# Toward Implementing Heisenberg's Distinction in the Quantum Formalism

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# Overview of Talk

This talk will

I. Briefly review Heisenberg's distinction between 'potentialities' and 'things' in Quantum Theory

II. Present an attempt to implement his distinction in what I call the 'Heisenberg Interpretation' of quantum mechanics.

III. Present what I call the ontic equivalence relation as a possible means of overcoming one of two major problems with the interpretation

IV. Briefly discuss how combining the two may lead to a potentially deeper theory.

# *Physics and Philosophy* by Werner Heisenberg

1. In 1954-55 Heisenberg delivered the Gifford lecture series at University of St. Andrews entitled *Physics and Philosophy*, one of the highest honors in Scottish Academia
2. The lectures were published in 1958 as a book under the same title
3. The ideas expressed are of philosophical interest insofar as they draw parallels between ancient Greek philosophy and modern physics
   - The distinction between actuality and potentiality was essential to and permeated all of Aristotle's philosophy
   - A similar suggestion was made in 1940 by the German philosopher Kurt Riezler in his lecture series (and book) *Physics and Reality*, but was regarded a one of a general set of dichotomies

# Potentialities/Possibilities vs Things/Facts

*In the experiments about atomic events we have to do with things and facts, with phenomena that are just as real as any phenomena in daily life. But the atoms or the elementary particles themselves are not as real; they form a world of potentialities or possibilities rather than of things or facts.*

*(Physics and Philosophy, p. 160)*

If this distinction exists in reality, then quantum theory *cannot be exact*: It fails to make it. But, as far as I know, we have never seriously tried to find out by developing the relevant physics.

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# Why has this distinction been essentially fruitless in physics?

- **Heisenberg formulated his distinction merely as a philosophical thesis, not a scientific hypothesis**, and almost no one followed up to turn it into the latter
  - Turn the philosophical thesis into a scientific hypothesis
- The distinction is at the level of a physical system's very nature of existence, what philosophers would call an *ontic distinction*. **But existence is currently not a physics concept!**
  - Find a way to integrate a relevant concept of existence into physics
- Even if these two hurdles are overcome, there is still a question of motivation: **Why does there need to be such a distinction in nature?** Other interpretations of quantum mechanics are supported by their own motivations.
  - Derive motivating arguments from applying a physics-based concept of existence to the scientific Hypothesis

# Turn the Philosophical Thesis into a Scientific Hypothesis

As a warm-up, consider first classical probability theory

- Suppose I hold a fair die, not yet cast. Possible outcomes ‘exist’ as mutually incompatible potentialities
- Mathematically, this can be modeled in terms of an inverse projection: *A fiber of potentialities*
- Will use the term *actualizability* instead of potentiality to divest connotations of latter term unrelated to quantum mechanics and avoid confusion with the word ‘potential’ (actualizable=capable of becoming actual)

# Actualizability in Axiomatic Probability Theory

The addition of a zeroth axiom allows us to *mathematically* distinguish between the *concept* of probability and non-probabilistic unit measures by adding a *zeroth axiom* to the axioms of Probability:

Let $\Omega = \bigcup_{i=1}^{N} E_i$ be a set where $N$ is either finite or countably infinite, $\mathcal{A} \subseteq \mathcal{P}(\Omega)$ a set of its mutually exclusive subsets $E_i$, and call the pair $(\Omega, \mathcal{A})$ a measurable space. A real-valued function $P : \mathcal{A} \to \mathbb{R}$ satisfying

- Axiom 0: $\Omega$ is an actualizability fiber
- Axiom 1: $0 \leq P(E_i) \leq 1$
- Axiom 2: $P(\Omega) = 1$
- Axiom 3: $P \bigcup_{i=1}^{N} E_i = \sum_{i=1}^{N} P(E_i)$

is called a *probability*.

