

Title: Sir Roger Penrose - Are We Due for a New Revolution in Fundamental Physics?

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URL: <http://pirsa.org/04100005>

Abstract: Are We Due for a New Revolution in Fundamental Physics? <kw>Sir Roger Penrose, fundamental physics, new revolution, quantum gravity, quantum mechanics, quantum field theory, singularities, Schrodinger, spin, Planck, entropy, thermodynamics, supersposition, linearity, quantum information, quanglement, twister theory</kw>

Quantum Gravity

The application of
standard procedures
of quantum (field) theory
to general relativity or
other gravitational theory?

OR

Some more even-handed
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by QUANTUM-MECHANICAL laws?

Quantum mechanics explains:

1. Stability of atoms
2. Spectral lines
3. Chemical forces
4. Black-body radn. (colours of hot bodies)
5. Reliability of inheritance
6. Lasers
7. Superconductors
8. Superfluids
9. etc. ... etc.

..... used essentially in many
areas of technology (including computers)

--- Combined with special relativity

→ Quantum Field Theory

Essential for particle physics etc.

Accuracy?

~1 pt. in 10^{11}

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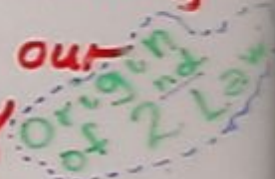
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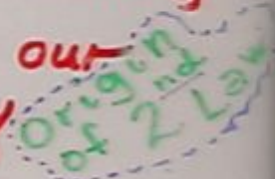
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- standard QM doesn't make sense on its own! [Measurement paradox]
- gravitation is the most natural place to introduce a change
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- relate to time-asymmetry in QM probability law
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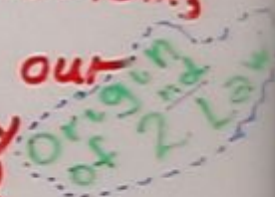
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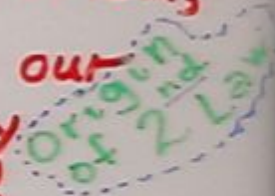
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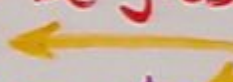
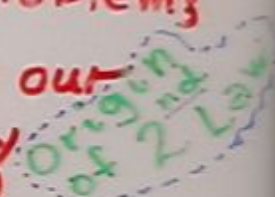
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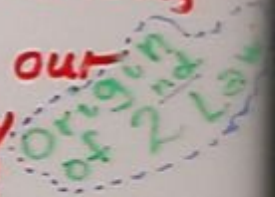
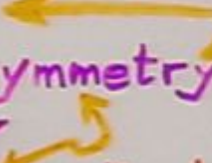
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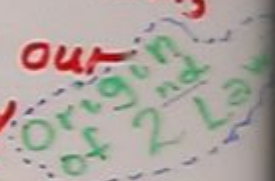
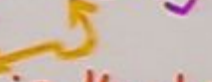
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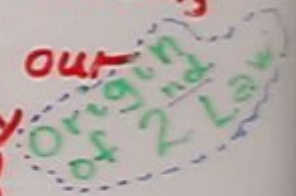
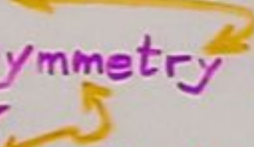
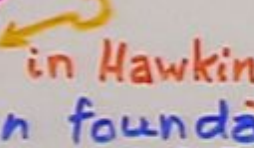
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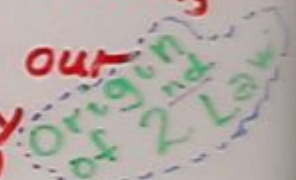
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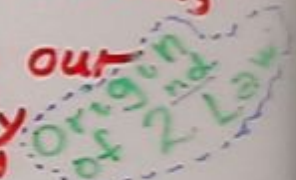
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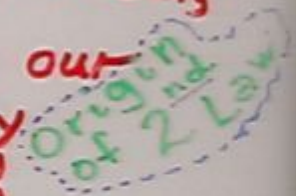
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Origin of 2 Laws

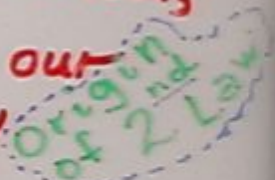
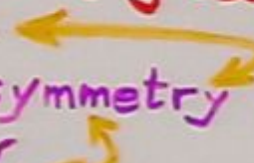
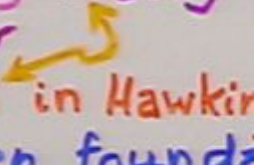
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Origin of 2nd Law



"Schrödinger's Little Mermaid"
Hans Christian Andersen Lecture

— a New Angle on the Basic Paradox of Quantum Mechanics



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— a New Angle on the Basic Paradox of Quantum Mechanics



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© Classical World

Ⓡ Quantum World

© : Classical physics — Deterministic

Quantum physics { Ⓡ
Ⓡ : Unitary evolution — Deterministic
Ⓡ : Reduction of state — Non-deterministic

N.B.
mutually
inconsistent!

© Classical World

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Quantum physics

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© Classical World

Ⓡ
Ⓢ Quantum World

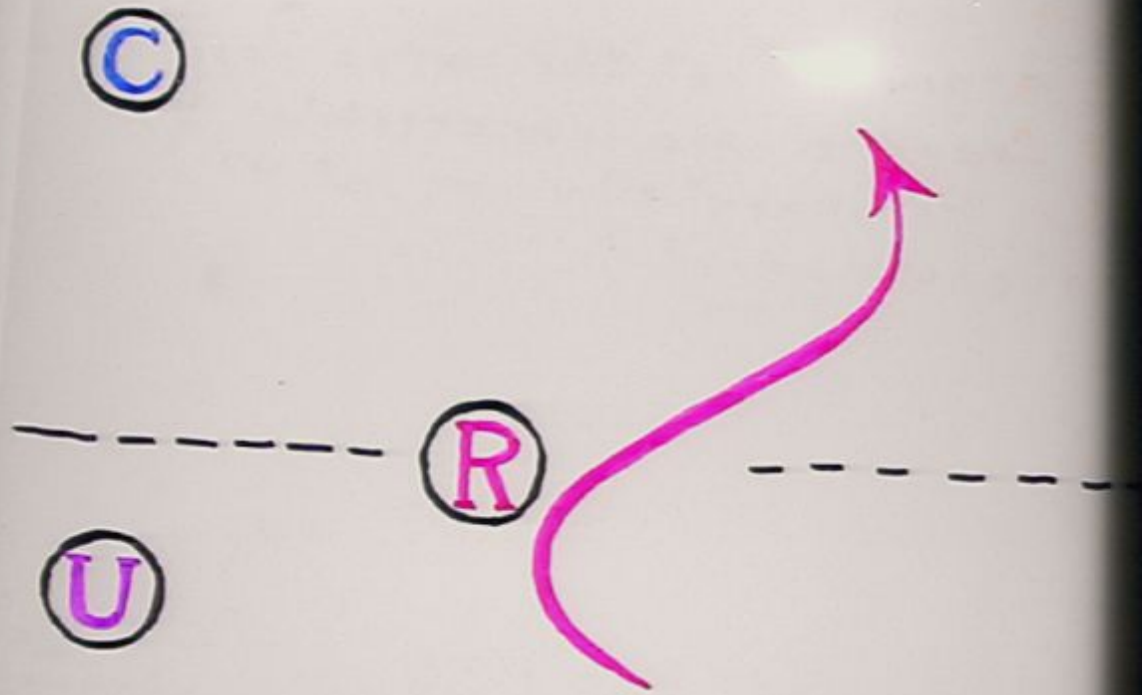
©: Classical physics — Deterministic

Quantum physics {

Ⓢ: Unitary evolution —

Ⓡ: Reduction of state — Non-deterministic

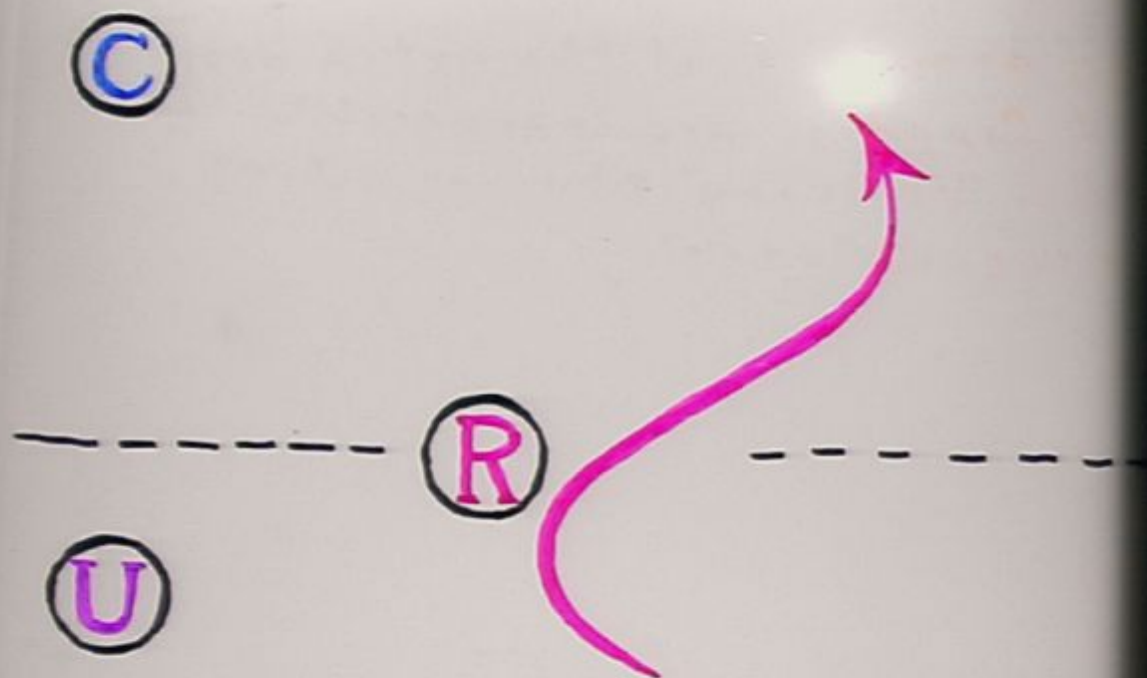
N.B.
mutually
inconsistent!



③ : Classical physics — Deterministic

Quantum physics {
④ : Unitary evolution —
⑤ : Reduction of state — Deterministic

N.B.
mutually
inconsistent!



