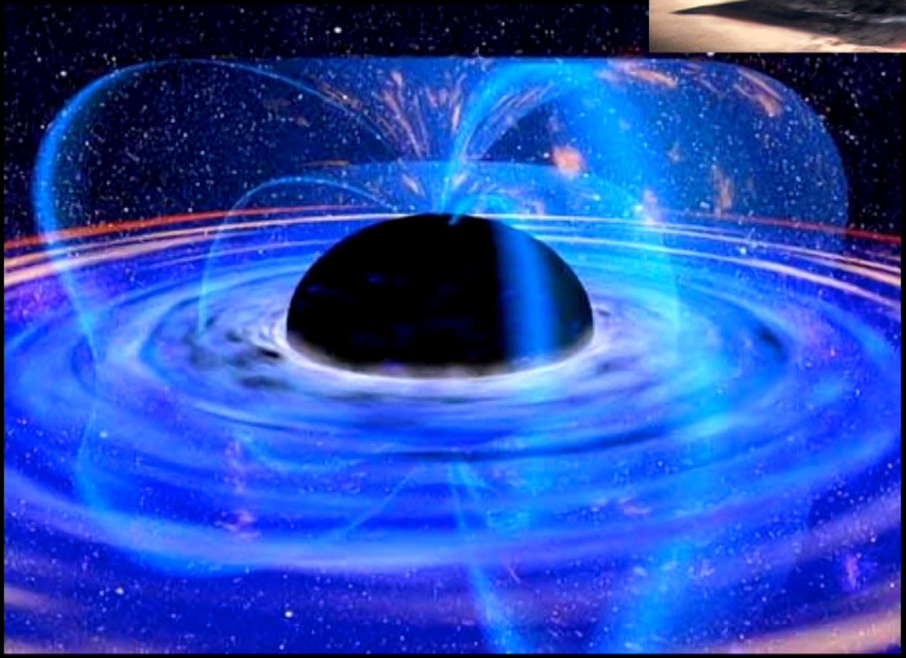
Entanglement in a Stellar Collapse

Once upon a time...

There was... NADA $\Psi_0 = |0\rangle$

But then...

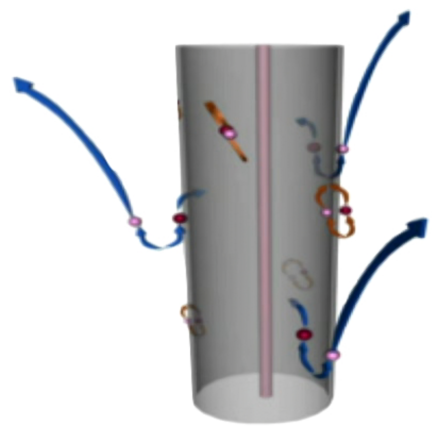
What happened to the field!?



Entanglement in a Stellar Collapse

Vacuum in the far past evolves into two mode squeezed state
between infalling and outgoing modes in the far future

$$\mathrm{Tr}_{\mathrm{hor}}\left(|0\rangle\langle 0|\right) = \bigotimes_{\omega} \frac{1}{\cosh^2 r} \sum \tanh^{2n} r_\omega \, |n_\omega\rangle_{\mathrm{out}} \langle n_\omega|_{\mathrm{out}}$$



We only see the modes that reach the future!

Black hole Information loss problem

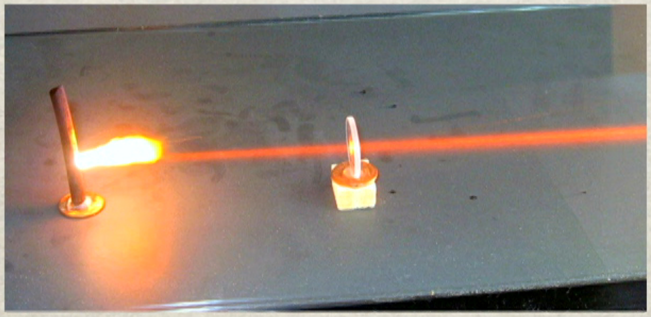
If we believe in quantum theory, information cannot be lost…

Black hole Information loss problem

If we believe in quantum theory, information cannot be lost…

After corrections, the outflow may not be entirely thermal…

Like when a piece of charcoal burns

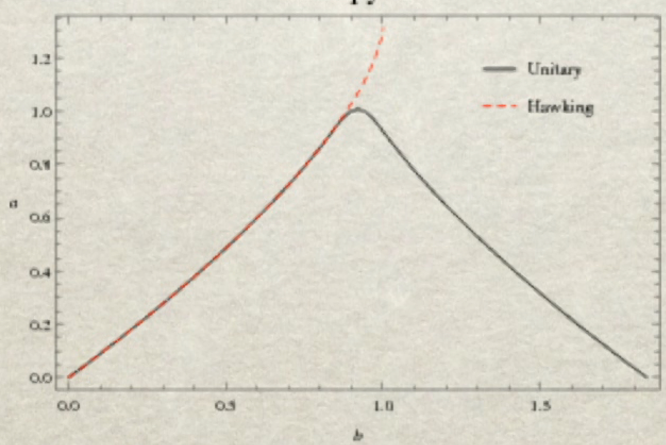


Black holes Information loss problem

Page Hypothesis:

Entanglement between radiation emitted at different times in the black hole life!

Entropy law



Page time

Black holes Information loss problem

So… The outflow is not entirely thermal…

Hold on!! that's potentially even worse!!

Black hole Information Paradox

A: Radiation emitted after Page Time

B: Infalling Radiation

C: Radiation emitted before Page Time

Entropy subadditivity:

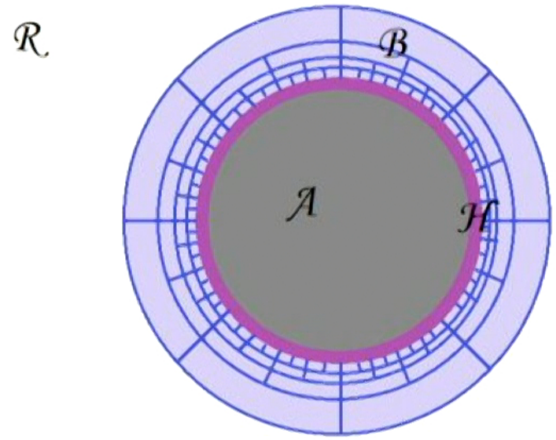
$$S(\rho_{\mathrm{ABC}}) + S(\rho_{\mathrm{A}}) \leq S(\rho_{\mathrm{AB}}) + S(\rho_{\mathrm{AC}})$$

Entanglement subadditivity:

$$\mathcal{E}(A,B) + \mathcal{E}(A,C) \leq \mathcal{E}(A,BC)$$

HAWKING RADIATION

What about monogamy?



Susskind's Black Hole complementary
The Harlow-Hayden Conjecture

Black hole Information Paradox

Possible Solution: Firewalls!

Almheiri, Ahmed; Marolf, Donald; Polchinski, Joseph; Sully, James. Journal of High Energy Physics 2013 (2).

Black hole Information Paradox (Firewalls)

What-if scenario:

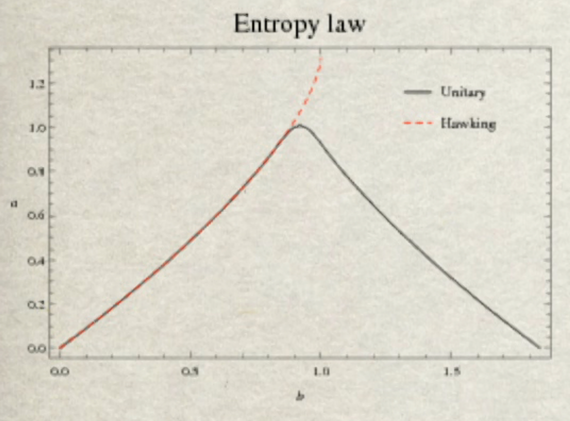
Somehow dynamics is such that it destroys the correlations between "in" and "out" regions

Entanglement subadditivity:

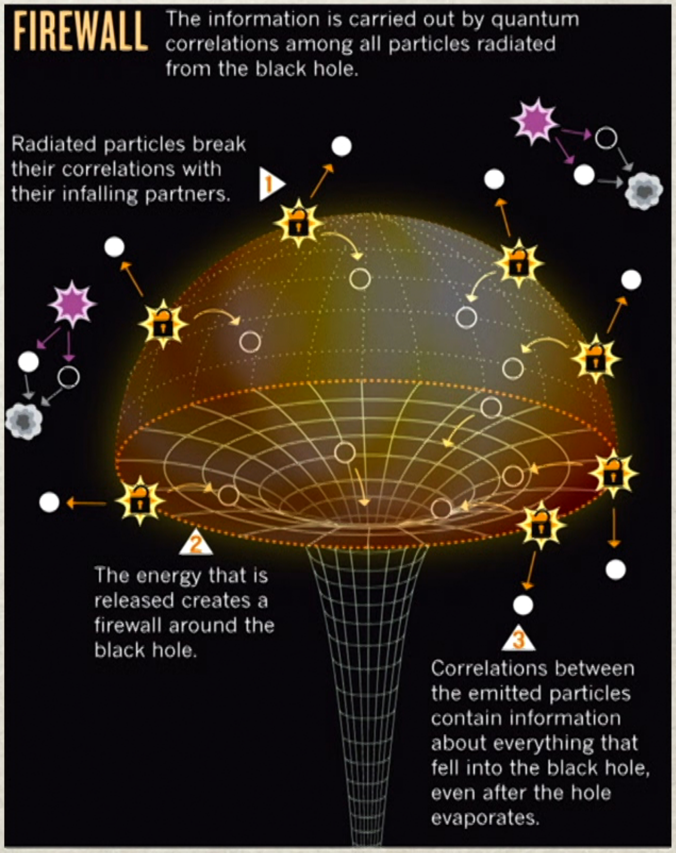
$$\mathcal{E}(A,B) + \mathcal{E}(A,C) \leq \mathcal{E}(A,BC)$$

Make this zero

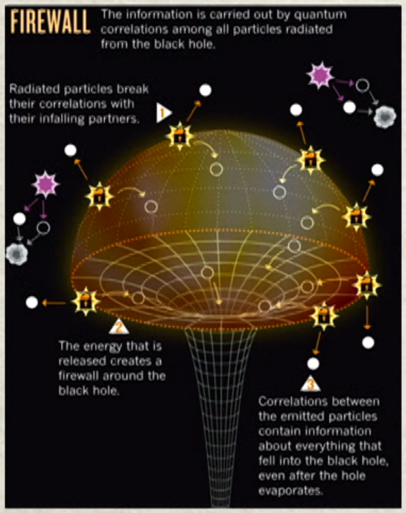
Black hole Information Paradox (Firewalls)



“Charcoalization” of the BH



Are Firewalls really '*Monsters*'?



Divergences in the stress-energy tensor: Violence at the horizon

PRL **115**, 031301 (2015) PHYSICAL REVIEW LETTERS week ending 17 JULY 2015

(1 + 1)D Calculation Provides Evidence that Quantum Entanglement Survives a Firewall

Eduardo Martín-Martínez[1,2,3] and Jorma Louko[4]
[1]*Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada*
[2]*Department of Applied Mathematics, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada*
[3]*Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada*
[4]*School of Mathematical Sciences, University of Nottingham, Nottingham NG7 2RD, United Kingdom*
(Received 26 February 2015; published 14 July 2015)

We analyze how preexisting entanglement between two Unruh-DeWitt particle detectors evolves when one of the detectors falls through a Rindler firewall in (1 + 1)-dimensional Minkowski space. The firewall effect is minor and does not wash out the detector-detector entanglement, in some regimes even preserving the entanglement better than Minkowski vacuum. The absence of cataclysmic events should continue to hold for young black hole firewalls. A firewall's prospective ability to resolve the information paradox must hence hinge on its detailed gravitational structure, presently poorly understood.

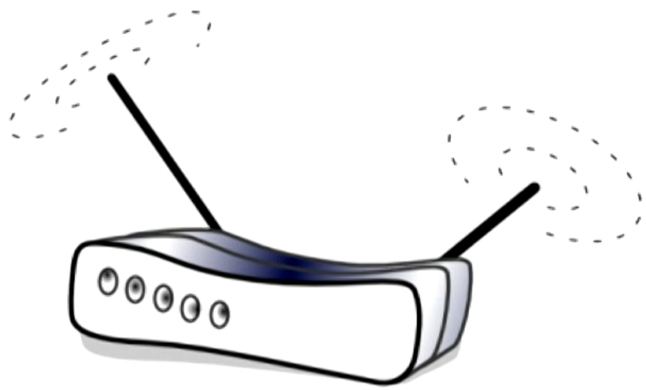
DOI: 10.1103/PhysRevLett.115.031301 PACS numbers: 04.70.Dy, 04.60.-m, 04.62.+v

The two results we will talk about

Vacuum Entanglement Harvesting and Farming

Quantum Collect Calling

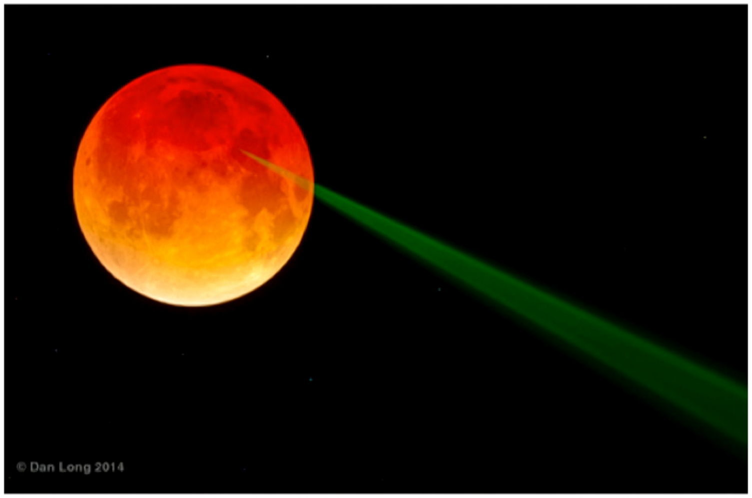
Communication through massless fields



General properties of wireless communication

Communication through the EM field

Communcation mediated by ‘real’ energy-carrying quanta



An emitter emits photons. A receiver captures photons.

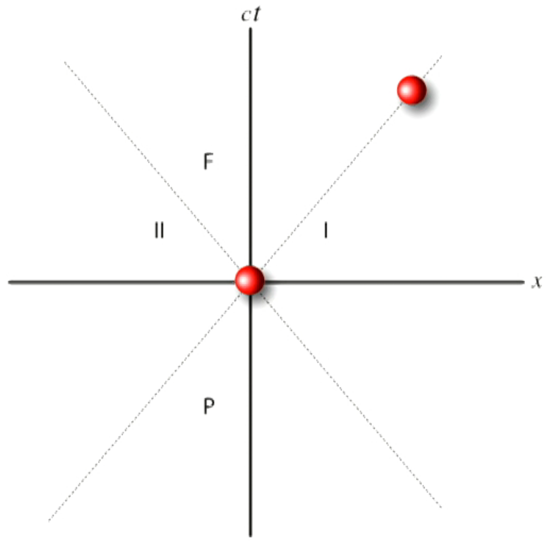
Communication through the EM field

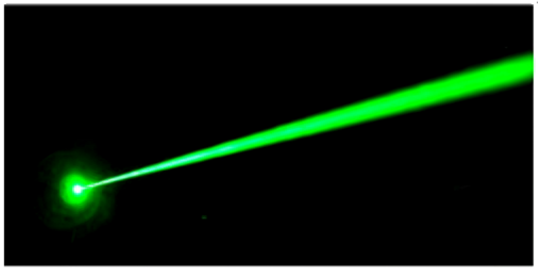
Information flow carried by (an average) energy flow

Information reaches you when energy reaches you

Communication through the EM field

Communication is only possible at the speed of light (in vacuum)



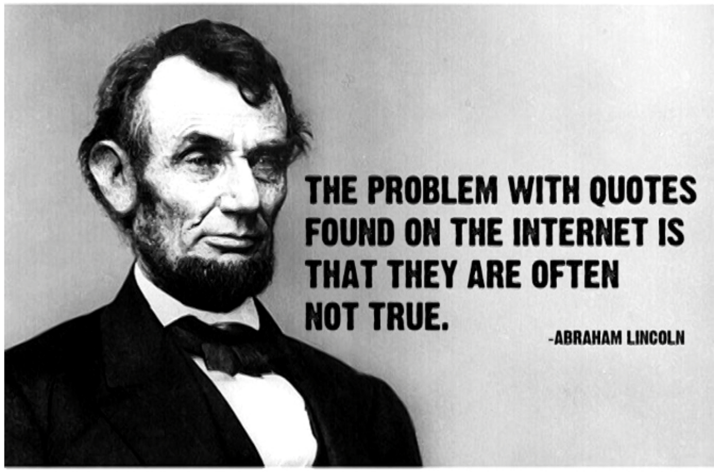


If you miss the beam, you miss the message

Communication through massless fields

Communication through a masses fields in the vacuum

- -Only At the speed of light.
- -Through the exchange of real quanta
- -Information flow carried by energy flow.
- -Miss the beam, miss the message



Communication through massless fields

Communication through a massless fields in vacuum

-Information propagates arbitrarily slow even for massless field.

-Recover the message even if the beam is missed.

-Information flow not supported by real quanta (photons) flow.

-Information flow in absence of energy flow.