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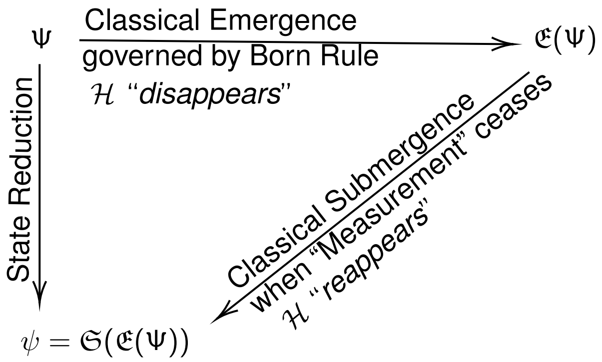
**Notice:** Under this conception, if we omit axiom 0, then $P$ is a *non-probabilistic* unit measure (e.g. unit length, mass etc.) because then $\Omega$ does not represent a set of unactualized potentialities.

# The Heisenberg Interpretation of Quantum Mechanics

- Axiom 0: The $L^2$ complex Hilbert space $\mathcal{H}$ is an actualizability space.
- Axiom 1: The physical states of a quantum systems are completely represented by elements of $\mathcal{H}$, denoted by $\Psi$.
- Axiom 2: Observables are represented by linear Hermitian operators acting on the elements of $\mathcal{H}$.
- Axiom 3: The time evolution of an element $\Psi$ of $\mathcal{H}$ is given by the Hamiltonian.
- Axiom 4: A “Measurement” of the property of a state is represented by a map $\mathfrak{E} : \mathcal{H} \rightarrow \mathcal{C}$, where $\mathcal{C}$ is the collection of all basis states of $\mathcal{H}$ in all bases as actualities, which will be called *‘classical states’*, and $\mathfrak{E}$ will be called the *classical emergence map*. The image of this map is denoted $\mathcal{B} \subset \mathcal{C}$, the collection of basis states as actualities in the measurement basis.
- Axiom 5: The Probability of obtaining a classical state $\mathfrak{E}(\Psi)$ upon a measurement of $\Psi$ is given by the Born Rule.
- Axiom 6: The Completion of a measurement is represented by a map $\mathfrak{S} : \mathcal{C} \rightarrow \mathcal{H}$ such that $\mathfrak{S}(\mathfrak{E}(\Psi)) = \psi$, an eigenstate of $\Psi$, where $\mathfrak{S}$ will be called the *classical submergence map.*

# Actualizability vs Heisenberg's "Things or Facts"




- Note that $\mathcal{E}(\Psi)$ is the counterpart as an actuality of the eigenstate $\psi$.
- Disappearance and reappearance of $\mathcal{H}$ is due to mutual exclusivity of actuality and actualizability
- Presumably, classicality emerges due to decreased frequency of submergence events.

# Advantages over other Copenhagen Interpretation Variants

- The HI is a formal implementation of Heisenberg's philosophical thesis, as other Copenhagen variants do not, and indeed *cannot* formally distinguish between actualities and potentialities/actualizabilities: an (actual) eigenstate in one basis is a superposition (therefore actualizable) of states in another basis.
- The 'Heisenberg Cut', the boundary separating the quantum and classical realms, is embedded within the axioms.
- The Heisenberg Cut is not determined by length scale but *ontic status*: actualizability vs. actuality. Absence of characteristic length scale is consistent with macroscopic quantum phenomena.
- In the HI, the violation of Unitarity is circumvented: Unitarity is always conserved within the Hilbert Space because the measured state is not an element of $\mathcal{H}$. The quantum state is *replaced* by an actual state during a measurement, the submergence of which is in accordance with unitarity.
- Analogy with fair die throw: Prior to event, each face has a probability of $1/6$, but immediately after, the outcome has probability 1. Since the outcome is not part of the actualizability fiber, it is not the case that the probabilities discontinuously changed to 1, but that the actualizability fiber was replaced by an actuality.Preparing for a new die throw gives rise to a new actualizability fiber, and at any time, probability is conserved within it.

# Two Types of Problems with the Heisenberg Interpretation

1. **Mathematical:**
   - The modal distinction between actualizability and actuality is implemented only at the level of physics. It is not inherent in the mathematical structures i.e. it is cosmetic, and this may be a hurdle to formulating a deeper theory.
     - It may be that the requisite modal mathematics does not yet exist
2. **Physical:**
   - The $\mathfrak{E}$ and $\mathfrak{S}$ maps are black boxes: No indication what physical interactions they represent
   - ‘Actualizability’ and ’actuality’ are just words without any physics concepts backing them up.
     - As a consequence, it is still unclear how to characterize the Heisenberg cut more fundamentally.
     - Novel experimental implications remain unclear.

