Chapter 5: Locality, Causality, and No-Signaling

Quantum energy teleportation sounds dangerous at first.

Alice measures one region of a quantum system. Bob, far away, uses Alice’s measurement result to extract energy from his own region. If we hear only that sentence, it is natural to wonder:

> Has energy traveled faster than light? > Has Alice sent a signal to Bob instantly? > Has quantum mechanics violated relativity?

The answer is no.

QET is subtle, but it is not a loophole in causality. It is a protocol that combines three ingredients:

1. Local quantum operations, performed only on chosen parts of a system.
2. Pre-existing quantum correlations, especially ground-state entanglement.
3. Ordinary classical communication, which cannot travel faster than allowed by relativity.

The purpose of this chapter is to make those constraints precise. We will learn what “local” means in a many-body quantum system, why local measurements cannot by themselves transmit messages, how classical communication enters QET, and how Lieb-Robinson bounds provide an effective speed limit in lattice systems.

These ideas are part of the standard language of quantum information and relativistic quantum theory (Nielsen and Chuang, 2010; Peres and Terno, 2004). They are also essential for understanding why Hotta’s QET protocol is physically consistent rather than paradoxical (Hotta, 2009).

5.1 Why Locality Matters in QET

A physical operation is called local when it acts only on a limited part of a larger system.

For example, suppose we have a spin chain:

$$1 - 2 - 3 - 4 - 5.$$

Alice controls spin 1. Bob controls spin 5. The full Hilbert space is

$$\mathcal{H} = \mathcal{H}_1 \otimes \mathcal{H}_2 \otimes \mathcal{H}_3 \otimes \mathcal{H}_4 \otimes \mathcal{H}_5.$$

An operation on Alice's spin has the form

$$\hat{A}_1 \otimes I_2 \otimes I_3 \otimes I_4 \otimes I_5.$$

Here I_j is the identity operator on spin j. It means "do nothing to that spin."

Similarly, an operation on Bob's spin has the form

$$I_1 \otimes I_2 \otimes I_3 \otimes I_4 \otimes \hat{B}_5.$$

These two operations act on different tensor factors. Because of that, they commute:

$$[\hat{A}_1 \otimes I_{2345}, I_{1234} \otimes \hat{B}_5] = 0.$$

This simple algebraic fact is the first mathematical expression of locality.

It does not mean Alice and Bob are uncorrelated. The state of the whole chain may be entangled. A local operation on Alice's spin can change the global state. But it cannot directly apply a force, pulse, or unitary operation to Bob's spin.

That distinction is central:

> Local operations may change global correlations, but they do not become remote physical actions.

5.2 Local Observables

An observable is a measurable physical quantity represented by a Hermitian operator. A local observable is an observable associated with one region of a larger system.

Suppose Alice's region is A, Bob's region is B, and the rest of the system is R. The full Hilbert space is

$$\mathcal{H} = \mathcal{H}_A \otimes \mathcal{H}_R \otimes \mathcal{H}_B.$$

A local observable measured by Alice has the form

$$\hat{O}_A \otimes I_R \otimes I_B.$$

A local observable measured by Bob has the form

$$I_A \otimes I_R \otimes \hat{O}_B.$$

If the system is in a density matrix ρ, Bob's expectation value for hatO(B) is

$$\langle \hat{O}_B \rangle = \mathrm{Tr}\left[\rho\left(I_A \otimes I_R \otimes \hat{O}_B\right)\right].$$

Equivalently, Bob can use his reduced density matrix

$$\rho_B = \mathrm{Tr}_{AR}(\rho),$$

where Tr(AR) means "trace out everything except Bob's region." Then

$$\langle \hat{O}_B \rangle = \mathrm{Tr}_B(\rho_B \hat{O}_B).$$

This equation tells us something important:

> Everything Bob can learn by measurements in his own region is contained in ρ(B).

So if Alice does something far away, and Bob's reduced density matrix ρ(B) does not change, then Bob cannot detect Alice's action by local measurements alone.

This is the mathematical heart of no-signaling.

5.3 Local Operations

A quantum operation is a mathematically allowed transformation of a quantum state. In quantum information theory, general physical operations are often represented by completely positive trace-preserving maps, abbreviated CPTP maps (Nielsen and Chuang, 2010).

Let us unpack that phrase.