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search

Home » Physics » Quantum Physics » March 31, 2015

Photon 'afterglow' could transmit information without transmitting energy

March 31, 2015 by Lisa Zyga feature

(Phys.org)—Physicists have theoretically shown that it is possible to transmit information from one location to another without transmitting energy. Instead of using real photons, which always carry energy, the technique uses a small, newly predicted quantum afterglow of virtual photons that do not need to carry energy. Although no energy is transmitted, the receiver must provide the energy needed to detect the incoming signal—similar to the

Mathematical Methods: Beyond the Strong Huygens Principle

Subtleties in the behaviour of the solutions of certain PDEs:
The strong Huygens principle

The Green's function of the (massless) wave equation in 3+1D Minkowski space has support only on the light cone. Hence, any disturbances propagate strictly along null geodesics (at the speed of light)

Mathematical Methods: Beyond the Strong Huygens Principle

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The strong Huygens principle

The Green's function of the (massless) wave equation in 3+1D Minkowski space has support only on the light cone. Hence, any disturbances propagate strictly along null geodesics (at the speed of light)

Exploitable when emitters are quantum!

TECHNICAL DETAILS

R. H. Jonsson, E. Martin-Martinez, A. Kempf, Phys. Rev. Lett. 114, 110505 (2015)

A. Blasco, L. J. Garay, M. Martin-Benito, E. Martin-Martinez, Phys. Rev. Lett. 114, 141103 (2015)

A. Blasco, L. J. Garay, M. Martin-Benito, E. Martin-Martinez, Phys. Rev. D 93, 024055 (2016)

P. Simidzija, E. Martin-Martinez, Phys. Rev. D 95, 025002 (2017)

See also:

R. H. Jonsson, J. of Phys. A, 44, 445402 (2016)

STRONG **HUYGENS PRINCIPLE**

The radiation Green's function (or equivalently the commutator) of a massless field has support only on the light-cone

$$\Box G(x,x') = -4\pi\delta_4(x,x') \qquad [\Phi(x),\Phi(x')] = \frac{\mathrm{i}}{4\pi}G(x,x')$$

⟶ **Communication** has support only on the **light-cone**

True in 3+1 Flat spacetime

BEYOND THE STRONG **HUYGENS PRINCIPLE**

In general: if there is curvature (unless there is conformal invariance)

⟶ In curved spacetimes, **communication through massless fields** is not confined to the light-cone, but there can be a leakage of information towards the **inside of the light-cone decoupled from energy propagation**.

SPACETIME
GEOMETRY

SPATIALLY **FLAT**, **OPEN** **FRW** SPACETIME 3+1D:

$$ds^2 = a(\eta)^2(-d\eta^2 + dr^2 + r^2 d\Omega^2)$$

η : conformal time

$a(\eta)$: scale factor

t : cosmological time,

$\mathrm{d}t = a(\eta)\mathrm{d}\eta$

units: $\hbar = c = 1$

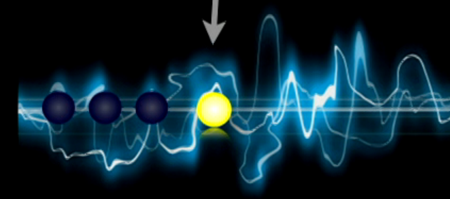
This geometry will be generated by:

a **perfect fluid** with a constant density-to-presure ratio $p = w\rho$

→ the **scale factor** evolves as $a \propto \eta^{\alpha+\frac{1}{2}} \propto t^{\frac{2\alpha+1}{2\alpha+3}}$ with $\alpha = \frac{3-3w}{6w+2}$

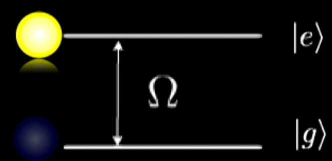
A TEST **SCALAR FIELD** QUANTIZED IN THE **BUNCH-DAVIS VACUUM** WILL BE COUPLED TO THE BACKGROUND GEOMETRY.

ALICE & BOB's
DETECTOR MODEL



Unruh-DeWitt DETECTOR

-Two-level system

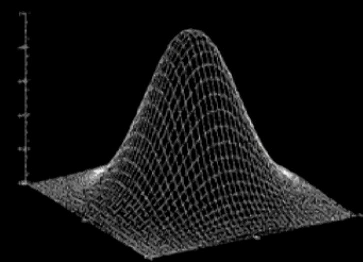


-Energy gap ground-excited states: Ω

-Monopole moment operator: $\mu_\nu(t) = |e_\nu\rangle\langle g_\nu| e^{i\Omega_\nu t} + |g_\nu\rangle\langle e_\nu| e^{-i\Omega_\nu t}$

$\nu = \{A, B\}$

-Spatially smeared: $F(\vec{x}, t) = \frac{1}{\sigma^3\sqrt{\pi^3}} e^{-a(t)^2\vec{x}^2/\sigma^2}$

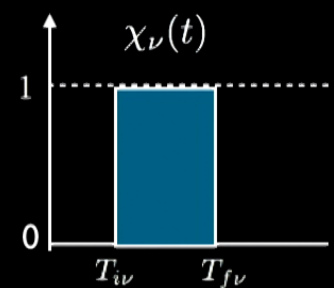


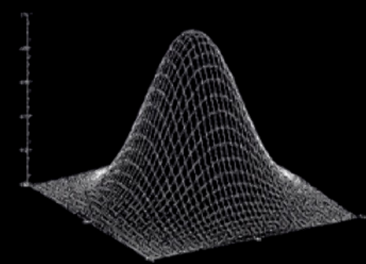
Detectors: $|\psi_\nu\rangle = \alpha_\nu\,|e_\nu\rangle + \beta_\nu\,|g_\nu\rangle$

DETECTOR-FIELD **INTERACTION** HAMILTONIAN

$$H_{I,\nu} = \lambda_\nu \chi_\nu(t) \mu_\nu(t) \int \mathrm{d}^3\boldsymbol{x}\; a(t)^3 F[\boldsymbol{x} - \boldsymbol{x}_\nu(t), t] \Phi[\boldsymbol{x}, \eta(t)]$$

- Coupling strength: λ_ν
- Switching function: $\chi_\nu(t)$
- Monopole moment: $\mu_\nu(t)$
- Scale factor: $a(t)$
- Smearing function: $F[\boldsymbol{x} - \boldsymbol{x}_\nu(t), t]$
- Detector's trajectory: $\boldsymbol{x}_\nu(t)$, $\eta(t)$