**In principle, both types of problems can be addressed:**

- The resolution to the first problem seems to require new mathematics. I have made some ongoing efforts but will consider this outside the scope of this talk.
- The resolution to the second problem requires starting with a physics-based concept of existence, to which I will now turn my attention.

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# Find a Way to Integrate a Relevant Concept of Existence into Physics

- I recently found a way to do this within the context of special relativity
- Why is SR relevant in a discussion on non-relativistic quantum mechanics?
  - Special relativity can be regarded metatheory which constrains even non-relativistic theories in non-obvious ways
- The main result is the derivation of what I call an ontic equivalence relation
- The ontic equivalence relation is easy to derive, easy to understand but may have far-reaching implications for physics.

# Integrating Existence into Physics: Order of Presentation

1. Introduce a novel reinterpretation of the Lorentz Transformations
   - **Note:** The re-interpretation is of course *in addition to*, rather than instead of, the standard interpretation.
2. The reinterpretations bring attention to 4 spacetime principles which seem to have gone unappreciated so far
3. From the 4 principles, derive the proposition that existence in Minkowski space, as defined below, is an equivalence relation by absolute dimensionality
4. Relate the ontic equivalence relation to the Heisenberg Interpretation in order to overcome the second objection

# An Informal Preview of the Reinterpretation of Length Contraction

Figure: A length-contracted object has a stronger 2-dimensional character

- **Dimensional abatement:** As an object is length-contracted it attains an greater two-dimensional character, up until in the limit of $c$, when the contraction is complete and the object is dimensionally reduced.
- Will now be made mathematically precise

# Lorentz Contraction as Dimensional Abatement I

**Definition**

**Absolute Dimensionality:** *The absolute dimensionality of an object is a dimensionless natural number that refers to the independent length dimensions which characterize it.*

**Definition**

**Volume-Boundary ratio:** *The Volume-Boundary ratio of a compact object with absolute dimensionality* $n > 1$ *is the ratio of its n-dimensional volume to its* $n - 1$*-dimensional boundary.*

**Definition**

**Relative Dimensionality:** *Relative Dimensionality is the dimensionless ratio of the Volume-Boundary ratio of a compact object with absolute dimensionality* $n > 1$ *to that of a compact reference object, also with absolute dimensionality n.*

# Lorentz Contraction as Dimensional Abatement II

$$\dim_{\text{rel}}(a/b) = \frac{\frac{\int dV_a}{\int dA_a}}{\frac{\int dV_b}{\int dA_b}}$$ where

- $a$ is the comparison object, $\int dV_a$ its volume, $\int dA_a$ its surface area
- $b$ is the reference object, $\int dV_b$ its volume, $\int dA_b$ its surface area
- $\dim_{\text{rel}}(a/b)$ is the relative dimensionality of $a$ to $b$ in three space dimensions,.

**Note:** $\dim_{\text{rel}}(a/b)$ is a dimensionless measure of the "dimensional character" of $a$ relative to $b$, but when $a$ and $b$ have identical shape, then it also becomes a measure of the size of $a$ relative to $b$.

### Definition

**Dimensional Diminution:** *For an n−dimensional compact object, dimensional diminution is the decrease of its relative dimensionality compared to its original state to a real number in the open interval* $(0, 1)$*.*

### Definition

**Dimensional Reduction:** *For an n−dimensional compact object (n>1), dimensional reduction is the decrease of its absolute dimensionality to* $n-1$*. Equivalently, it is the decrease of its relative dimensionality compared to its original state to* $0$*.*

# Lorentz Contraction as Dimensional Abatement III

## Definition

**Dimensional Abatement:** *A less specific umbrella term which can either refer to Dimensional Diminution or to Dimensional Reduction.*

## Proposition

***Lorentz contraction can be conceptualized in terms of dimensional abatement. More specifically, it signifies dimensional diminution for*** $0 < v < c$ ***and dimensional reduction for*** $v = c$***.***