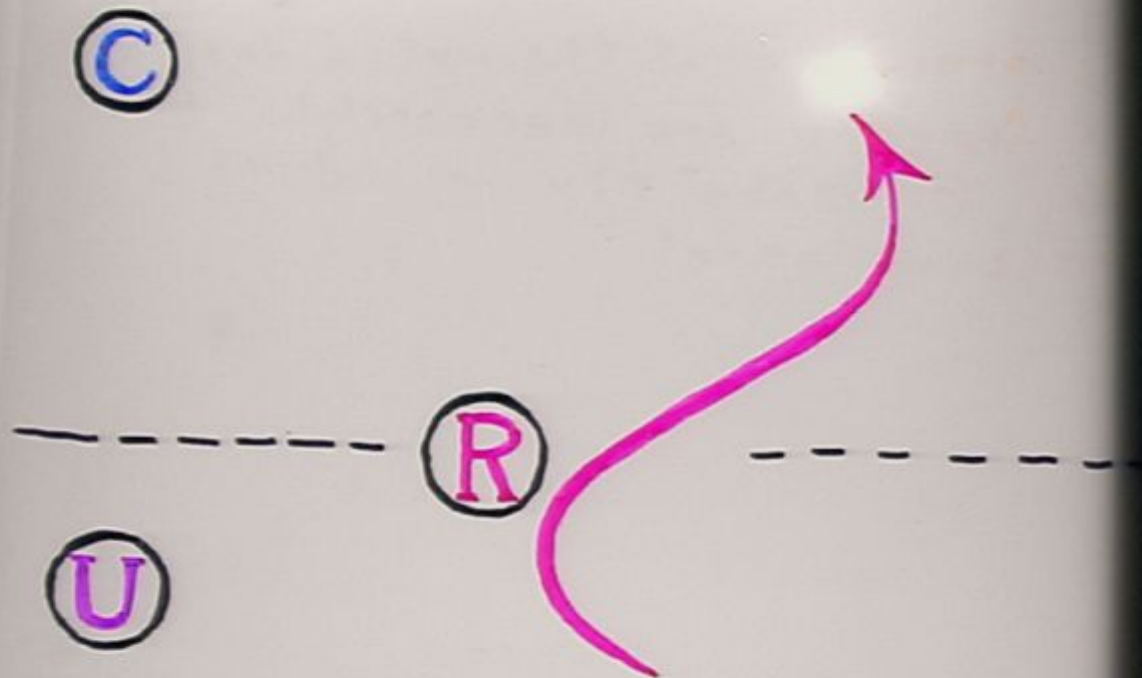
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Quantum physics {

Ⓐ: Unitary evolution — Deterministic

Ⓡ: Reduction of state — Non-deterministic

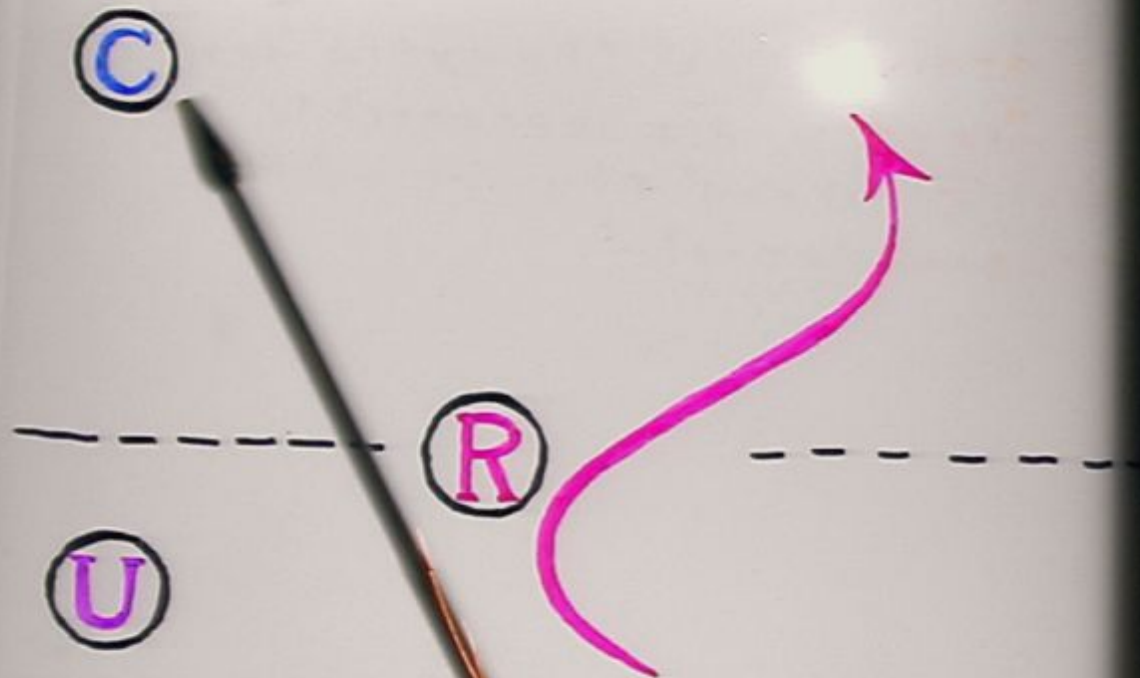
N.B.
mutually
inconsistent!



③ : Classical physics — Deterministic

Quantum physics { ④ ⑤
④ : Unitary evolution — Deterministic
⑤ : Reduction of state — Non-deterministic

N.B.
mutually
inconsistent!



①: Classical physics — Deterministic

Quantum physics —

②: Unitary evolution —

③: Reduction of state —

②
③
N.B. mutually inconsistent!

Deterministic
Non-deterministic

Ⓒ

Ⓓ

⒰



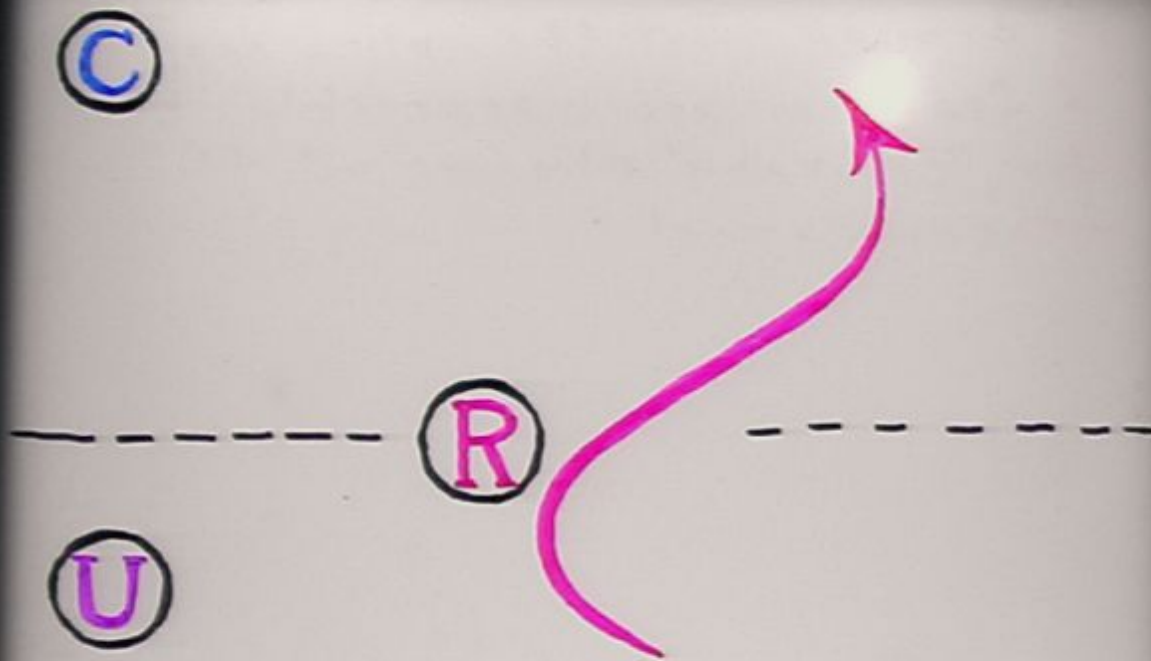
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Quantum physics { ⒰
Ⓓ

N.B.
mutually
inconsistent!

⒰: Unitary evolution — Deterministic

Ⓓ: Reduction of state — Non-deterministic



①: Classical physics — Deterministic

Quantum physics {
②: Unitary evolution — Deterministic
③: Reduction of state — Non-deterministic

N.B.
mutually
inconsistent!

Ⓒ

⒰

⒱



Ⓒ : Classical physics — Deterministic

Quantum physics {

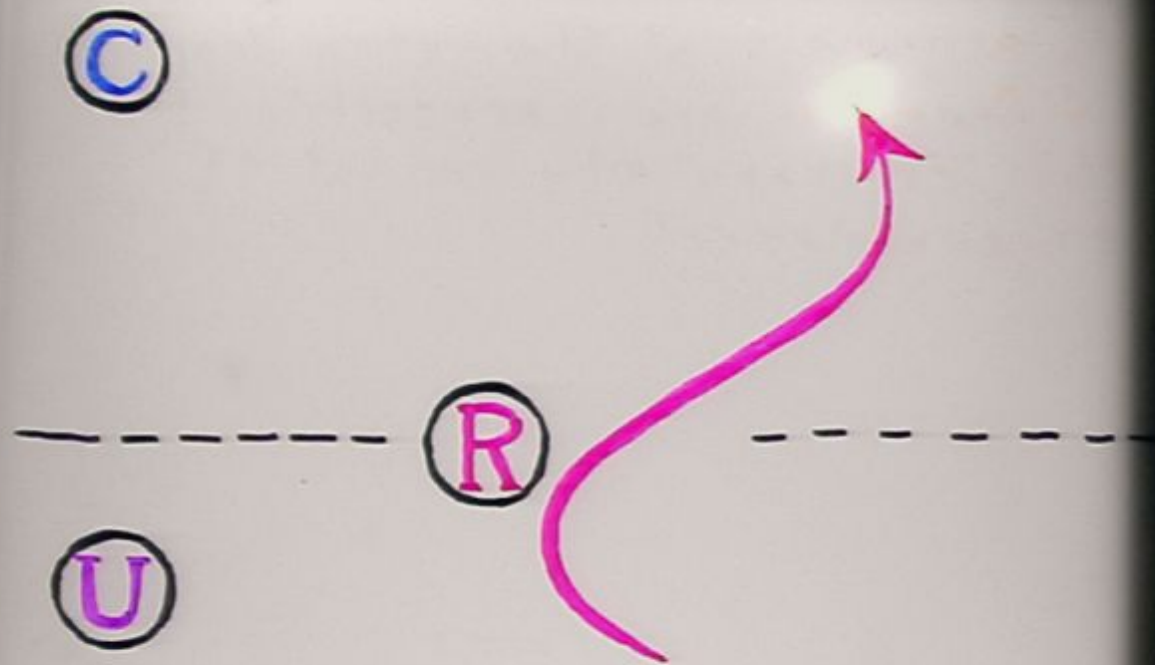
⒰

⒱

N.B.
mutually
inconsistent!