A map □ takes density matrices to density matrices:

$$\rho \mapsto \mathcal{E}(\rho).$$

It is trace-preserving if probabilities still add to one:

$$\mathrm{Tr}[\mathcal{E}(\rho)] = \mathrm{Tr}(\rho) = 1.$$

It is positive if it maps valid density matrices to valid density matrices. It is completely positive if it remains positive even when the system is entangled with another system. This extra condition is needed because real quantum systems are often parts of larger composite systems.

A common representation of a CPTP map is the Kraus representation:

$$\mathcal{E}(\rho) = \sum_{\mu} K_{\mu} \rho K_{\mu}^{\dagger},$$

with the completeness condition

$$\sum_{\mu} K_{\mu}^{\dagger} K_{\mu} = I.$$

The operators Kμ are called Kraus operators.

If Alice performs a local operation, her Kraus operators act only on □(A). On the full system, they look like

$$K_{\mu}^{A} \otimes I_{RB}.$$

Thus Alice’s local operation is

$$\rho \mapsto \rho' = \sum_{\mu} (K_\mu^A \otimes I_{RB}) \rho (K_\mu^{A\dagger} \otimes I_{RB}).$$

This includes many physical processes:

- Alice measuring a spin.
- Alice applying a local unitary pulse.
- Alice coupling her region to a local measuring device.
- Alice performing a noisy operation on her subsystem.

The word “local” does not mean “unimportant.” A local operation can strongly disturb the global state if the original state is entangled. But locality limits what can be affected in an operationally usable way.

5.4 Classical Communication

A classical message is ordinary information encoded in classical variables, such as bits:

$$0, 1, 00, 01, 10, 11, \dots$$

In QET, Alice’s measurement has possible outcomes, often denoted by μ. For example, Alice may measure a qubit and obtain

$$\mu = +1$$

or

$$\mu = -1.$$

She then sends μ to Bob through an ordinary classical channel.

That channel could be:

- an electrical signal,
- a laser pulse,
- a microwave signal,

- a radio transmission,
- a stored digital message delivered later.

The important point is that classical communication is constrained by ordinary causality. In relativistic physics, no usable signal can travel faster than light in vacuum (Peres and Terno, 2004). Therefore Bob cannot know Alice's outcome until the message has had enough time to reach him.

If Alice and Bob are separated by a distance L, then a light-speed message takes at least

$$t_{\text{message}} \geq \frac{L}{c},$$

where c is the speed of light.

QET never removes this waiting time. Bob's conditional operation depends on Alice's message, so Bob cannot implement the correct conditional operation before receiving it.

This is why QET is not faster-than-light energy delivery.

5.5 LOCC: Local Operations and Classical Communication

The phrase LOCC means local operations and classical communication. It is a central concept in quantum information theory (Nielsen and Chuang, 2010).

An LOCC protocol allows separated parties to do the following:

1. Perform operations on their own local systems.
2. Record classical outcomes.
3. Send classical messages to one another.
4. Choose later local operations based on received messages.

But LOCC does not allow Alice to directly operate on Bob's system, or Bob to directly operate on Alice's system.

QET has exactly this structure:

1. Alice performs a local measurement on region A.
2. The measurement produces an outcome μ.

3. Alice sends μ to Bob by a classical channel.
4. Bob performs a local operation on region B, chosen according to μ.

Symbolically, Bob's operation may be written as

$$U_B(\mu).$$

The dependence on μ is essential. If Bob does not know Alice's outcome, he cannot choose the correct operation.

This is the key difference between two statements:

- "Alice's measurement changes the global quantum state."
- "Alice can send Bob a usable signal instantly."

The first statement is true. The second is false.

5.6 The No-Signaling Theorem

The no-signaling theorem says that a local quantum operation performed by Alice cannot, by itself, change the statistics of measurements performed by Bob at a distant location.

This does not mean entanglement is useless. It means entanglement cannot be used alone to transmit controllable messages faster than allowed by causality.

Let us prove the version needed for QET.