*Proof:* Consider a compact body $B$ moving in a frame $S$ and a moving frame $S'$ in which $B$ is at rest. We imagine $B$ in $S'$ as being made out of infinitesimal cubical volume elements oriented, without loss of generality, such that the direction of contraction in $S$ will be normal to one of the sides. It is trivial to show that the Lorentz contraction of each cubical element in $S$ causes it to be dimensionally abated. Since this is true of every infinitesimal volume element of $B$, it is true of $B$. ■

# An Informal Preview of the Re-interpretation of Time Dilation

- **Time** is reinterpreted from an external parameter to a property of an object: Its *duration of existence in spacetime* between two spacetime events.
- **Proper time** is reinterpreted as the observed duration of existence of an object in spacetime between two spacetime events.
- **Coordinate time** is reinterpreted as the observed duration of existence of the observer in spacetime between two spacetime events (or of a class of clocks at rest with respect to the observer).
- **Ontochronic abatement:** As an object is time-dilated, its duration of existence in spacetime between two given spacetime events is diminished, up until in the limit of $c$, when time dilation is complete and its duration of existence in spacetime between spacetime events is exactly zero.

# A Criterion for Physical Existence in Spacetime

Arguably, our understanding of nature has become so deep that in order to make further progress, we need to incorporate the concept of existence into physics. The following existence criterion, presented as an axiom, is an attempt to do so:

### Criterion

*A physical object exists in Minkowski spacetime if and only if it is characterized by a timelike spacetime interval.*

**Two Plausibility Arguments:**

- Proper time is Lorentz invariant, already making it a good candidate for having ontological significance
- Three ways to fail to satisfy the criterion:
  - **Spacelike Interval**: Already considered unphysical due to causality violations/speed of light limit
  - **No spacetime Interval**: It seems reasonable to associate this with non-existence in spacetime
  - **Lightlike Interval:** Will discuss shortly

# Time Dilation as Ontochronic Abatement I

### Definition

**Spacetime Ontic Function:** *The spacetime ontic function is a map* $\exists_S : \mathfrak{O} \rightarrow \{0, 1\}$ *where* $\mathfrak{O}$ *is the set of all physical objects taken to be within the domain of physics and* $S \subset \mathfrak{O}$ *is the subset of* $\mathfrak{O}$ *of all objects that exist in spacetime. The spacetime ontic value of an object is determined by whether it satisfies the existence criterion* $(\exists_S(x) = 1)$ *or not* $(\exists_S(x) = 0)$.

### Definition

**Ontochronicity:** *Ontochronicity is the quality of having a duration of physical existence.*

### Definition

**Relative Ontochronicity:** *Relative ontochronicity is the dimensionless ratio of the the observed duration of existence of an object compared to that of a reference object, usually the observer.*

# Time Dilation as Ontochronic Abatement II

$\text{ont}_{\text{rel}}(a/b) = \frac{\int d\tau_a}{\int d\tau_b}$ where

- $a$ is the comparison object and $\int d\tau_a$ will turn out to be its proper time
- $b$ is the reference object and $\int d\tau_b$ will turn out to be coordinate time.
- $\text{ont}_{\text{rel}}(a/b)$ is the relative ontochronicity of $a$ to $b$

**Note:** When $b$ is an observer observing $a$, we can write $\int \tau_a = \tau$, $\int \tau_b = t$ and thus $\text{ont}_{\text{rel}}(a/b) = \frac{\tau}{t}$ which is similar to, but distinct from $\gamma^{-1} = \frac{d\tau}{dt}$. In situations in which the context is clear, the definition may be relaxed to subsume $\gamma^{-1}$.