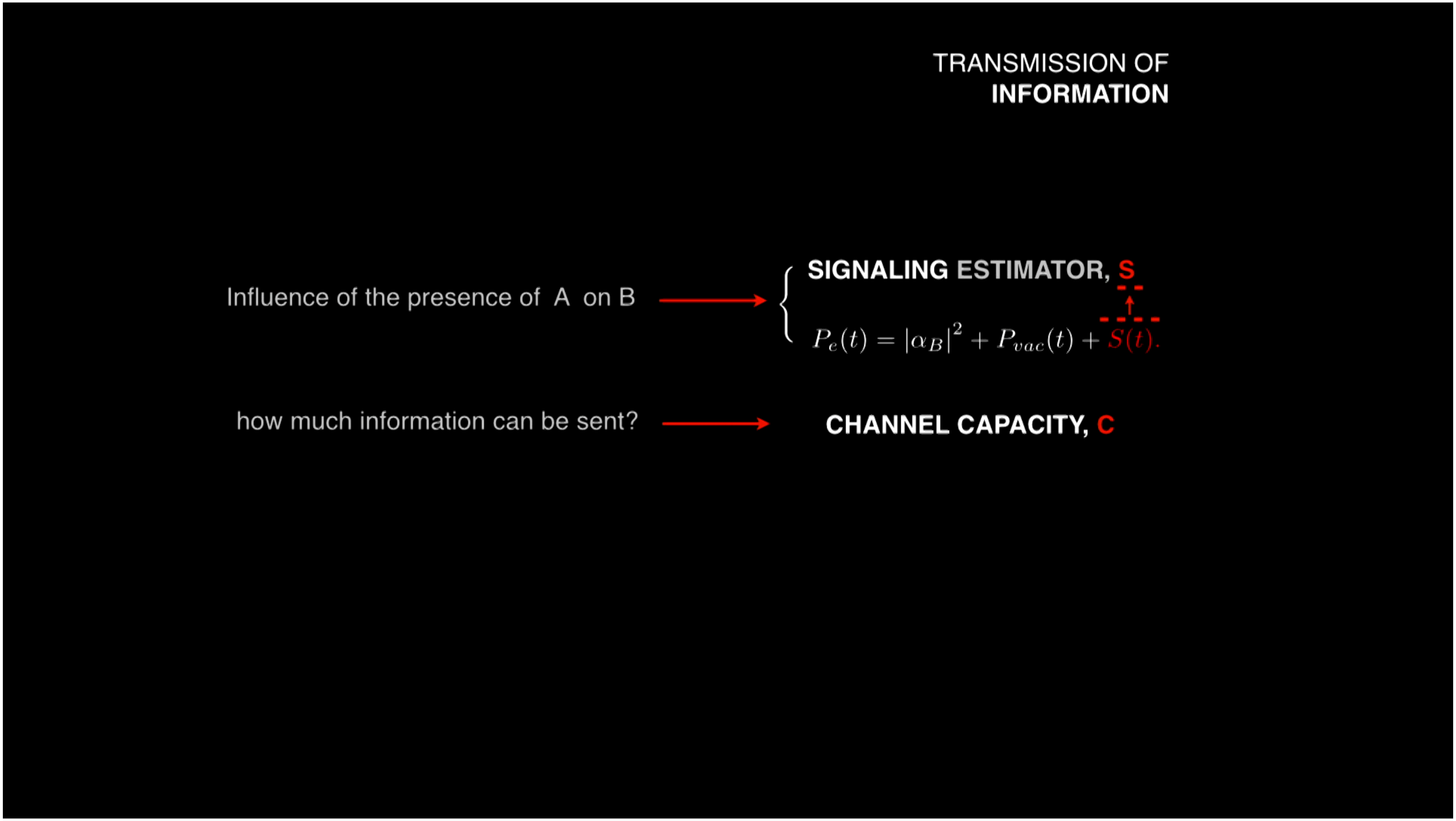


Total Interaction Hamiltonian: $H_I = H_{I,A} + H_{I,B}$

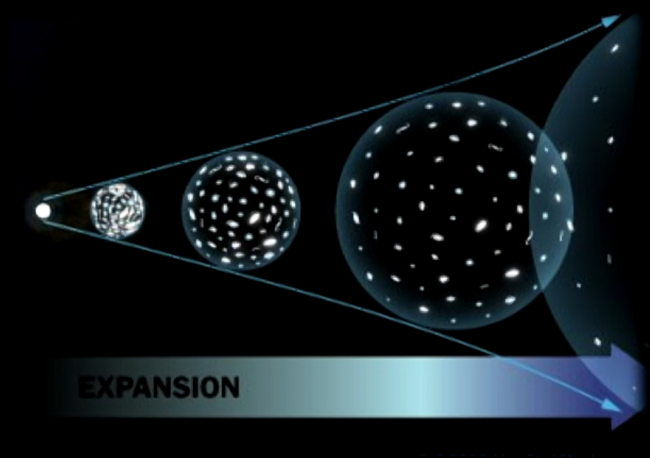
TRANSMISSION OF
INFORMATION

Influence of the presence of A on B → **SIGNALING ESTIMATOR, S**

how much information can be sent? → **CHANNEL CAPACITY, C**


TRANSMISSION OF
INFORMATION
Influence of the presence of A on B
SIGNALING ESTIMATOR, S
$P_e(t) = |\alpha_B|^2 + P_{vac}(t) + S(t).$
how much information can be sent?
CHANNEL CAPACITY, C

THE **BIG BANG** Setting



BIG BANG CASE, ST. COSMOLOGICAL MODEL: GENERAL RELATIVITY

SCALAR FIELD:
COUPLING TO GRAVITY

KLEIN-GORDON EQUATION

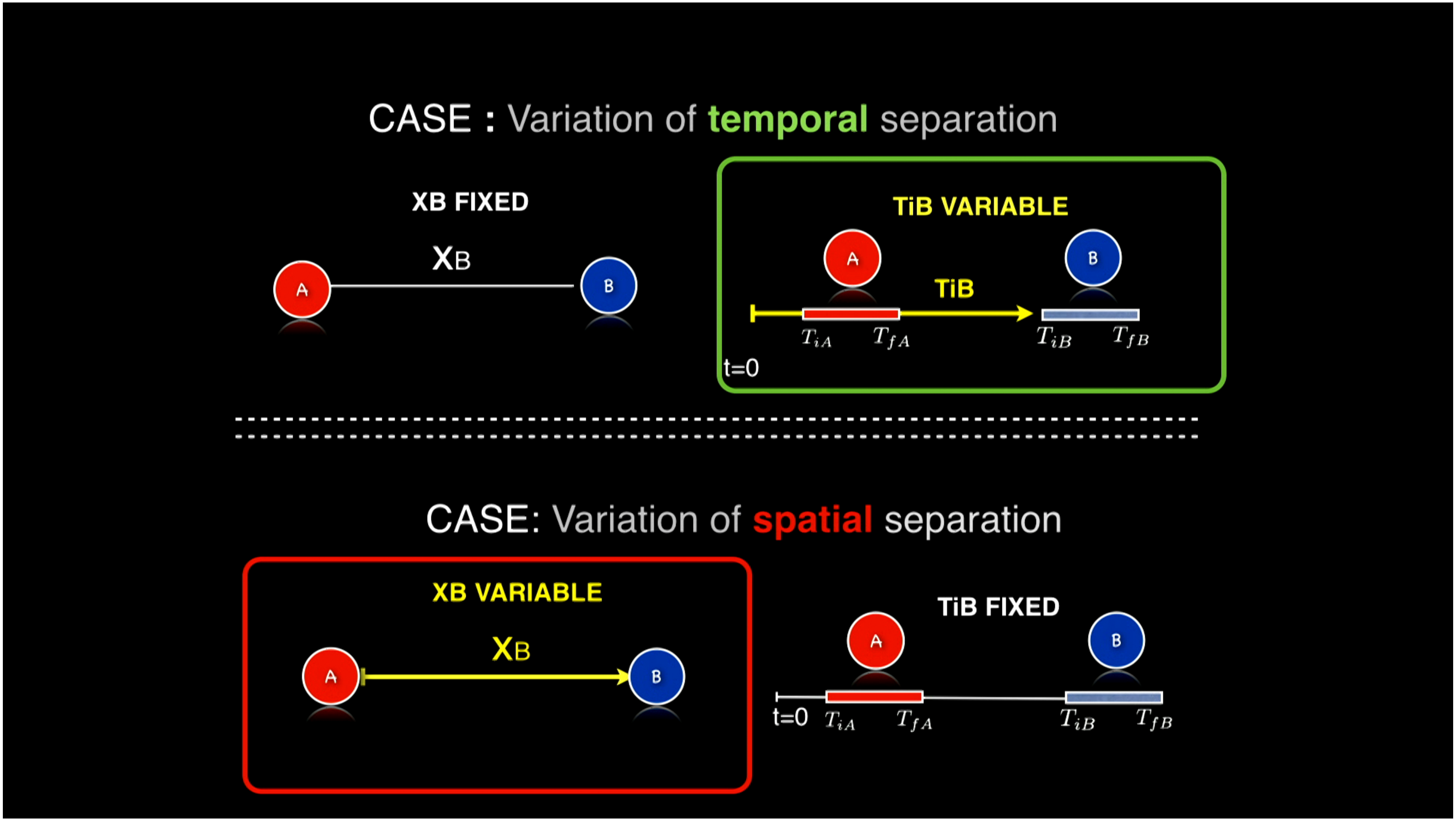
$$(\Box - m^2 + \xi R)\phi = 0 \qquad \Box = \frac{1}{\sqrt{|g|}}\partial_\mu\left(\sqrt{|g|}g^{\mu\nu}\partial_\nu\right)$$

CONFORMAL COUPLING

$$\xi = \frac{1}{6}$$ Yields Conformally Invariant Action

MINIMAL COUPLING

$$\xi = 0$$ Gives good predictions (Cosmology, etc..)


CASE : Variation of temporal separation
XB FIXED
XB
A
B
TiB VARIABLE
A
B
TiB
T_{iA} T_{fA} T_{iB} T_{fB}
t=0
CASE: Variation of spatial separation
XB VARIABLE
XB
A
B
TiB FIXED
A
B
t=0 T_{iA} T_{fA} T_{iB} T_{fB}

IS INFORMATION
TRANSMITED?