Consider a bipartite system with Hilbert space

$$\mathcal{H}_A \otimes \mathcal{H}_B.$$

Let the joint state be $\rho_{(AB)}$. Bob's reduced state is

$$\rho_B = \mathrm{Tr}_A(\rho_{AB}).$$

Now suppose Alice performs a general local operation with Kraus operators $K\mu^{(A)}$. The post-operation joint state, if Alice's outcome is not revealed, is

$$\rho'_{AB} = \sum_{\mu} (K_\mu^A \otimes I_B) \rho_{AB} (K_\mu^{A\dagger} \otimes I_B).$$

The Kraus operators satisfy

$$\sum_{\mu} K_\mu^{A\dagger} K_\mu^A = I_A.$$

Bob's new reduced state is

$$\rho'_B = \mathrm{Tr}_A(\rho'_{AB}).$$

To see whether Bob can detect Alice's operation, we compute the expectation value of any Bob-local observable hatO(B):

$$\langle \hat{O}_B \rangle' = \mathrm{Tr}_{AB} \left[\rho'_{AB} (I_A \otimes \hat{O}_B) \right].$$

Substitute ρ'(AB):

$$\langle \hat{O}_B \rangle' = \sum_{\mu} \mathrm{Tr}_{AB} \left[(K_\mu^A \otimes I_B) \rho_{AB} (K_\mu^{A\dagger} \otimes I_B)(I_A \otimes \hat{O}_B) \right].$$

Using cyclicity of the trace, and the fact that Alice's operators commute with Bob's observable, this becomes

$$\langle \hat{O}_B \rangle' = \sum_{\mu} \mathrm{Tr}_{AB} \left[\rho_{AB} (K_\mu^{A\dagger} K_\mu^A \otimes \hat{O}_B) \right].$$

Now use the completeness relation:

$$\sum_{\mu} K_\mu^{A\dagger} K_\mu^A = I_A.$$

Therefore

$$\langle \hat{O}_B \rangle' = \mathrm{Tr}_{AB}\left[\rho_{AB}(I_A \otimes \hat{O}_B)\right] = \langle \hat{O}_B \rangle.$$

Since this is true for every Bob-local observable hatO(B), Bob's local measurement statistics are unchanged.

Thus,

$$\rho'_B = \rho_B.$$

Alice's unrevealed local operation cannot send a signal to Bob.

This is the no-signaling theorem in the form most useful for QET.

5.7 Example: A Bell Pair Does Not Send a Message

Let Alice and Bob share the entangled Bell state

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right).$$

The density matrix is

$$\rho_{AB} = |\Phi^+\rangle\langle\Phi^+|.$$

Bob's reduced state is

$$\rho_B = \mathrm{Tr}_A(\rho_{AB}) = \frac{I_B}{2}.$$

This means Bob's qubit looks completely random by itself.

Now Alice measures her qubit in the computational basis \|0⟩, |1⟩\.

If Alice obtains 0, Bob's conditional state becomes

$$|0\rangle.$$

If Alice obtains 1, Bob's conditional state becomes

$$|1\rangle.$$

So Alice's measurement outcome is perfectly correlated with Bob's conditional state.

But if Bob does not know Alice's outcome, he describes his state as the average

$$\rho_B' = \frac{1}{2}|0\rangle\langle 0| + \frac{1}{2}|1\rangle\langle 1| = \frac{I_B}{2}.$$

That is exactly the same as before.

So Alice has changed the conditional description of Bob's state, but she has not changed anything Bob can observe without receiving her classical message.

This example contains the same logical structure as QET:

- Alice's outcome contains useful information.
- Bob's conditional action can use that information.
- Without the message, Bob sees no controllable signal.

5.8 Conditional States Are Not Signals

A conditional state is the state assigned to a subsystem after we learn that a particular measurement outcome occurred.

In the Bell-pair example, Bob's conditional state is

$$\rho_B^{(0)} = |0\rangle\langle 0|$$

if Alice obtains 0, and

$$\rho_B^{(1)} = |1\rangle\langle 1|$$

if Alice obtains 1.

But Bob does not automatically know whether he has $\rho_{(B)}^{(0)}$ or $\rho_{(B)}^{(1)}$. Before receiving Alice's message, he must use the average state

$$\rho_B = p_0 \rho_B^{(0)} + p_1 \rho_B^{(1)}.$$

In QET, Alice's measurement outcome gives information about energy-density fluctuations near Bob. Bob's conditional operation is designed to exploit that information. But before Bob receives the outcome, he only has the average description, and the no-signaling theorem prevents that average from revealing Alice's result.