### Definition

**Ontochronic Diminution:** *Ontochronic diminution is the decrease of the observed duration of existence of an object in a given time interval by a dimensionless factor in the open interval* $(0, 1)$*.*

### Definition

**Ontic Reduction:** *Ontic reduction is the reduction of the ontic value of an object to* $0$*.*

# Time Dilation as Ontochronic Abatement III

## Definition

**Ontochronic Abatement:** *Ontochronic abatement is a less specific umbrella term which can either refer to ontochronic diminution or to ontic reduction.*

## Proposition

***Relativistic time dilation can be conceptualized in terms of ontochronic abatement. More specifically, it signifies ontochronic diminution for*** $0 < v < c$ ***and ontic reduction for*** $v = c$***.***

*Proof*: Follows trivially from re-interpreting the proper time of an object as its observed duration of existence in spacetime, and coordinate time as the duration of existence in spacetime of the observer, between two given spacetime events.■

# Four Unappreciated Spacetime Principles

The reinterpretation focuses attention on two invariance and two symmetry principles:

1. **Invariance of Absolute Dimensionality:** *The absolute dimensionality of any compact body is invariant under spacetime coordinate transformations.*
2. **Homodimensionality of Space:** *The dimensionality of every (maximally dimensional) space-like hypersurface of Minkowski spacetime is everywhere the same.*
3. **Invariance of Spacetime Ontic Value:** *The spacetime ontic value of any compact body is invariant under spacetime coordinate transformations.*
4. **Homodimensionality of Time:** *The dimensionality of every timelike hypersurface of Minkowski spacetime is everywhere the same.*

# The Relationship Between the Spacetime Principles and the LT

1. The Lorentz transformations ensure that an object observed to be 3-dimensional in one spacetime frame will never observed to be 2-dimensional in any other spacetime frame, and vice versa.
   - Lorentz contraction obeys the invariance of absolute dimensionality.
2. The Lorentz transformations ensure that an object observed to have a finite duration of existence in spacetime in one spacetime frame will never observed to have a zero duration of existence in spacetime in any other spacetime frame, and vice versa.
   - Time Dilation obeys invariance of spacetime ontic value

# Physical Existence in Spacetime as an Equivalence Relation I

- **Principles 1 and 3 together couple absolute dimensionality to spacetime ontic value.** Propositions 1 and 2 together already show that dimensional and ontochronic diminution couple to each other exactly as Lorentz contraction and time dilation couple to each other, but the two invariance principles together extend this to dimensional and ontic reduction.
- **Principles 2 and 4 together ensure that the coupling of absolute dimensionality to spacetime ontic value holds globally.** In a spacetime in which the homodimensionality of space or of time fails to hold, there could conceivably be regions in which spacelike or timelike hypersurfaces have a different dimensionality inside the region than outside, and in such regions absolute dimensionality and ontic value could decouple. The two homodimensionality principles together ensure that this does not happen.

### Definition

**Isodimensional:** *A Spacetime is isodimensional if and only if both its timelike and maximally dimensional spacelike hypersurfaces are homodimensional.*

# Physical Existence in spacetime as an Equivalence Relation II

### Proposition

*Physical existence in Minkowski spacetime is an equivalence relation by absolute dimensionality.*

*Proof*: An equivalence relation is determined by the properties of reflexivity, symmetry and transitivity. Consider an $n$-dimensional compact object $A$ subject to the above principles. By the the coupling of ontic value to absolute dimensionality, it must exist in an $n+1$ dimensional Minkowski spacetime region. By the isodimensionality of Minkowski spacetime, this region is, in fact, all of $n+1$ dimensional spacetime. In particular, $A$ exists in the $n+1$-dimensional Minkowski spacetime in which it exists. This proves reflexivity. Now consider an $m$-dimensional compact object $B$. By the same argument as given for reflexivity, it must exist in an $m+1$ dimensional spacetime. Suppose $A$ exists in the same spacetime as $B$. This requires that $n+1=m+1$, and, consequently, that $n=m$. But that means $B$ has the same absolute dimensionality as $A$, and therefore exists in the same spacetime as $A$. This proves symmetry. Finally, consider an $l$-dimensional compact object $C$. By the same argument as given for reflexivity, it must exist in an $l+1$-dimensional spacetime. Now suppose that $B$ exists in the same spacetime as $C$, and that $A$ exists in the same spacetime as $B$. This requires $m+1=l+1$ and $n+1=m+1$, respectively, from which it follows that $n=m=l$, so $A$ has the same absolute dimensionality as $C$ and therefore exists in the same spacetime as $C$. This proves transitivity. ■

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# Some Implications of the Equivalence relation

The equivalence relation has many consequences for physics, only a few of which are listed below:

1. It induces a partition on all things that physically exist
2. It implies that speed-of light objects belong to a different ontic equivalence class than spacetime objects (and observers)
3. It can be generalized to more realistic spacetimes
4. It may provide a physical foundation for the Heisenberg Interpretation

# 1. A Partition on all Things that Physically Exist *per se*

The ontic equivalence relation considered here partitions the set of all objects that physically exist *per se* into *ontic equivalence classes* such that for each $n+1$ dimensional Minkowski spacetime, there is a corresponding equivalence class of $n$-dimensional objects that exist in it.

| 0+1 Spacetime | 1+1 Spacetime | 2+1 Spacetime | 3+1 Spacetime | 4+1 Spacetime | ... |
|---|---|---|---|---|---|
| 0-dimensional objects | 1-dimensional objects | 2-dimensional objects | 3-dimensional objects | 4-dimensional objects | ... |

Figure: A partition of all physically existing objects into ontic equivalence classes by absolute dimensionality.

# Speed-of-light objects belong to a different ontic equivalence class than spacetime observers

- This can now be given as an *explanation* for the impossibility of transforming to the rest frame of a speed-of-light object: If a spacetime observer could transform to a speed-of-light rest frame, he or she would no longer be a *spacetime* observer.
- We have been desensitized by a deluge of science fiction-y speculations in modern physics (Extra dimensions, multiverse, MUH, simulation hypothesis etc). Because of that, when a straightforward but paradigm-shifting implication of an established theory of physics is discovered, we may not appreciate its significance.
- The discovery that speed of light objects belong to a different ontic equivalence class than spacetime observers implies that **it is possible for something to exist without existing in spacetime**. Arguably, this is comparable to the discovery, some 500 years ago, that it is possible for something to be a sun without it being our own sun, namely a star.
- Yet, from its inception, special relativity, one of our best and most established scientific theories, held this implication right before us: The duration of existence of a photon in spacetime, from the moment it is emitted to the moment it is absorbed somewhere else, is exactly zero. We did not notice the significance of this because its implication does not fit into the prevailing worldview.

# The Ontic Equivalence Relation Can Be Applied More Generally

1. We tacitly assume the four spacetime principles apply to spacetimes other than Minkowski because spacetimes which violate them would seem sufficiently weird for us to notice the violation.
    1. Ordinarily, we take it as part of the *definition* of a pseudo-Riemannian manifold $(M, g)$ that it is isodimensional. If $M$ is isodimensional, then the two homodimensionality principles hold in $M$.
    2. The invariance of absolute dimensionality and spacetime ontic value seem to be assumed without an accompanying definition.
2. If the homodimensionality and invariance principles hold in $M$, then the ontic equivalence relation also holds in $M$.
3. **But:** It appears that singularities (e.g. inside Black holes) denote point-like spatial regions in which the four spacetime principles may not hold.

### Definition

**Isodimensional almost everywhere:** *A spacetime is isodimensional almost everywhere if and only if it is isodimensional up to a countable number of point-like (in space) singularities .*

Can modify proof of the ontic equivalence relation so that it holds 'almost everywhere' in $M$.

# Spacetime Ontic Value May Provide a Physics Foundation for the Heisenberg Interpretation

- Photons are inherently quantum. If they belong to an ontic equivalence class of objects distinct from the equivalence class of spacetime objects, then this suggests the possibility that all quantum objects belong to a distinct ontic equivalence class.
- A working hypothesis: Quantum systems fail to exist as a spacetime objects, but manifest as a combination of possibilities until spacetime objects emerge out of as yet unspecified interaction $\Rightarrow$ **Measurement**
- Spacetime ontic value may be what keeps the domains of applicability of quantum and classical physics mutually exclusive.