⒰ : Unitary evolution — Deterministic

⒱ : Reduction of state — Non-deterministic



③ : Classical physics — Deterministic

Quantum physics { U R }
③ : Unitary evolution — Deterministic
③ : Reduction of state — Non-deterministic

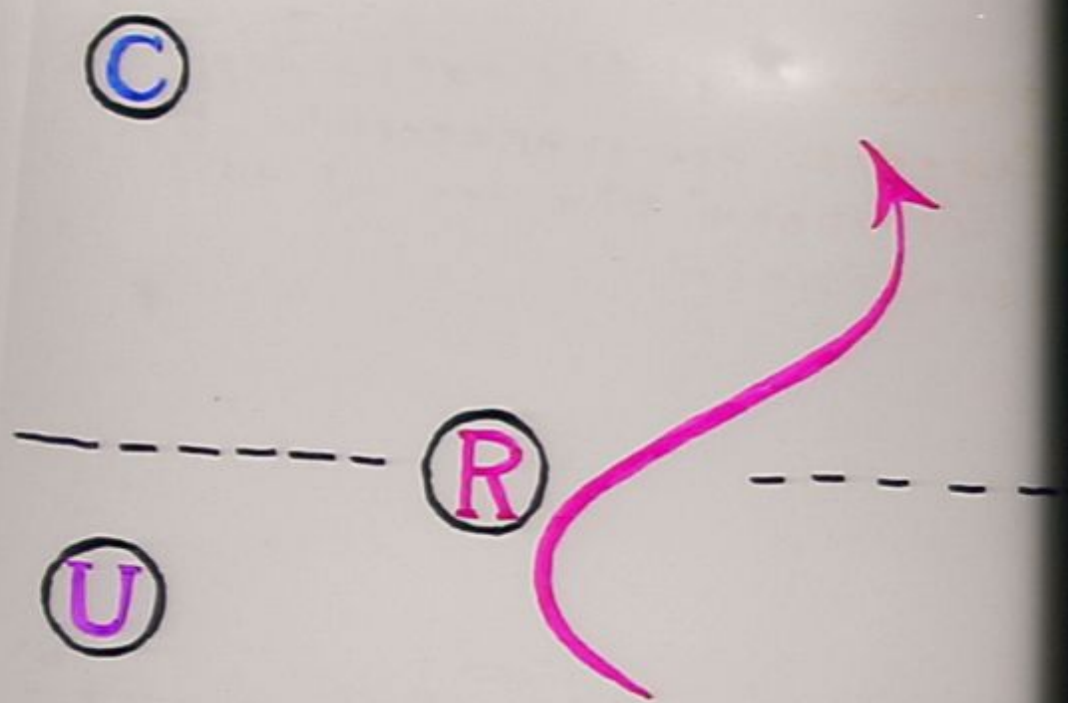
N.B.
mutually
inconsistent!



C: Classical physics - Schrodinger's Little Mermaid
 Hans Christian Andersen Lecture
 Quantum physics { U, R } N.B. mutually inconsistent!
 a New Angle on the Basic Paradigm of Quantum Mechanics
 U: Unitary evolution - Deterministic
 R: Reduction of state - Non-deterministic



C: Classical physics - Schrodinger's Little Mermaid
 Hans Christian Andersen Lecture
 Quantum physics { N.B. mutually inconsistent!
 a New Angle on the Basic Paradigm
 U: Unitary evolution - Deterministic
 R: Reduction of state - Non-deterministic



Ⓒ: Classical physics — Deterministic

Quantum physics { Ⓐ Ⓑ_{N.B. mutually inconsistent!}

Ⓐ: Unitary evolution — Deterministic

Ⓑ: Reduction of state

Ⓒ

⒰

⒱



Ⓒ : Classical physics — Deterministic

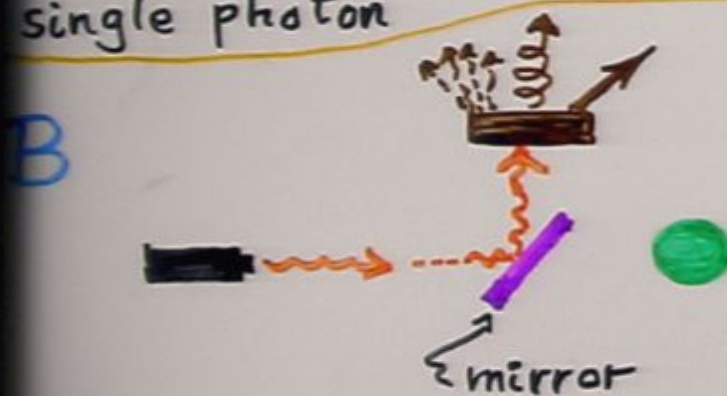
Quantum physics { ⒰
⒱ } N.B. mutually inconsistent