This distinction is often the source of confusion:

> Quantum theory permits distant conditional correlations. > Quantum theory forbids controllable faster-than-light signaling.

Both statements are true.

5.9 Relativistic Causality and Light Cones

In relativity, events are organized by their spacetime separation.

Suppose Alice performs a measurement event at spacetime point

$$(t_A, x_A),$$

and Bob performs an operation at

$$(t_B, x_B).$$

For simplicity, consider one spatial dimension. Define

$$\Delta t = t_B - t_A,$$

and

$$\Delta x = x_B - x_A.$$

A light signal can travel distance |Δ x| in time

$$\frac{|\Delta x|}{c}.$$

If

$$c|\Delta t| < |\Delta x|,$$

then the two events are called spacelike separated. No light-speed or slower signal can connect them.

If

$$c|\Delta t| \geq |\Delta x|,$$

then the events are timelike or lightlike related, meaning a causal signal from Alice to Bob is possible in principle.

QET requires Bob to receive Alice’s classical outcome before applying the correct conditional operation. Therefore, for a relativistically safe QET protocol, Bob’s conditional operation must occur inside or on Alice’s future light cone:

$$t_B - t_A \geq \frac{|x_B - x_A|}{c}.$$

This condition is not optional. If Bob’s operation depends on Alice’s message, then ordinary causality demands enough time for the message to arrive.

This is why QET does not contradict relativity.

5.10 Microcausality: The Field-Theory Version of Locality

In relativistic quantum field theory, locality is often expressed through microcausality.

Microcausality says that observables localized in spacelike separated regions commute. If hatO₍A₎(x) is localized near Alice and hatO₍B₎(y) is localized near Bob, then for spacelike separation,

$$[\hat{O}_A(x), \hat{O}_B(y)] = 0.$$

This equation says that measurements in spacelike separated regions cannot disturb each other in a way that creates observable causal influence. It is one of the basic compatibility conditions between quantum theory and special relativity (Peres and Terno, 2004).

QET in quantum fields must respect this principle. Alice's local measurement can update the conditional state assignment for Bob's region, but Bob cannot use that update unless Alice's classical message reaches him.

Later, when we study QET from the quantum field theory viewpoint, microcausality will become especially important. For now, the main lesson is simple:

> Relativistic QET protocols use vacuum correlations, not faster-than-light influence.

5.11 Lattice Systems and Effective Causality

Many QET models are not full relativistic quantum field theories. They are lattice models: spin chains, coupled oscillators, or other many-body systems with discrete sites.

A typical spin-chain Hamiltonian might look like

$$H = \sum_n h_{n,n+1},$$

where $h_{(n,n+1)}$ couples neighboring sites n and n+1.

Such a model does not always have exact Lorentz symmetry. Nevertheless, local interactions still restrict how quickly disturbances spread.

This restriction is captured by Lieb-Robinson bounds, first proved by Elliott Lieb and Derek Robinson in 1972 (Lieb and Robinson, 1972). These bounds show that in many quantum lattice systems with sufficiently local interactions, there is an effective maximum speed for the spread of information and correlations. Modern reviews explain their central role in quantum many-body physics (Nachtergaele and Sims, 2010).

This effective speed is called the Lieb-Robinson velocity, often written as v_{LR}.

It is not usually equal to the speed of light c. It is a speed set by the interaction strengths and geometry of the lattice model.

5.12 The Lieb-Robinson Bound

Let X and Y be two separated regions of a lattice. Let hatA_{X} be an operator supported only in region X, and let hatB_{Y} be an operator supported only in region Y.

Under time evolution generated by a local Hamiltonian H, the Heisenberg-evolved operator is

$$\hat{A}_X(t) = e^{iHt}\hat{A}_X e^{-iHt}.$$

At time t=0, if X and Y do not overlap, then

$$[\hat{A}_X, \hat{B}_Y] = 0.$$

But as time passes, hatA_{X}(t) spreads through the lattice. The question is: how quickly?

A typical Lieb-Robinson bound has the form

$$\left\|[\hat{A}_X(t), \hat{B}_Y]\right\| \leq C\|\hat{A}_X\|\|\hat{B}_Y\| \exp\left[-\frac{d(X,Y) - v_{\mathrm{LR}}|t|}{\xi}\right].$$

Let us define the terms:

- \|·\| is an operator norm, a measure of operator size.
- d(X,Y) is the lattice distance between regions X and Y.
- v_{LR} is the Lieb-Robinson velocity.
- xi is a length scale.
- C is a model-dependent constant.