Influence of the presence of A on B →

SIGNALING ESTIMATOR, S

$$P_e(t) = |\alpha_B|^2 + P_{vac}(t) + S(t).$$

SIGNALING
ESTIMATOR, S

CONFORMAL COUPLING

$$S = \lambda_A \lambda_B S_2 + \mathcal{O}(\lambda_\nu^4)$$

$$S_2 = 4 \int a(t)^3 \, \mathrm{d}^3\boldsymbol{x} \, \mathrm{d}t \int a(t')^3 \, \mathrm{d}^3\boldsymbol{x}' \, \mathrm{d}t' \chi_A(t)\chi_B(t')\mathrm{Re}(\alpha_A^* \beta_A) F(\boldsymbol{x} - \boldsymbol{x}_A, t)$$
$$\times F(\boldsymbol{x}' - \boldsymbol{x}_B, t)\mathrm{Re}\left(\alpha_B^* \beta_B [\phi(\boldsymbol{x}, t), \phi(\boldsymbol{x}', t')]\right)$$

$$[\phi(\boldsymbol{x}, t), \phi(\boldsymbol{x}', t')] = \frac{\mathrm{i}}{4\pi}\left[\frac{\delta(\Delta\eta + |\boldsymbol{x} - \boldsymbol{x}'|) - \delta(\Delta\eta - |\boldsymbol{x} - \boldsymbol{x}'|)}{a(t)a(t')|\boldsymbol{x} - \boldsymbol{x}'|}\right]$$

$$\Delta\eta = \eta(t) - \eta(t')$$

$$|\psi_{0,\nu}\rangle = \alpha_\nu |e_\nu\rangle + \beta_\nu |g_\nu\rangle$$

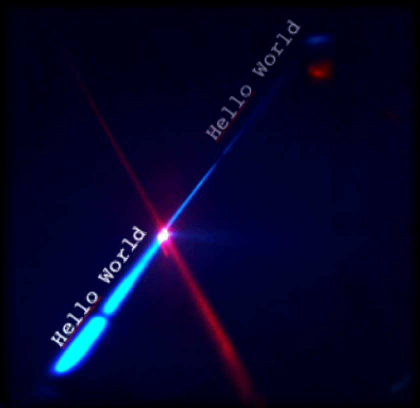
CHANNEL
CAPACITY

To obtain a lower bound to the channel capacity, we use a simple
COMMUNICATION PROTOCOL:

- **Alice** encodes “**1**" by coupling her detector A to the field, and “**0**" by not coupling it.

- Later **Bob** switches on B and measures its energy. If B is excited, Bob interprets a “**1**", and a “**0**" otherwise.

$$C \simeq \lambda_A^2 \lambda_B^2 \frac{2}{\ln 2} \left(\frac{S_2}{4|\alpha_B||\beta_B|} \right)^2 + \mathcal{O}(\lambda_\nu^6)$$



(noisy asymmetric binary channel)

Robert H. Jonsson, Eduardo Martín-Martinez, and Achim Kempf.
Quantum Collect Calling.
Phys. Rev. Lett. 114, 110505 (2015).

CONFORMAL COUPLING

support on the light cone

$$[\phi(\boldsymbol{x}, t), \phi(\boldsymbol{x}', t')] = \frac{\mathrm{i}}{4\pi}\left[\frac{\delta(\Delta\eta + |\boldsymbol{x} - \boldsymbol{x}'|) - \delta(\Delta\eta - |\boldsymbol{x} - \boldsymbol{x}'|)}{a(t)a(t')|\boldsymbol{x} - \boldsymbol{x}'|}\right]$$

Decay with Spatial separation

Not surprising:

Conformal Symmetry makes it too similar to flat spacetime

SIGNALING
ESTIMATOR, S

$$[\phi(\boldsymbol{x}_A, t_A), \phi(\boldsymbol{x}_B, t_B)] = \mathrm{i}\frac{\theta(\eta(t_B) - \eta(t_A)) - \theta(\eta(t_A) - \eta(t_B))}{(2\pi)^3|\boldsymbol{x} - \boldsymbol{x}'|a(\eta(t_A))a(\eta(t_B))}\int_0^\infty \mathrm{d}k\ k\ \sin(k|\boldsymbol{x} - \boldsymbol{x}'|)\hat{g}(\eta(t_A), \eta(t_B), k)$$

$$\hat{g}(\eta, \eta', k) = \frac{8\pi}{k}\sqrt{\left|\frac{\eta}{\eta'}\right|}\frac{\mathrm{sgn}(\eta')[J_{\alpha-1/2}(k|\eta|)Y_{\alpha-1/2}(k|\eta'|) - Y_{\alpha-1/2}(k|\eta|)J_{\alpha-1/2}(k|\eta'|)]}{Y_{\alpha-1/2}(k|\eta'|)\left[J_{\alpha-3/2}(k|\eta'|) - J_{\alpha+1/2}(k|\eta'|)\right] - J_{\alpha-1/2}(k|\eta'|)\left[Y_{\alpha-3/2}(k|\eta'|) - Y_{\alpha+1/2}(k|\eta\right.}$$

J_α Y_α BESSEL FUNCTIONS

MATTER DOMINATED UNIVERSE $\longrightarrow$ $\alpha = 2$ $\longrightarrow$ $a \propto \eta^2 \propto t^{2/3}$

$$J_{2-1/2}(k|\eta|) = \sqrt{2/\pi}\frac{1}{\sqrt{k|\eta|}}\left[-\cos(k\eta) + \frac{\sin(k\eta)}{k\eta}\right]$$

$$Y_{2-1/2}(k|\eta|) = \sqrt{2/\pi}\frac{\mathrm{sgn}(\eta)}{\sqrt{k|\eta|}}\left[-\sin(k\eta) + \frac{\cos(k\eta)}{k\eta}\right]$$

SIGNALING
ESTIMATOR, S

MINIMAL COUPLING

MATTER DOMINATED UNIVERSE ⟶ $\alpha = 2$ ⟶ $a \propto \eta^2 \propto t^{2/3}$

$$[\phi(\boldsymbol{x},t),\phi(\boldsymbol{x}',t')] = \frac{\mathrm{i}}{4\pi}\left[\frac{\delta(\Delta\eta+|\boldsymbol{x}-\boldsymbol{x}'|)-\delta(\Delta\eta-|\boldsymbol{x}-\boldsymbol{x}'|)}{a(t)a(t')|\boldsymbol{x}-\boldsymbol{x}'|}+\frac{\theta(-\Delta\eta-|\boldsymbol{x}-\boldsymbol{x}'|)-\theta(\Delta\eta-|\boldsymbol{x}-\boldsymbol{x}'|)}{a(t)a(t')\eta(t)\eta(t')}\right]$$

SIGNALING ESTIMATOR, S

CONFORMAL COUPLING

support on the light cone

$$[\phi(\boldsymbol{x},t),\phi(\boldsymbol{x}',t')] = \frac{\mathrm{i}}{4\pi}\left[\frac{\delta(\Delta\eta+|\boldsymbol{x}-\boldsymbol{x}'|)-\delta(\Delta\eta-|\boldsymbol{x}-\boldsymbol{x}'|)}{a(t)a(t')|\boldsymbol{x}-\boldsymbol{x}'|}\right]$$

Decay with Spatial separation

VIOLATION OF STRONG HUYGENS PRINCIPLE !!!!

MINIMAL COUPLING

$$[\phi(\boldsymbol{x},t),\phi(\boldsymbol{x}',t')] = \frac{\mathrm{i}}{4\pi}\left[\frac{\delta(\Delta\eta+|\boldsymbol{x}-\boldsymbol{x}'|)-\delta(\Delta\eta-|\boldsymbol{x}-\boldsymbol{x}'|)}{a(t)a(t')|\boldsymbol{x}-\boldsymbol{x}'|}+\frac{\theta(-\Delta\eta-|\boldsymbol{x}-\boldsymbol{x}'|)-\theta(\Delta\eta-|\boldsymbol{x}-\boldsymbol{x}'|)}{a(t)a(t')\eta(t)\eta(t')}\right]$$