⒰ : Unitary evolution — Deterministic

⒱ : Reduction of state — Non-deterministic

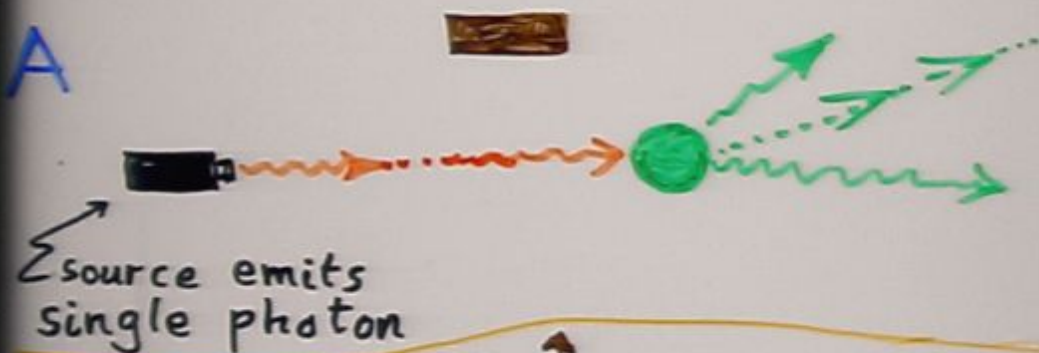


Quantum Linearity

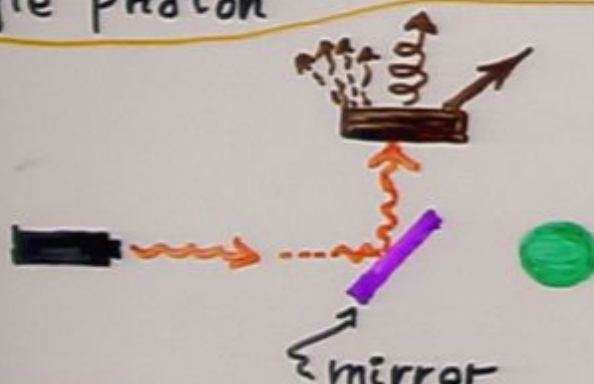


Quantum Linearity

A

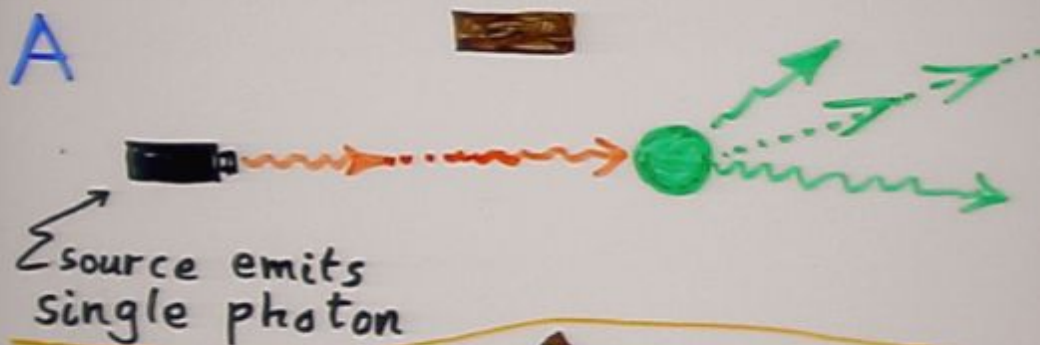


B

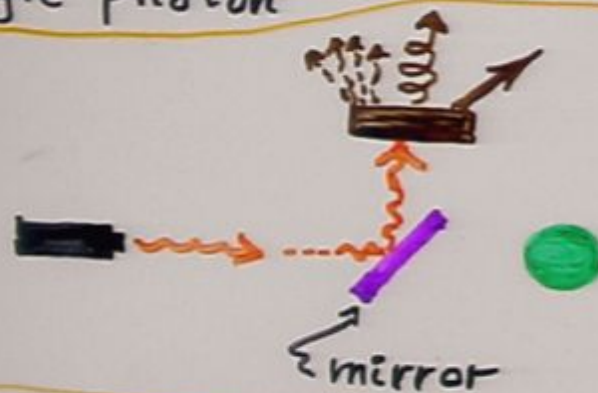


Quantum Linearity

A

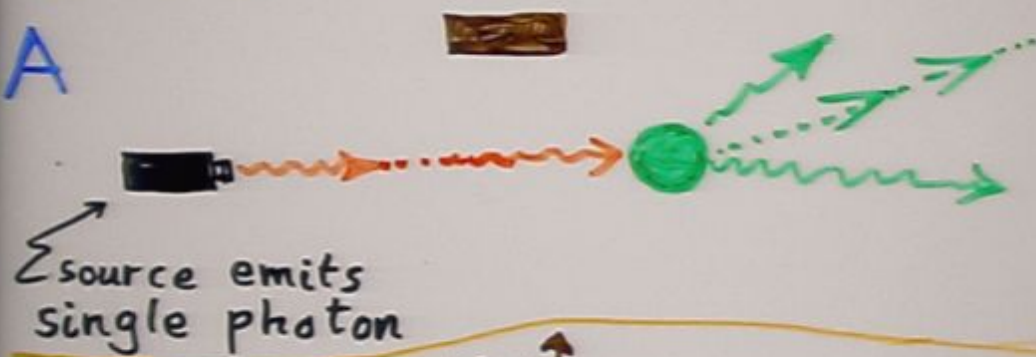


B

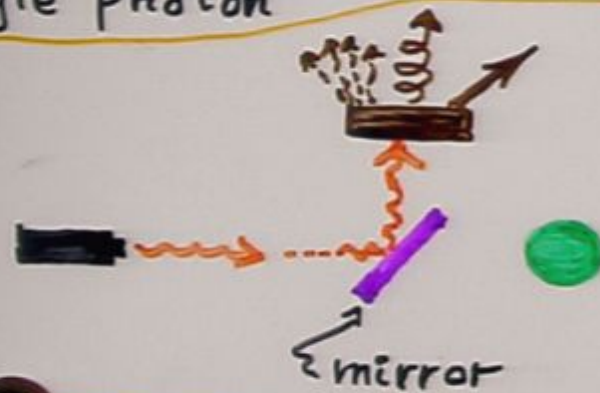


Quantum Linearity

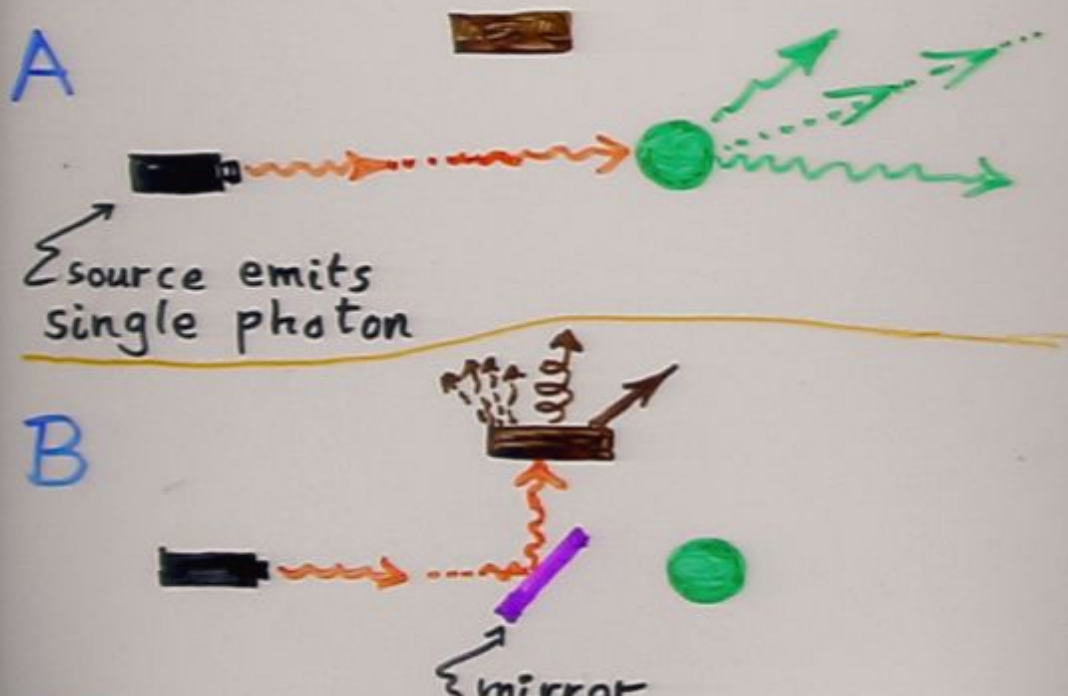
A



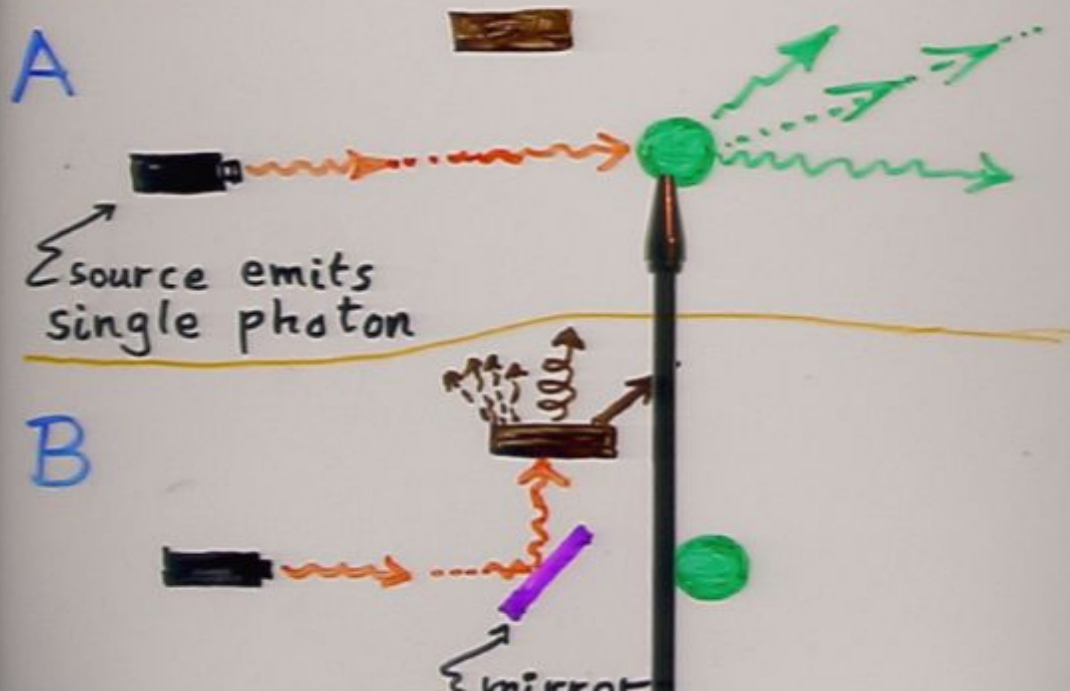
B



Quantum Linearity

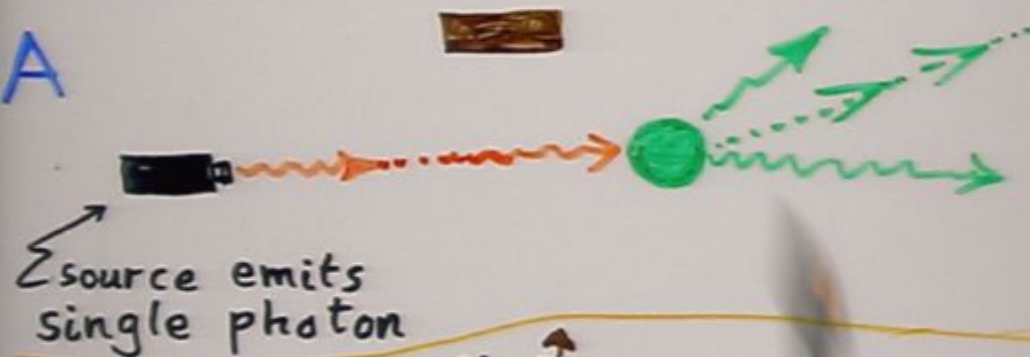


Quantum Linearity



Quantum Linearity

A

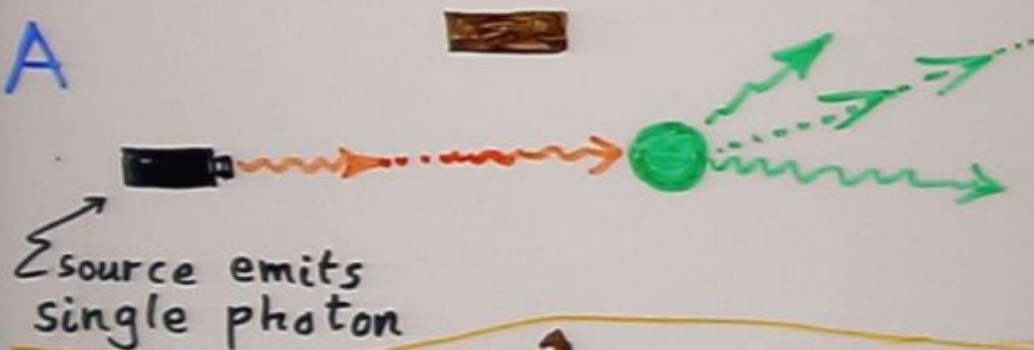


B



Quantum Linearity

A

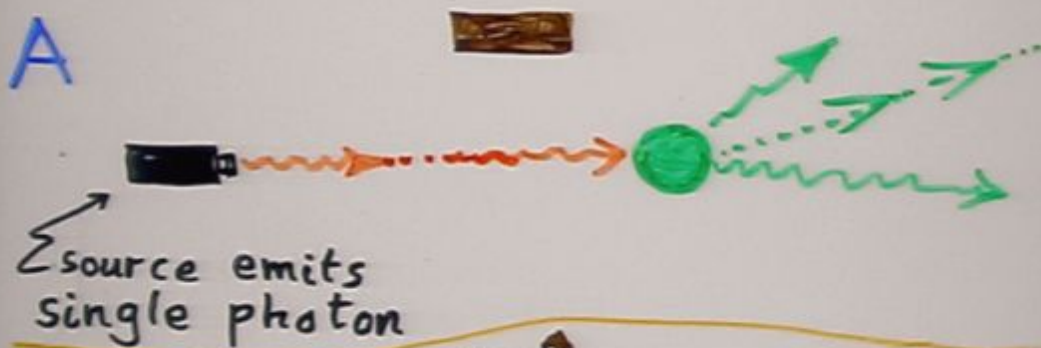


B



Quantum Linearity

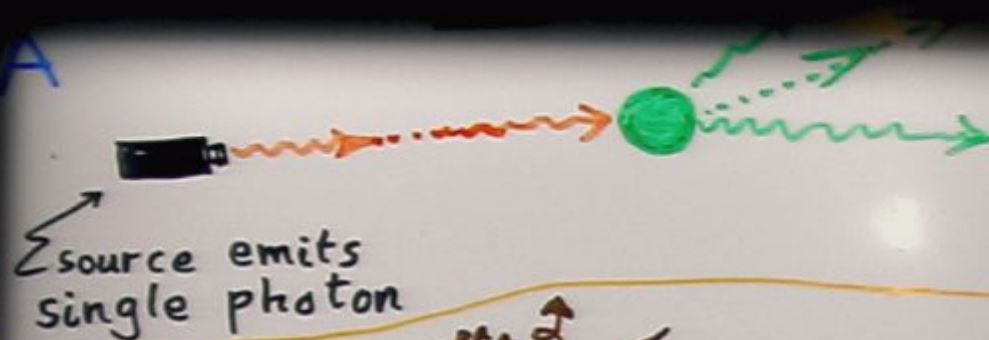
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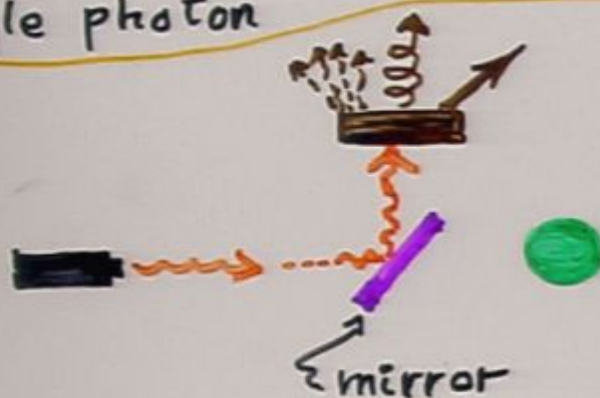
B