The exact constants depend on the lattice, Hamiltonian, and interaction range. The important structure is the exponential factor:

$$\exp\left[-\frac{d(X,Y)-v_{\mathrm{LR}}|t|}{\xi}\right].$$

If

$$d(X,Y) \gg v_{\mathrm{LR}}|t|,$$

then the commutator is exponentially small.

This means that outside an effective light cone,

$$d(X,Y) \approx v_{\mathrm{LR}}|t|,$$

the influence of hatA(X) on hatB(Y) is extremely suppressed.

So lattice systems often have an emergent causal structure even though they are not exactly relativistic.

5.13 Example: A Disturbance in a Spin Chain

Imagine a chain of ten spins with nearest-neighbor interactions:

$$1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10.$$

Alice acts on spin 1 at time t=0. Bob controls spin 10.

Because the Hamiltonian only directly couples neighbors, Alice’s disturbance cannot strongly affect spin 10 immediately. It must propagate through the chain by the local interactions:

$$1 \to 2 \to 3 \to \cdots \to 10.$$

The Lieb-Robinson bound says that, for a broad class of local lattice Hamiltonians, any effect outside the effective light cone is exponentially small.

This matters for QET.

Suppose Bob extracts energy from spin 10 shortly after receiving Alice's classical message, at a time when ordinary Hamiltonian propagation from Alice's local disturbance has not significantly reached Bob's region according to the lattice model. Then the protocol is not simply ordinary energy transport along the chain.

Instead, Bob uses Alice's information about correlations already present in the ground state.

This is one of the most important conceptual points in QET:

> QET is not energy carried by a wave packet from Alice to Bob. > It is local energy extraction guided by classical information about pre-existing quantum correlations.

5.14 Why Bob Cannot Extract Energy Before Alice's Message

Let the many-body system begin in its ground state |g⟩. Choose the zero of energy so that

$$H|g\rangle = 0,$$

and

$$H \geq 0.$$

This means every physical state has nonnegative total energy expectation:

$$\langle H\rangle \geq 0.$$

Suppose Bob applies a local unitary $U_{(B)}$ without receiving any information from Alice. The final state is

$$U_B|g\rangle.$$

The final energy is

$$\langle g|U_B^\dagger H U_B|g\rangle.$$

Because H≥ 0, this expectation value cannot be negative:

$$\langle g|U_B^\dagger H U_B|g\rangle \geq 0.$$

The original ground-state energy was zero. Therefore Bob's operation cannot lower the total energy below the ground-state value.

So Bob cannot extract positive energy from the ground state by an uninformed local unitary.

In QET, Bob acts after Alice has measured the system. Alice's measurement injects energy and changes the global state. More importantly, Alice's outcome tells Bob which local operation can reduce the system's energy in his region. The extracted energy comes from lowering the system's local energy near Bob after Alice's measurement, not from the classical message itself.

Hotta's spin-chain QET protocol makes this logic explicit: Alice's local measurement injects energy, and Bob's outcome-dependent local operation can extract energy from a distant region while the protocol remains consistent with locality and no-signaling (Hotta, 2009).

5.15 What Exactly Travels in QET?

It is useful to separate three things that are often confused.

1. Classical information travels

Alice's outcome μ travels to Bob through a classical channel.

This message is necessary. Bob needs μ to choose the correct operation $U_{(B)}(\mu)$.

The message obeys ordinary causal limits.

2. Energy does not travel as a faster-than-light signal

Bob's extracted energy is not carried by Alice's message. A classical bit can tell Bob what to do, but the energy Bob extracts is taken from the quantum many-body system in Bob's region.

Alice's measurement usually injects energy into the system near Alice. Later, through ordinary dynamics, that injected energy can propagate. But QET is designed so that Bob's extraction can occur before that injected energy physically reaches Bob by local Hamiltonian propagation.

3. Correlations are already present

The ground state of an interacting quantum system can contain correlations between separated regions. Alice's measurement outcome gives partial information about fluctuations in Bob's region.

Bob uses that information to perform a conditional local operation that reduces the system's energy near him.