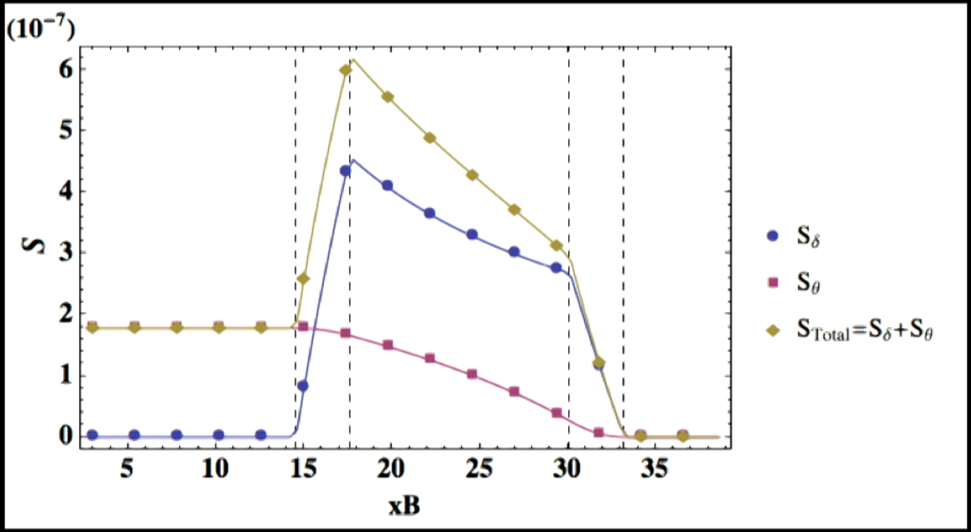
Does NOT decay with Spatial separation

Timelike-leakage

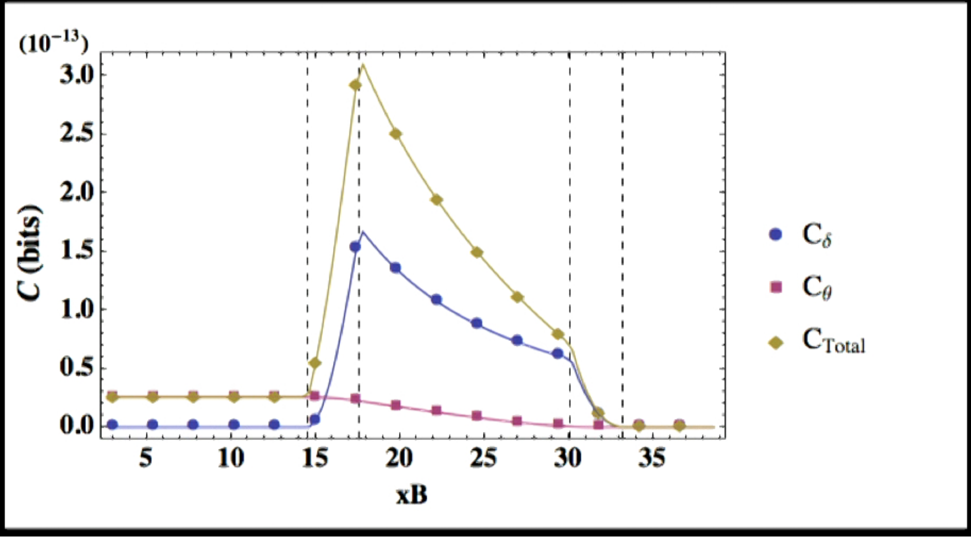
Case:
Variation of **spatial** separation

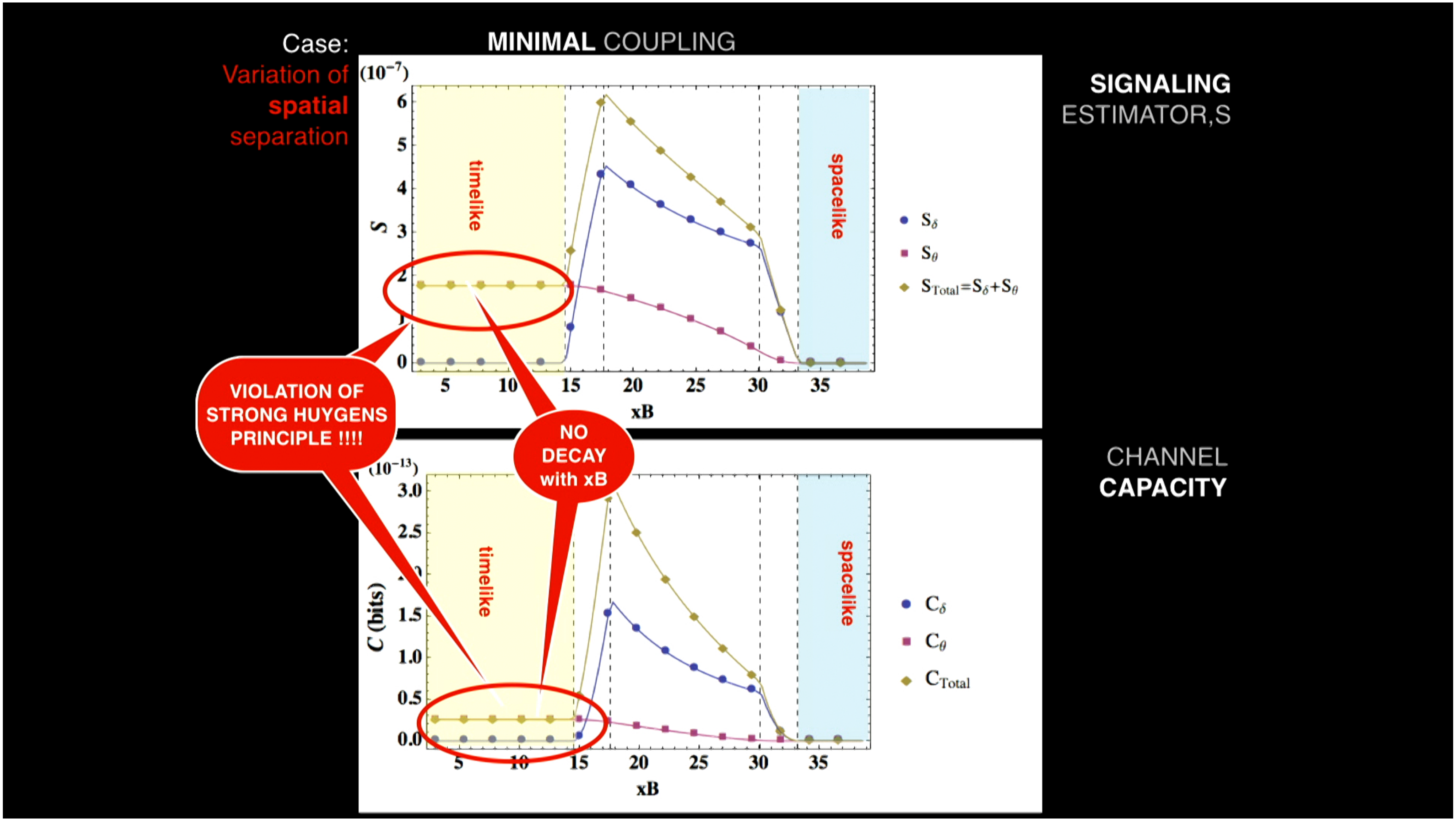
MINIMAL COUPLING

SIGNALING ESTIMATOR,S



CHANNEL **CAPACITY**

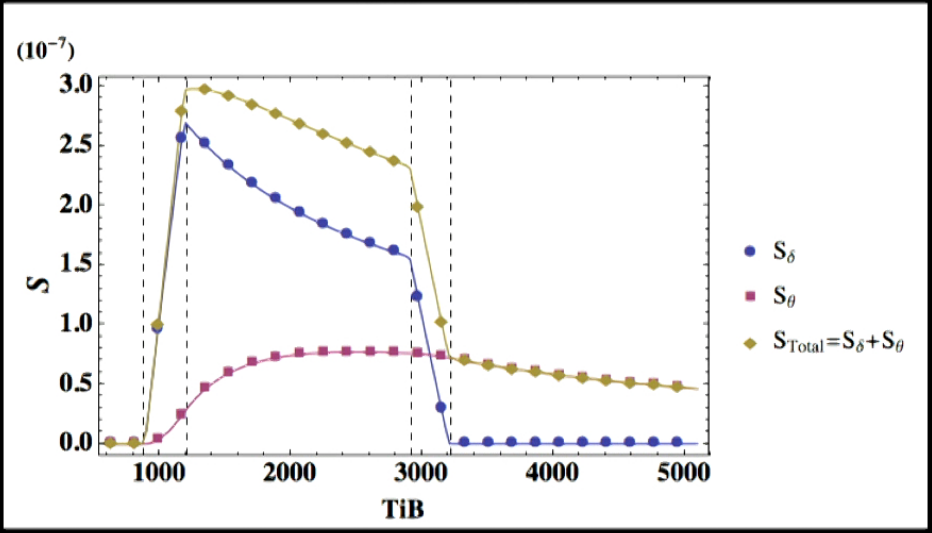



Case:
Variation of spatial separation
MINIMAL COUPLING
SIGNALING ESTIMATOR,S
CHANNEL CAPACITY
VIOLATION OF STRONG HUYGENS PRINCIPLE !!!!
NO DECAY with xB
timelike
spacelike
(10^{-7})
S
xB
S_δ
S_θ
$S_{Total}=S_\delta+S_\theta$
(10^{-13})
C (bits)
C_δ
C_θ
C_{Total}

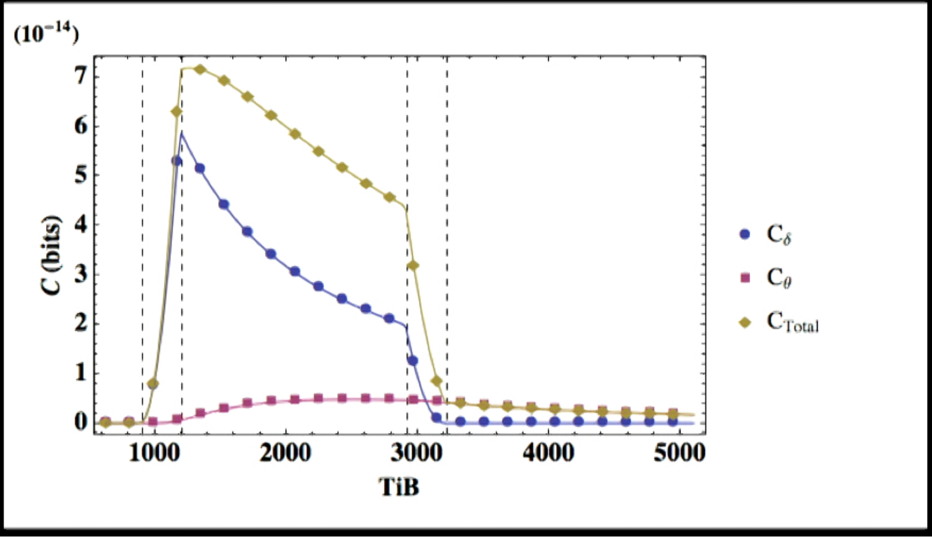
Case:
Variation of **temporal** separation