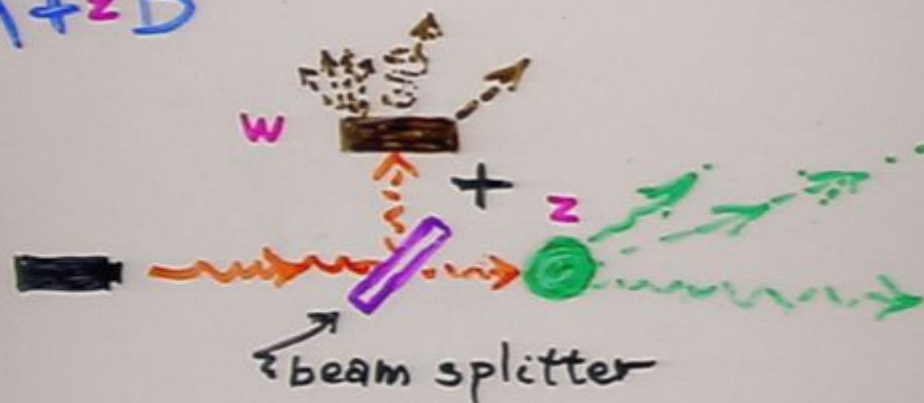
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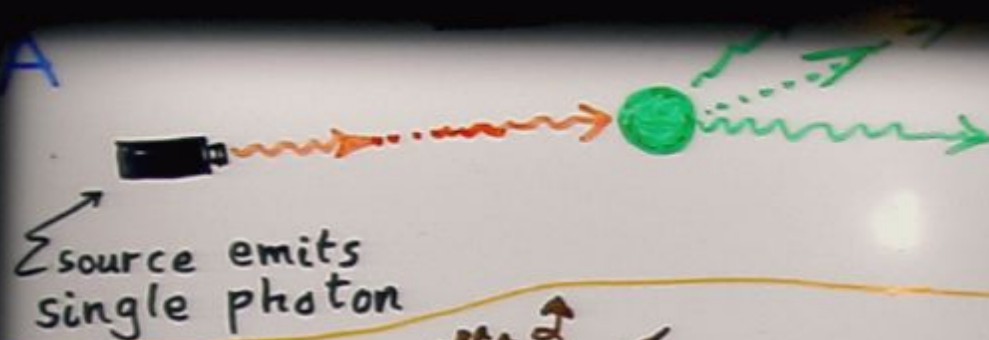
B