Thus, the "teleportation" in QET is not the transport of a material object, and not the transport of energy as a signal. It is the operational use of remotely obtained information to extract energy locally.

5.16 The Causal Timeline of a QET Protocol

A clean QET protocol has a causal timeline like this:

$$\text{Initial ground state}$$

$$\Downarrow$$

$$\text{Alice performs local measurement in region } A$$

$$\Downarrow$$

$$\text{Alice obtains classical outcome } \mu$$

$$\Downarrow$$

$$\text{Alice sends } \mu \text{ through a classical channel}$$

$$\Downarrow$$

Bob receives μ

$$\Downarrow$$

Bob performs local conditional operation $U_B(\mu)$

$$\Downarrow$$

Bob extracts energy from region B.

The critical causal condition is

$$t_B - t_A \geq \frac{L}{c}$$

for relativistic separation L, or an analogous communication-time condition in a laboratory device.

In lattice models, one may also compare Bob's operation time with the Lieb-Robinson time scale

$$t_{\mathrm{LR}} \sim \frac{d(A,B)}{v_{\mathrm{LR}}}.$$

If Bob acts before ordinary local excitations from Alice's region have appreciably reached B, then the protocol demonstrates the distinctive QET mechanism rather than ordinary energy transport.

5.17 No-Signaling and Energy Measurements

A subtle question remains:

> If Alice’s measurement changes the global energy distribution, why can Bob not detect that immediately by measuring local energy?

The answer is the same as before. If Bob does not condition on Alice’s outcome, his local statistics cannot reveal Alice’s choice or result.

Let hath(B) be a local energy-density operator near Bob. Bob’s average local energy is

$$\langle \hat{h}_B \rangle = \mathrm{Tr}(\rho \hat{h}_B).$$

If Alice performs a local operation and Bob has not received her outcome, then by no-signaling,

$$\langle \hat{h}_B \rangle' = \langle \hat{h}_B \rangle$$

provided hath(B) is localized in Bob’s region and Alice’s operation is represented as a trace-preserving local operation on a distinct subsystem.

However, after Alice sends μ, Bob can sort the situation into conditional cases. The conditional expectation

$$\langle \hat{h}_B \rangle_\mu$$

may depend on μ. Bob’s operation U(B)(μ) can then be chosen to lower the local energy in the corresponding conditional state.

Thus QET uses conditional energy information without violating no-signaling.

5.18 A Simple Analogy—and Its Limits

A classical analogy can help, though it is not perfect.

Imagine two distant boxes containing correlated coins. If Alice opens her box and sees heads, she knows Bob’s coin is likely heads. If she sees tails, she knows Bob’s coin is likely tails. Her observation gives her information about Bob’s box.

But Bob does not know what Alice saw until she sends a message.

QET has a similar information structure, but the physical resource is quantum. The many-body ground state contains quantum correlations. Alice's measurement reveals information about fluctuations relevant to Bob's local energy. Bob uses that information to choose a physical operation.

The analogy fails if we imagine merely uncovering pre-existing classical facts. In quantum mechanics, measurement also changes the state. Alice's measurement injects energy and modifies global correlations. QET depends on both information gain and measurement back-action.

So the analogy teaches one lesson only:

> Correlation is not communication.

That lesson is exactly what no-signaling makes precise.

5.19 Common Misunderstandings

Misunderstanding 1: "QET sends energy faster than light."

No. Bob's extracted energy is not a faster-than-light energy packet sent by Alice. Bob extracts energy locally from his region of the quantum system after receiving Alice's classical message.

Misunderstanding 2: "Entanglement allows instant communication."

No. Entanglement creates correlations, but the no-signaling theorem prevents those correlations from becoming controllable faster-than-light messages.

Misunderstanding 3: "Alice's measurement has no effect at Bob."

This is too simple. Alice's measurement can change the conditional state assigned to Bob's region. But without Alice's classical outcome, Bob's local density matrix and measurement statistics remain unchanged.

Misunderstanding 4: "The classical message carries the teleported energy."

No. The classical message carries information. The energy Bob extracts comes from the quantum system near Bob.

Misunderstanding 5: "Lieb-Robinson bounds are the same as relativity."

No. Lieb-Robinson bounds give an effective causal structure in lattice systems with local interactions. They are not identical to the universal

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