# Actualizable Mass

However, there is a glaring problem:

- Quantum systems are often associated with mass, so need to introduce the concept of "mass as a potentiality", or what I call *actualizable mass*[1].
- To apply the concept:
  - Associate actualizable mass with systems which exist, but are characterized by the absence of a spacetime interval
  - Actualizable mass implies that such systems can be associated with possible worldlines of spacetime systems that can emerge out of them, but as actualizabilities. One wordline per possibility. Presumably, the precise quantitative implementation of this is the Feynman Path Integral

[1] *Are the Concepts of Mass in Quantum Mechanics and in General Relativity the same?* AN https://deepblue.lib.umich.edu/handle/2027.42/87999

# Actualizable mass and the Equivalence Principle

- Actualizable mass breaks the equivalence principle, so it might seem like a non-starter.
- Usual argument goes as follows:
  - We have observed that quantum systems obey the passive equivalence principle e.g. gravitational bending of light, gravitational acceleration in matter wave interferometry
  - That is, the field acted on the quantum system. By a conservation of momentum argument, we can then deduce that the active equivalence holds also.
- But assumption of momentum exchange cannot hold here: potentialities cannot exchange momentum with actual physical systems. There can be no action-reaction.
- Background spacetime simply constrains possibilities because of mutual exclusion of actuality and actualizability. Actualizabilities fill everything that actualities allow them to fill in. Constraint on apperance of actualizabilities is presumably modeled qantitatively by QFT in curved spacetime.
- To rule out actualizable mass, we must test active equivalence principle for quantum systems directly, which has never been done so far.

# Areatime Theory: A Sketch

The theory I investigate to give an underpinning for the Heisenberg Interpretation:

1. There are 2-dimensional objects which exist in a $2+1$-dimensional spacetime with Lorentzian signature which I will call areatime
2. By the ontic equivalence relation, areatime objects do not exist in spacetime and are therefore not directly observable to us.
3. However, their existence manifests indirectly through the emergence of spacetime objects upon certain interactions we call “measurements” from them.
4. In the absence of such “measurement” interactions, areatime objects are only describable *by us* in terms of the spacetime objects which can emerge from them, but *as actualizabilities*.
5. If they are associated with null spacetime intervals, they are massless, if they are associated with no spacetime intervals at all, they are characterized by actualizable mass.

I call this framework *Areatime theory*.

# What Underlies Heisenberg's distinction according to Areatime Theory

Areatime theory implies that:

1. General relativity is the fundamental theory of spacetime observers describing spacetime objects (i.e. both exist in spacetime)
2. Quantum Theory is the fundamental theory of spacetime observers describing areatime objects.

If this is correct, then General Relativity and Quantum Theory have mutually exclusive domains of validity i.e. they do not need to be unified.

# Some Novel Empirical Predictions of Areatime Theory

Because this conception is different from the current paradigm, it gives rise to highly unfamiliar empirical predictions under the auxiliary assumption that *only spacetime objects can be gravitational sources*:

1. **Quantum Mechanical Systems are not Gravitational Sources** Since they are not spacetime objects, they should not produce gravitational fields until “measured”. Actualizable mass breaks the active equivalence principle, while the passive equivalence principle still holds (gravitational bending of light, matter wave interferometry in gravitational fields) because the background spacetime still affects the potentialities (quantitatively expressed through the Feynman Path integral in curved spacetime).
2. **A Beam of Light Does not produce a gravitational field** In 1931 Tolman calculated the acceleration a test particle would experience in the vicinity of a "pencil of light" according to General Relativity. The prediction here is that there would be no acceleration. This does not mean GR is wrong, but that light is really outside its domain of applicability. An experiment to measure the gravity field of an ultra high energy laser would possibly be the single best investment in experimental fundamental physics because there is no "bad" outcome.

# Conclusion: A Work in Progress

- In this talk, I introduced
  - The Heisenberg interpretation of quantum mechanics
  - The ontic equivalence relation.
  - The concept of actualizable mass
- Each stands on its own, but in combination they suggest a candidate for a deeper theory
- I attempt to combine them in what I call Areatime theory, which is at this time still more of a theory sketch. A lot more work needs to be done:
  - Develop a suitable modal mathematics
  - Work out further consequences of the ontic equivalence relation
  - Identify and work out the physical processes represented by the $\mathcal{E}$ and $\mathcal{S}$ maps.
  - Identify and work out further predictions, preferably precision predictions.
  - Generalize to relativistic Quantum Field Theory
- I believe that if Heisenberg's distinctions really exist in reality, then they will bring about a *paradigm shift* in physics.

# Thank you!