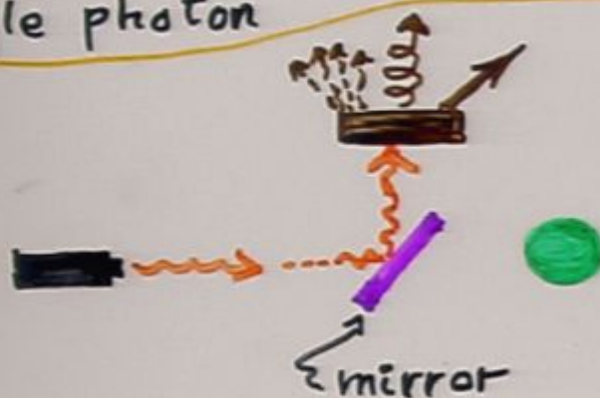
$wA + zB$



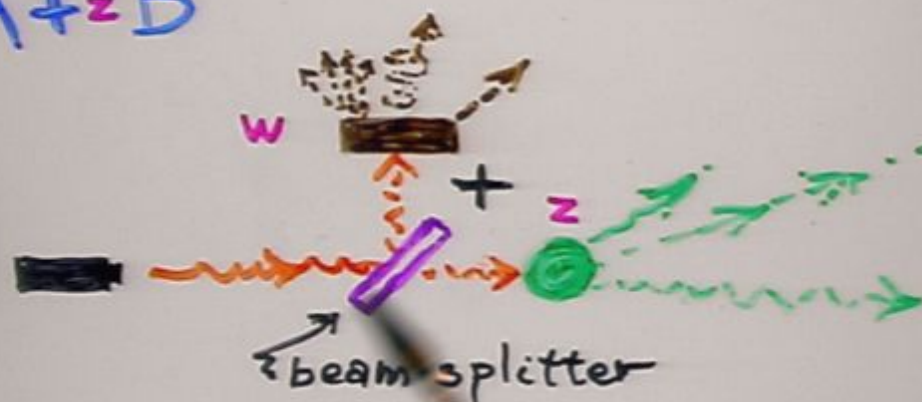
A



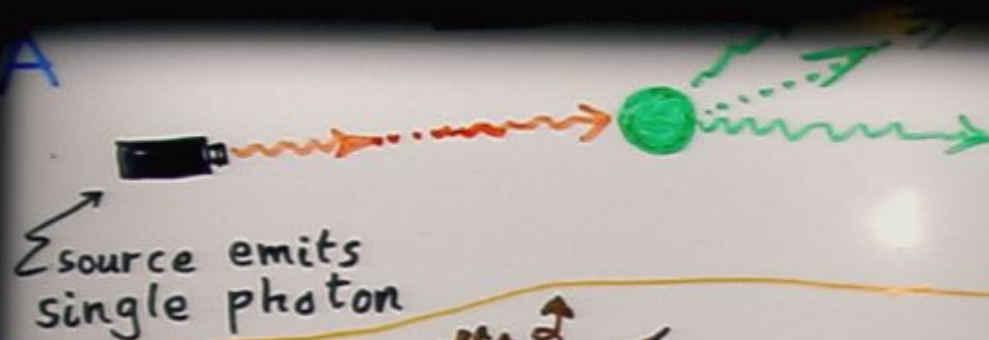
B



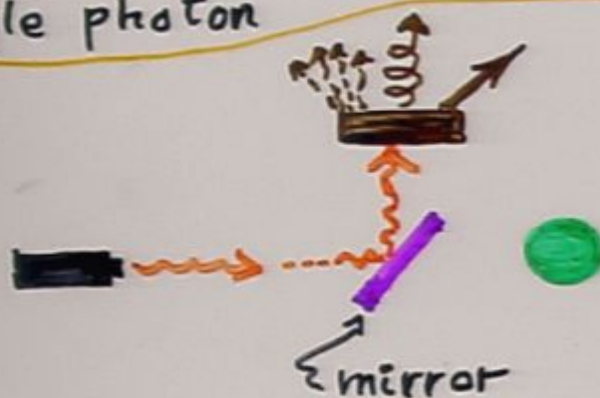
$wA + zB$



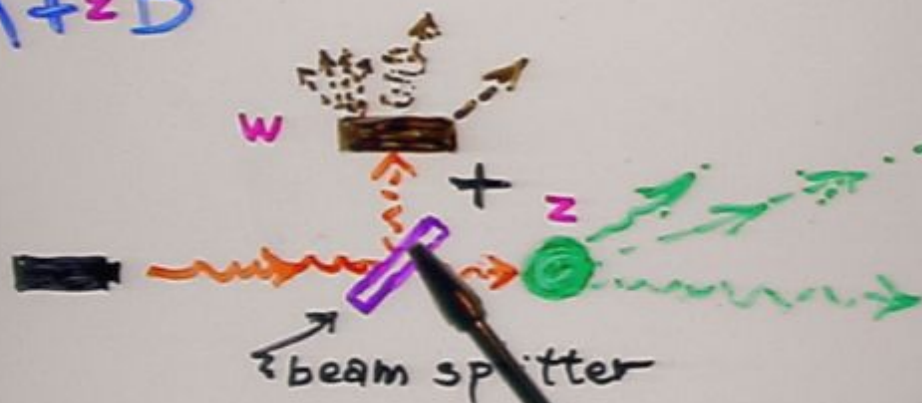
A



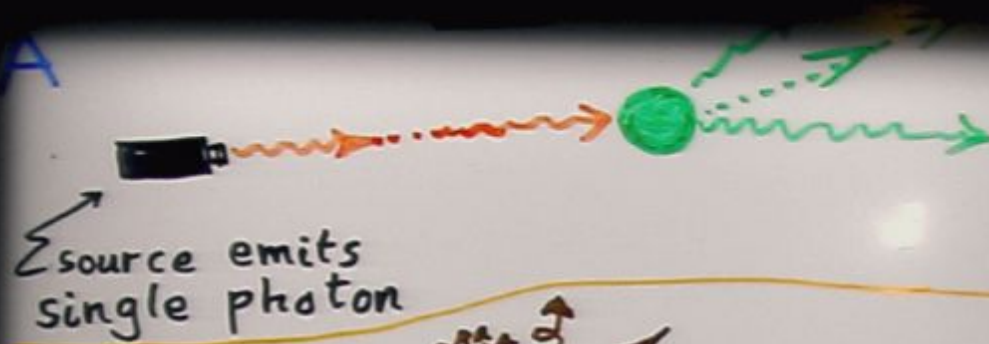
B



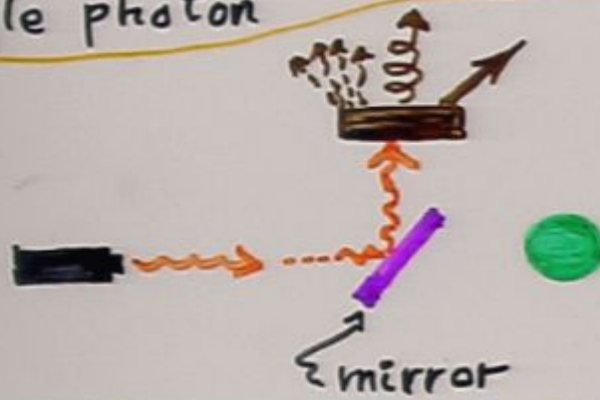
$$wA + zB$$



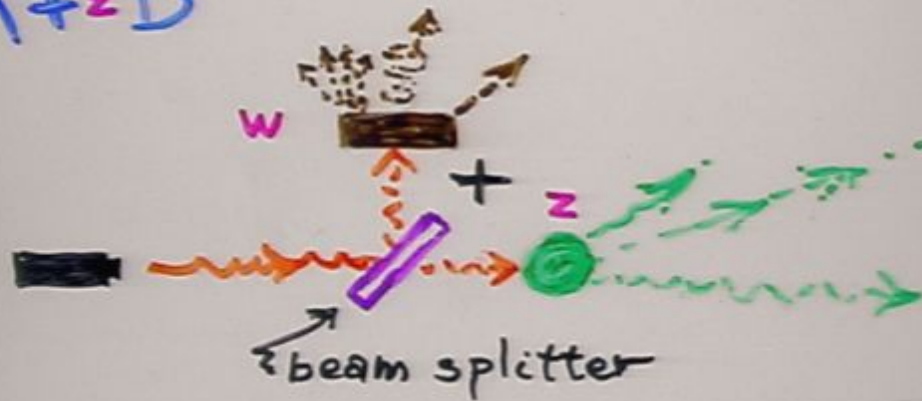
A



B



$wA + zB$



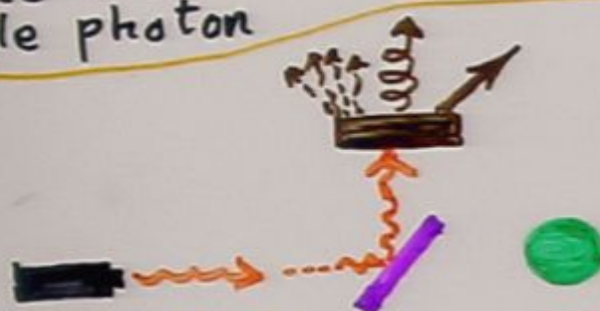
A

source emits
single photon



B

mirror



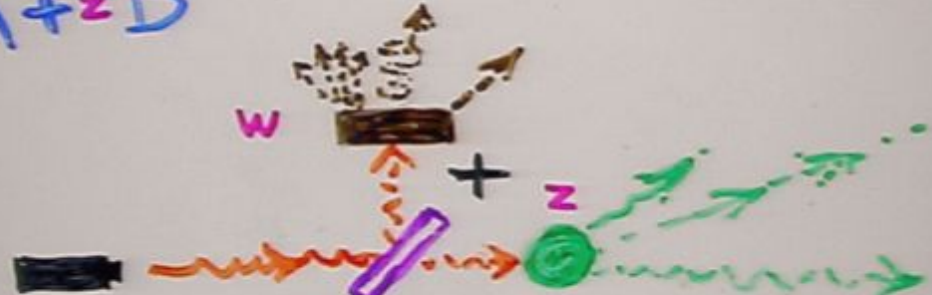
$wA + zB$

w

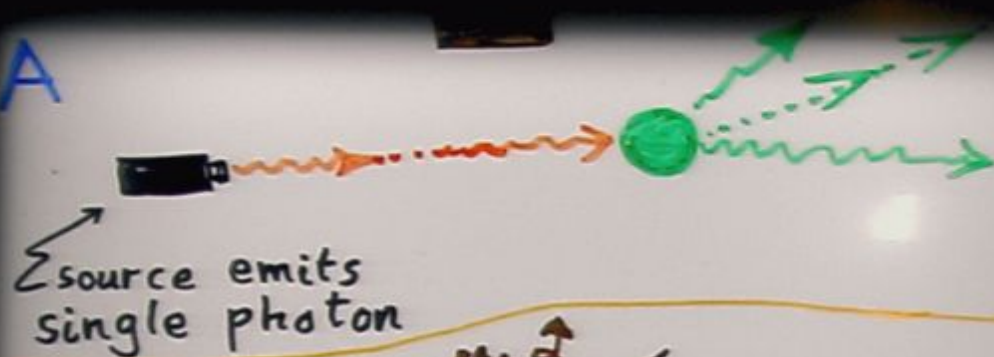
+

z

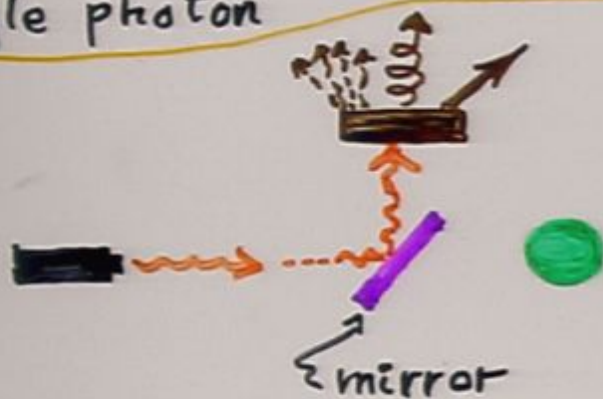
beam splitter



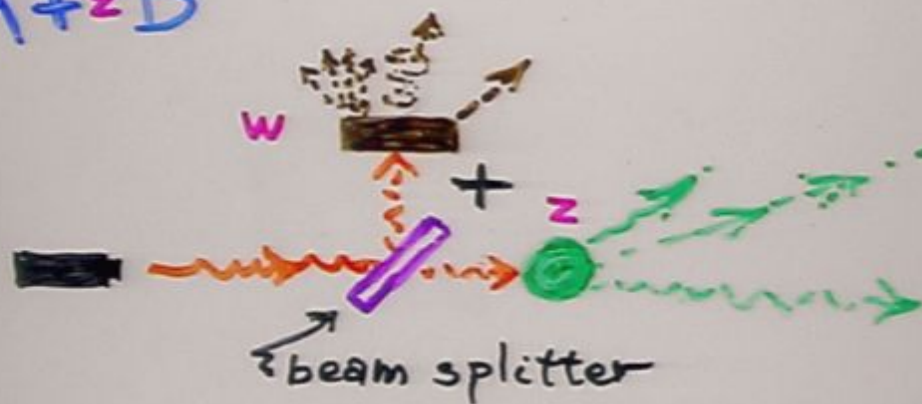
A



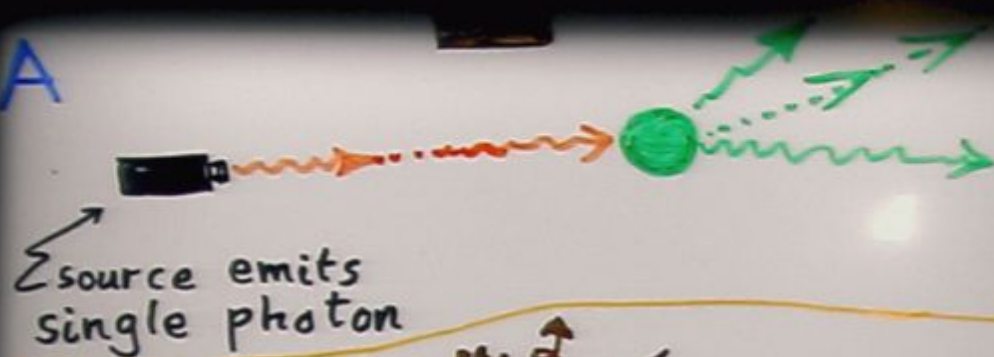