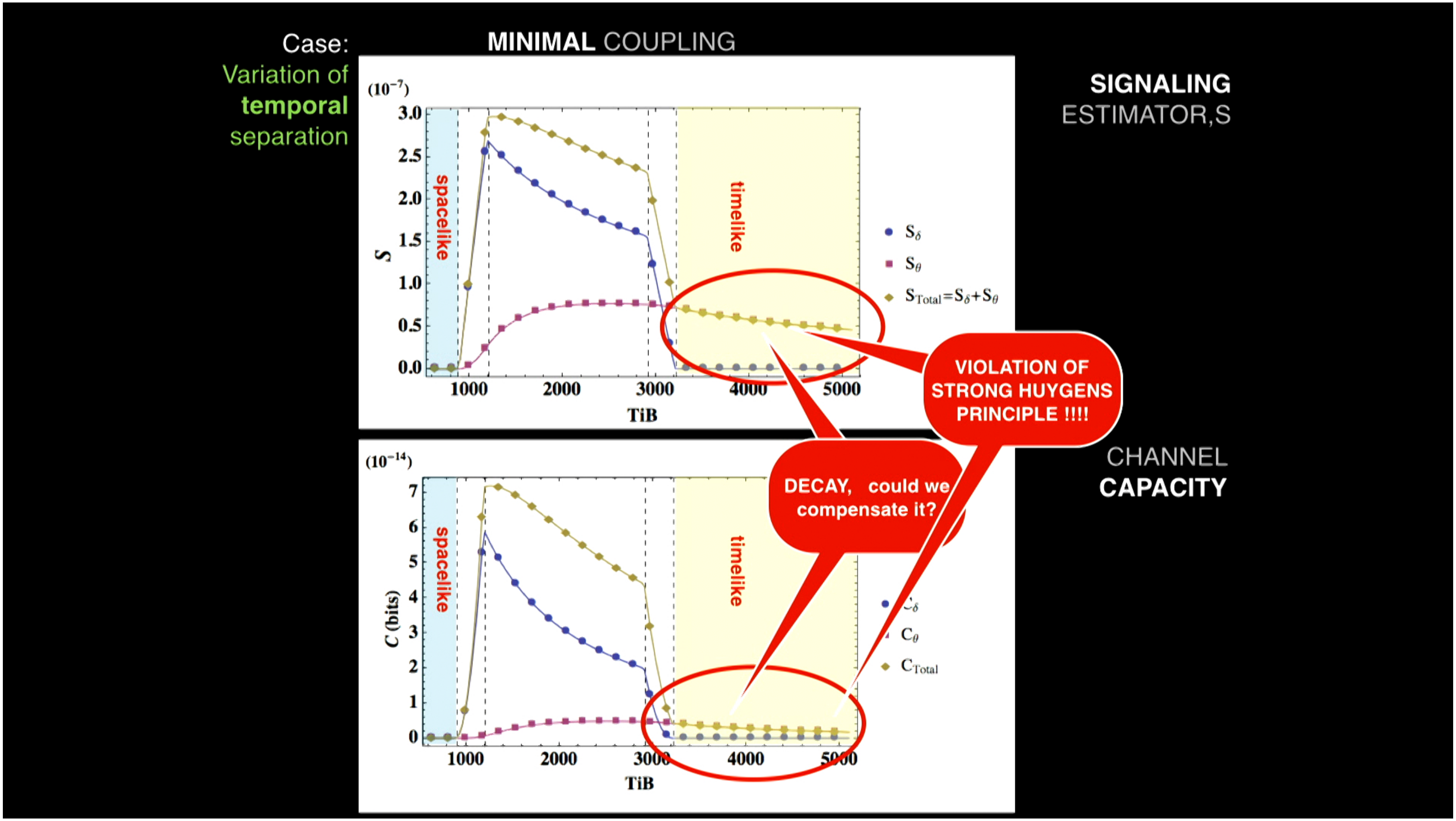
MINIMAL COUPLING

SIGNALING ESTIMATOR,S



CHANNEL **CAPACITY**



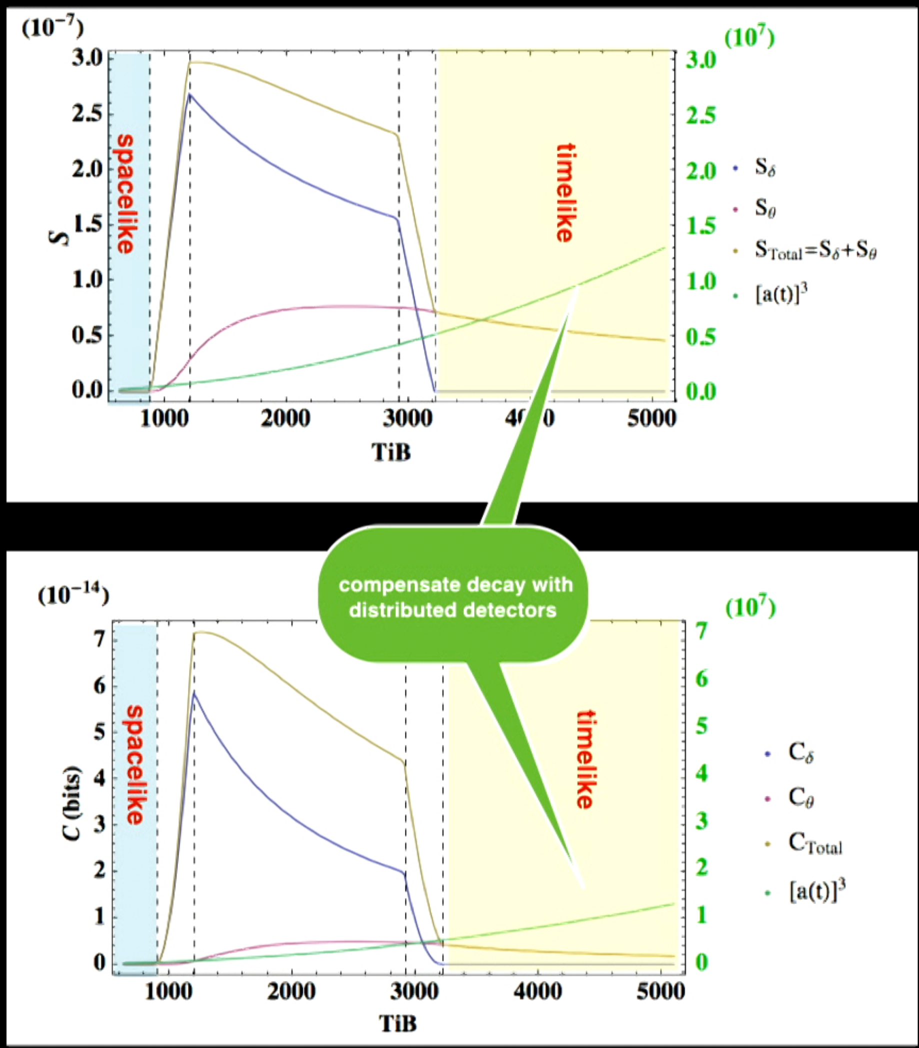


Case:
Variation of
temporal
separation
MINIMAL COUPLING
SIGNALING
ESTIMATOR,S
(10⁻⁷)
S
spacelike
timelike
TiB
Sδ
Sθ
STotal=Sδ+Sθ
VIOLATION OF STRONG HUYGENS PRINCIPLE !!!!
DECAY, could we compensate it?
CHANNEL
CAPACITY
(10⁻¹⁴)
C (bits)
Cθ
CTotal