B



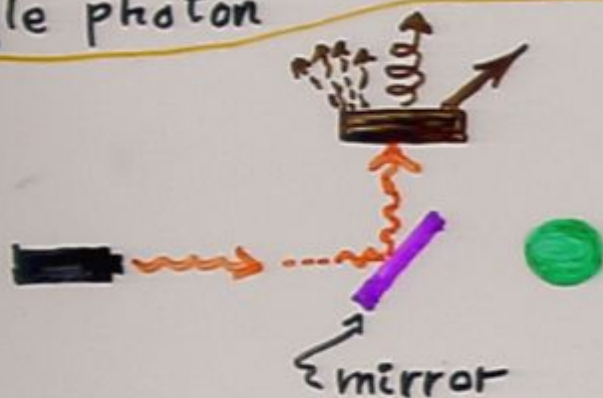
$wA + zB$



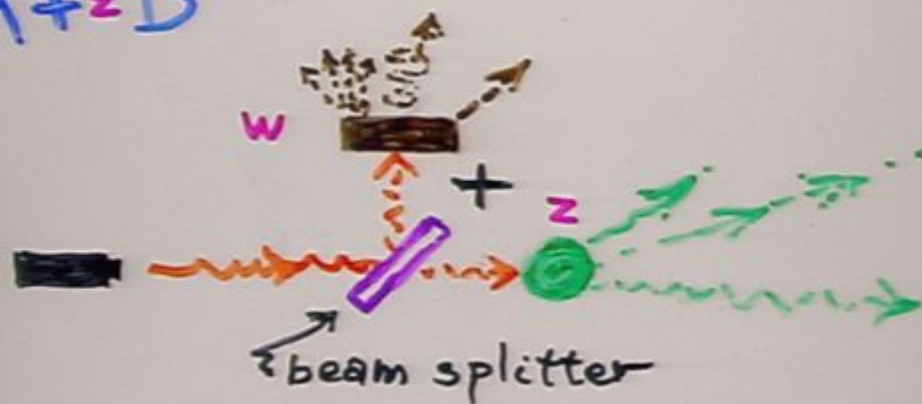
A



B

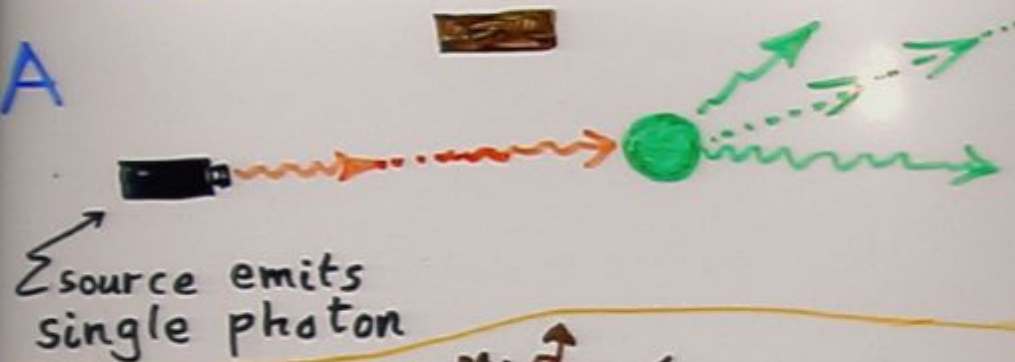


$wA + zB$

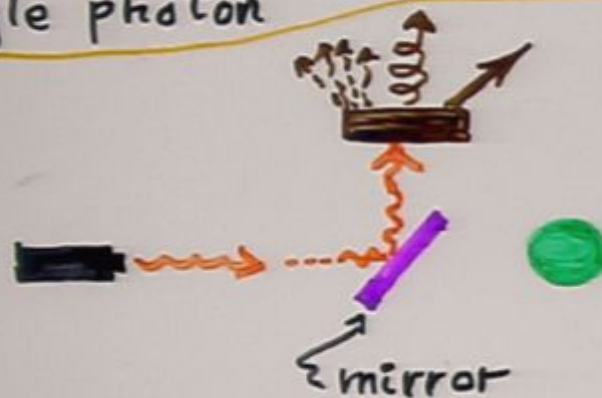


Quantum Linearity

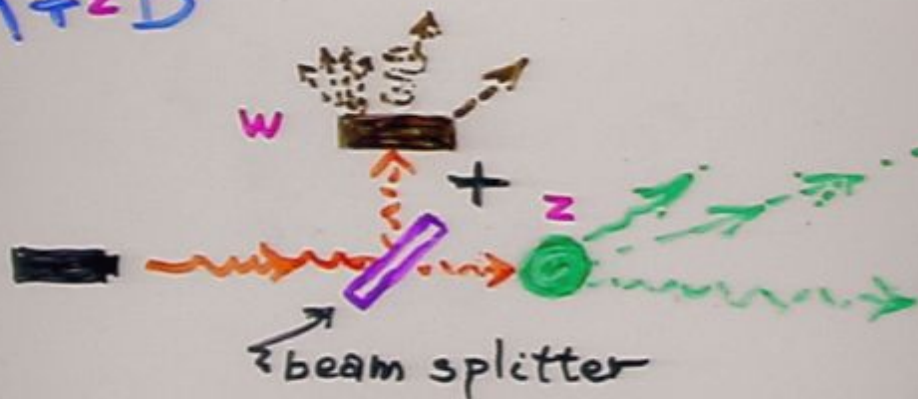
A



B



$wA + zB$

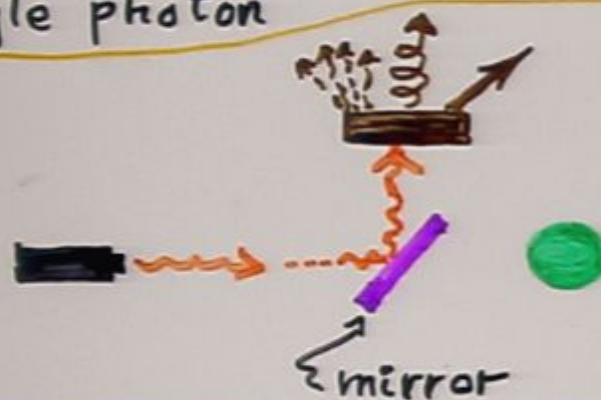


Quantum Linearity

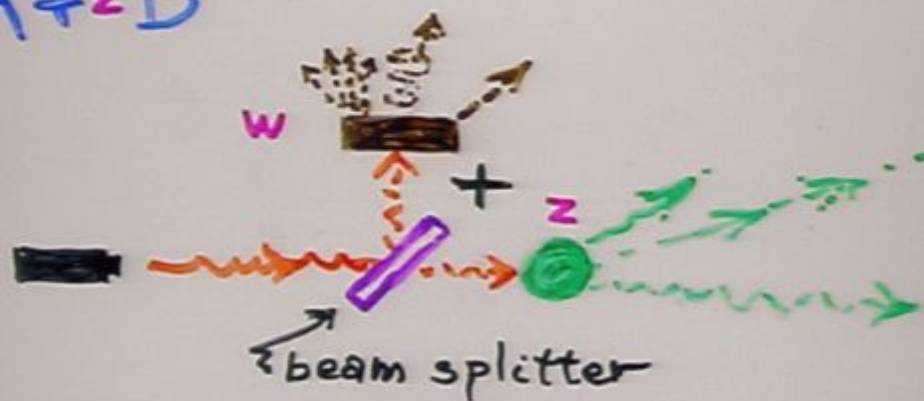
A



B

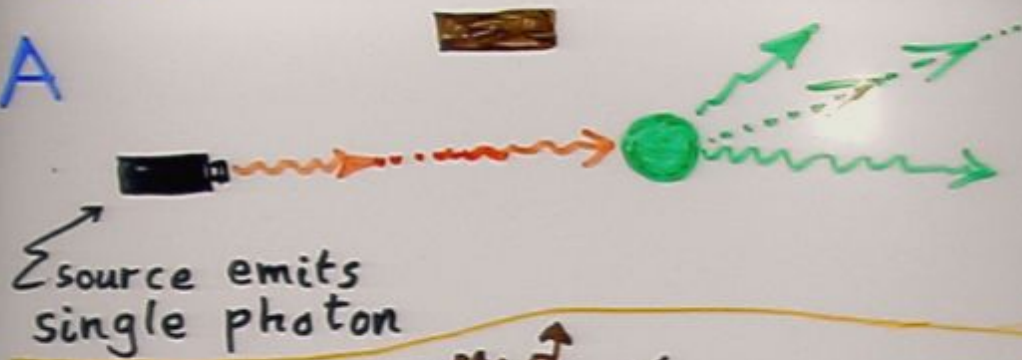


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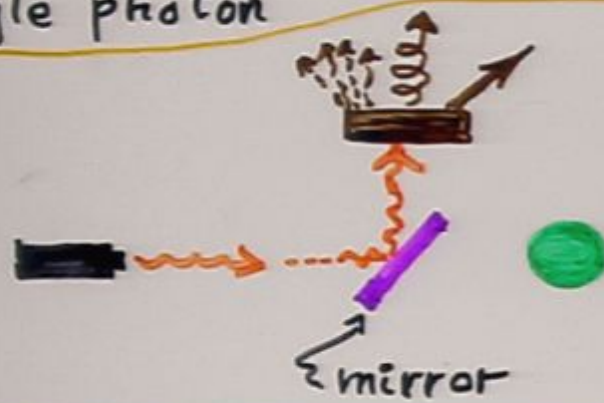


Quantum Entanglement

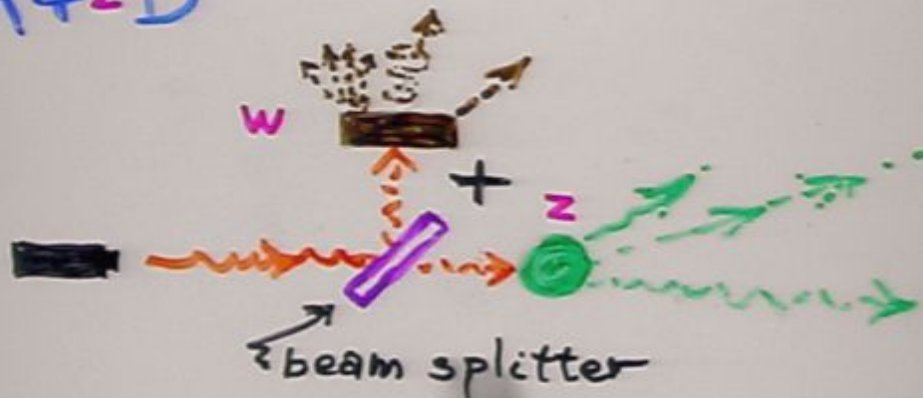
A



B

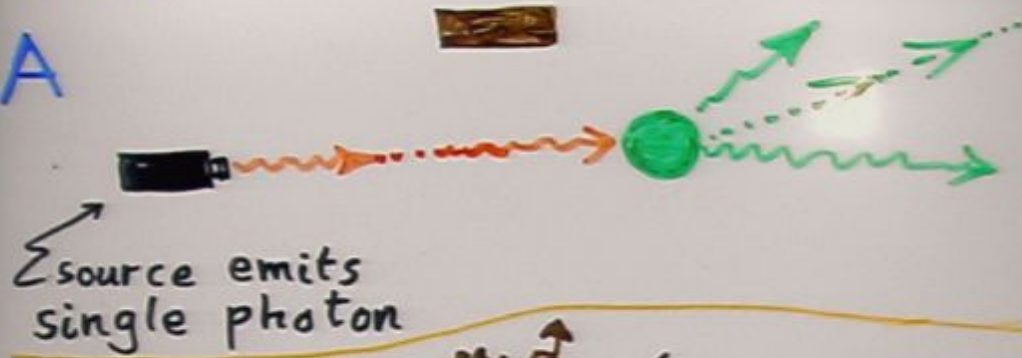


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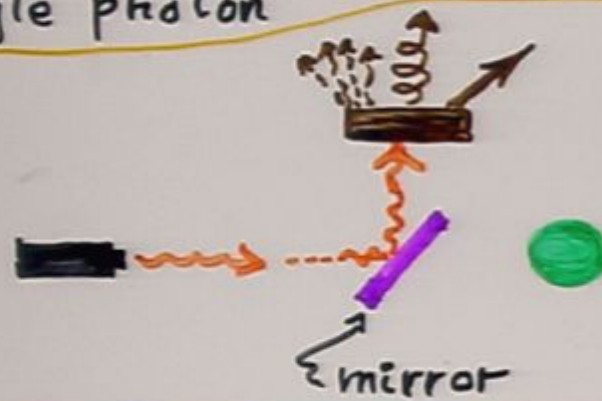