Case:
Variation of **temporal** separation

MINIMAL COUPLING

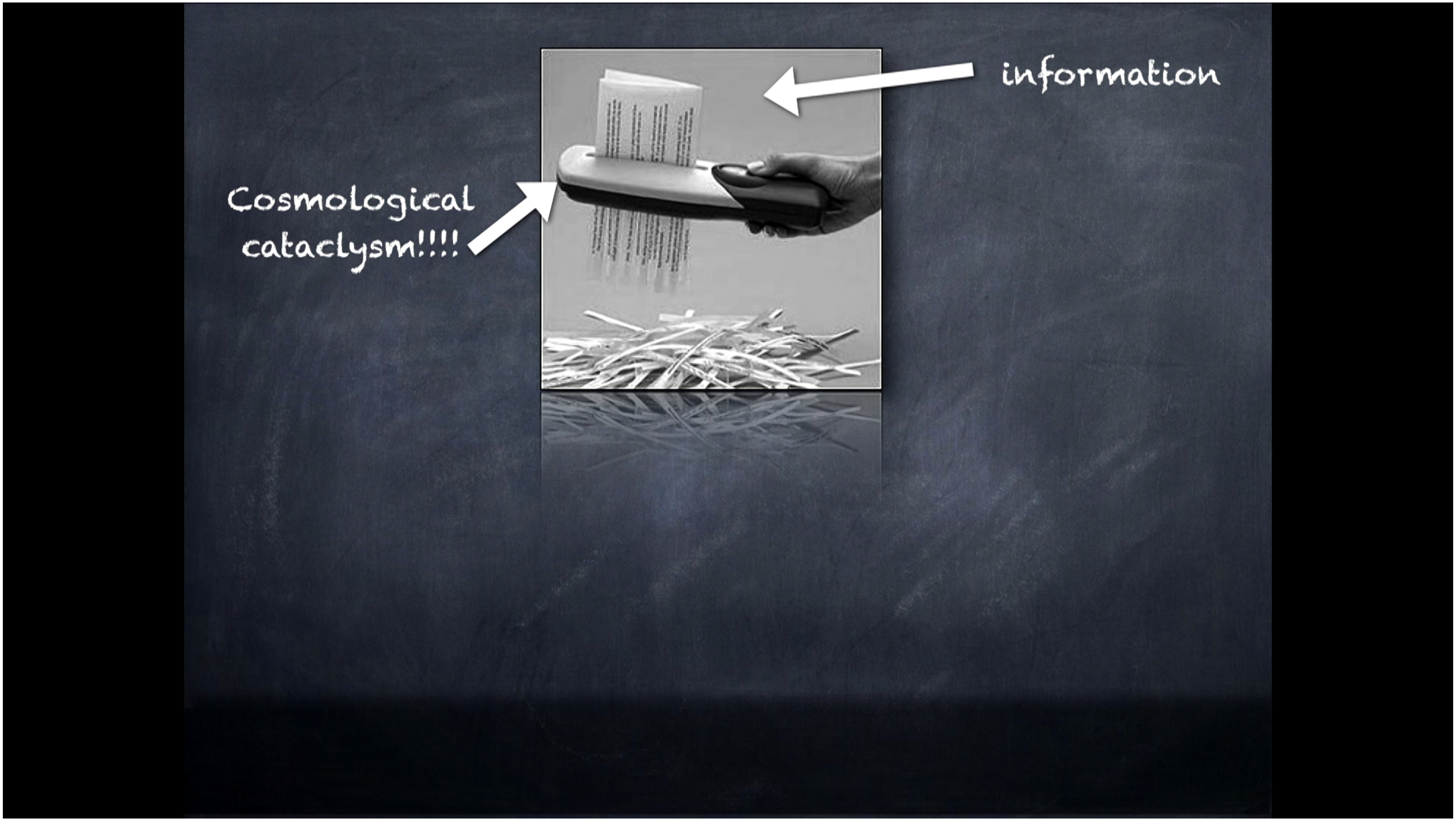
SIGNALING ESTIMATOR,S



CHANNEL **CAPACITY**

Exponential Expansion (deSitter): No decay in time!

P. Simidzija, E. Martin-Martinez, Phys. Rev. D 95, 025002 (2017)

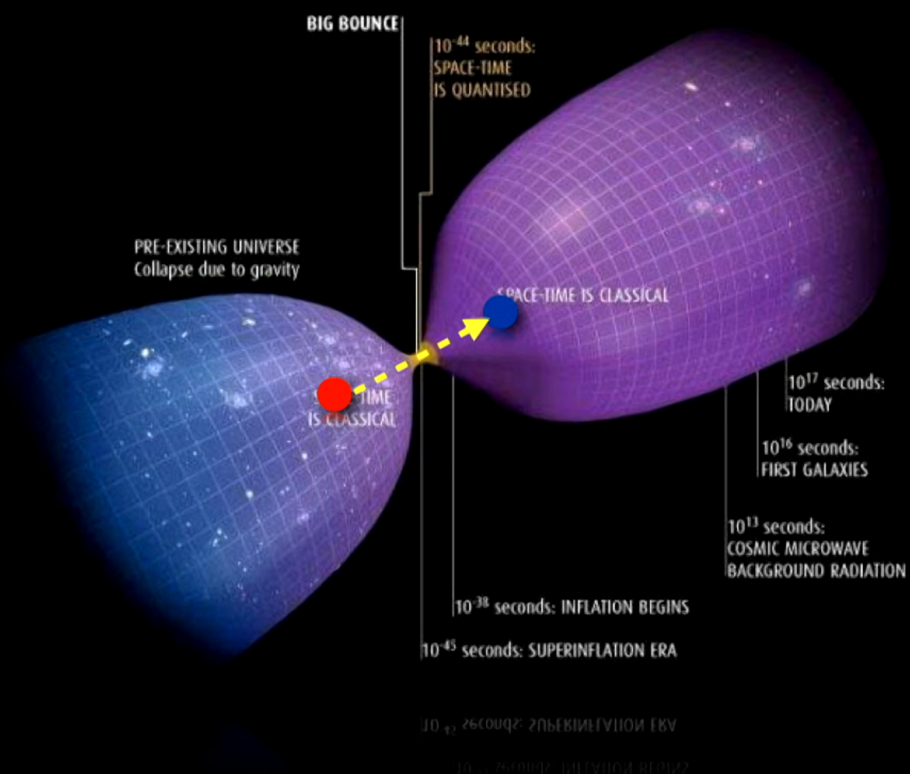

information
Cosmological
cataclysm!!!!

Setting
QUANTUM
BOUNCE

EXAMPLE:
LOOP QUANTUM COSMOLOGY

- Replaces the Big Bang by a Big Bounce

- Bridge between two large classical universes: a contracting and an expanding cosmological phase



Martin Bojowald. Loop quantum cosmology. Living Rev.Rel., 11:4, 2008.

Setting
QUANTUM
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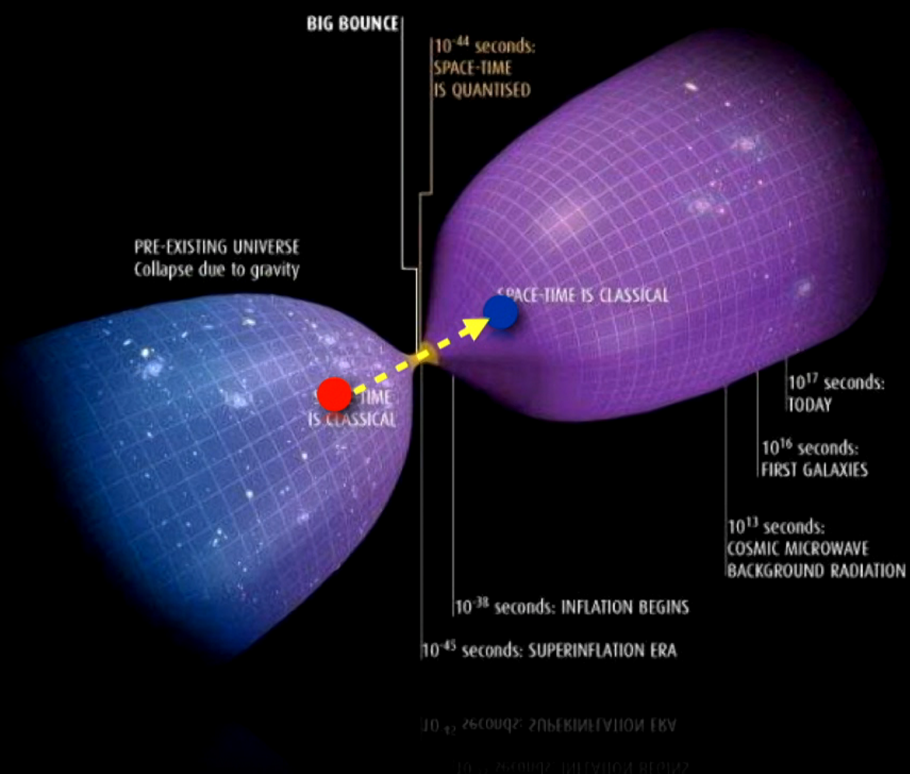

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Setting
QUANTUM
BOUNCE

Atoms (or any complex system) will not survive a quantum bounce

Imagine an ancient (pre-bounce) and very advanced civilization

What would you do if you wanted your legacy to survive?

Encode the information in the quantum field: detectors and field get entangled.