Quantum Entanglement

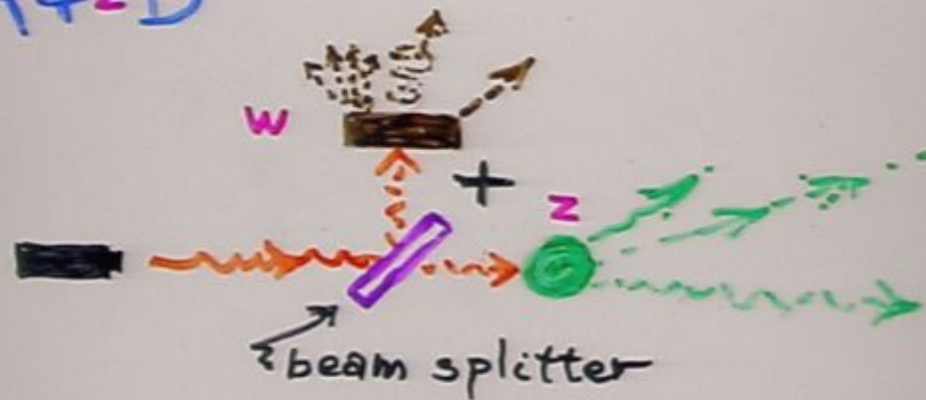
A



B

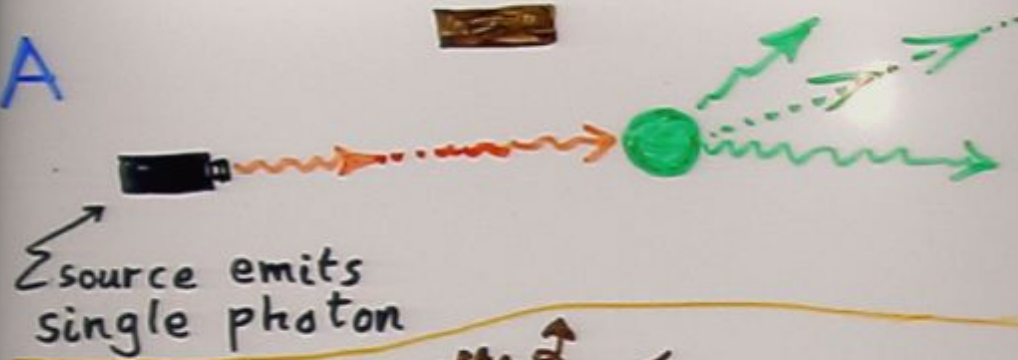


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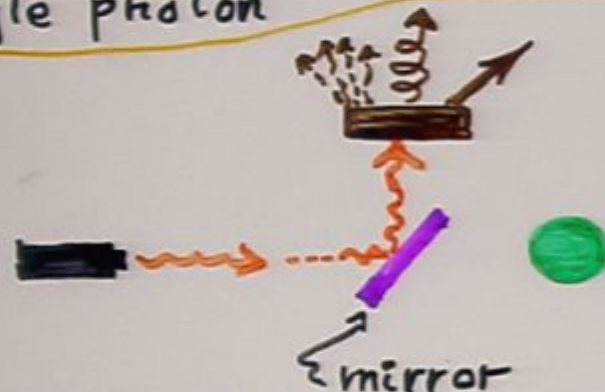


Quantum Linearity

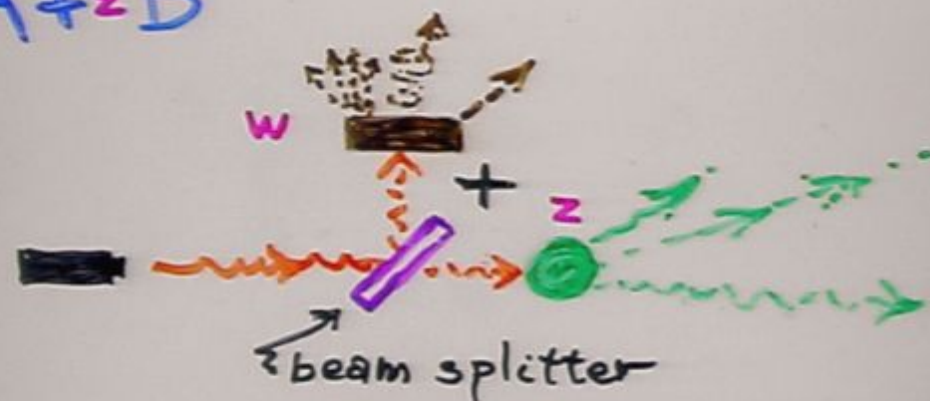
A



B

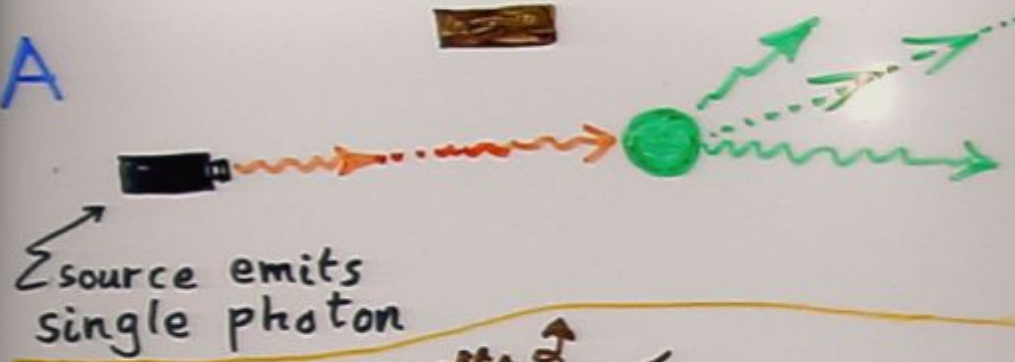


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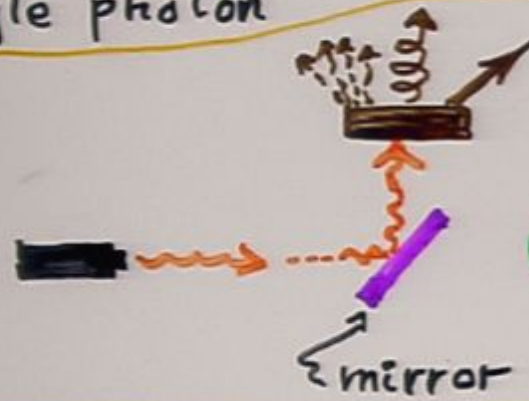


Quantum Electrodynamics

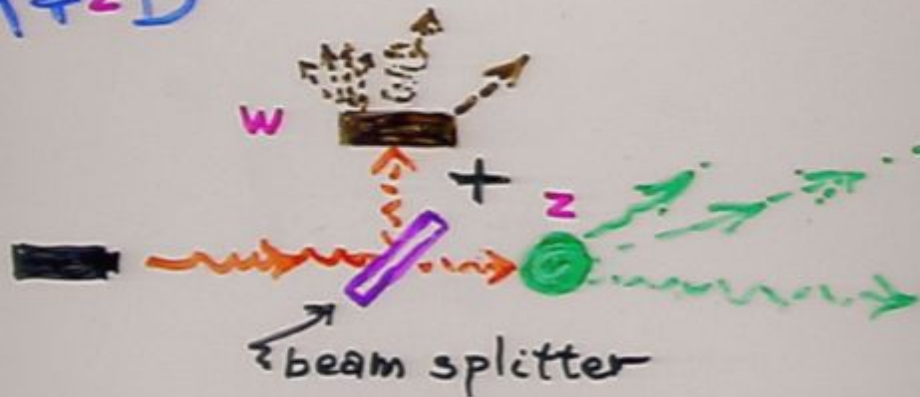
A



B

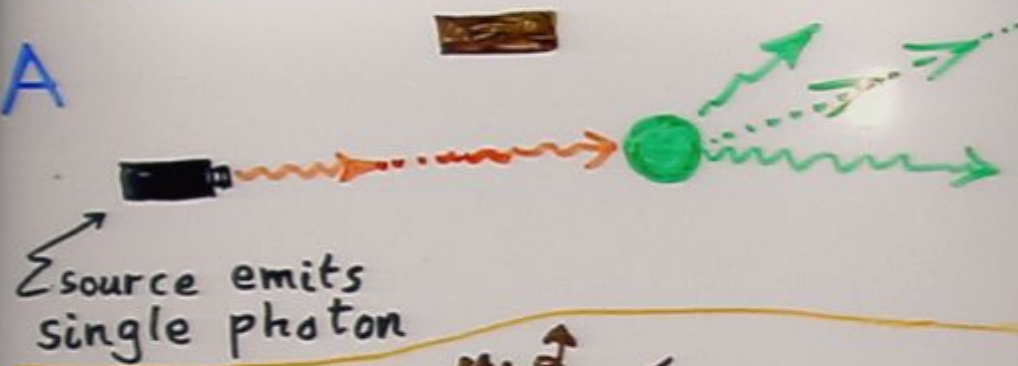


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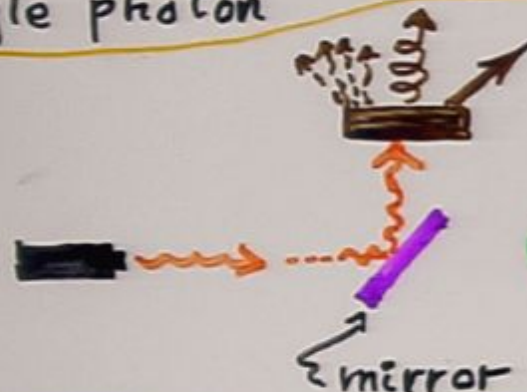


Quantum Linearity

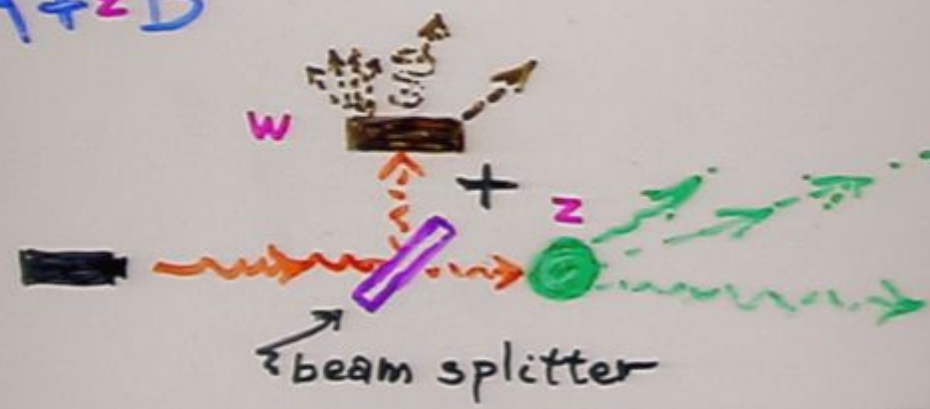
A



B

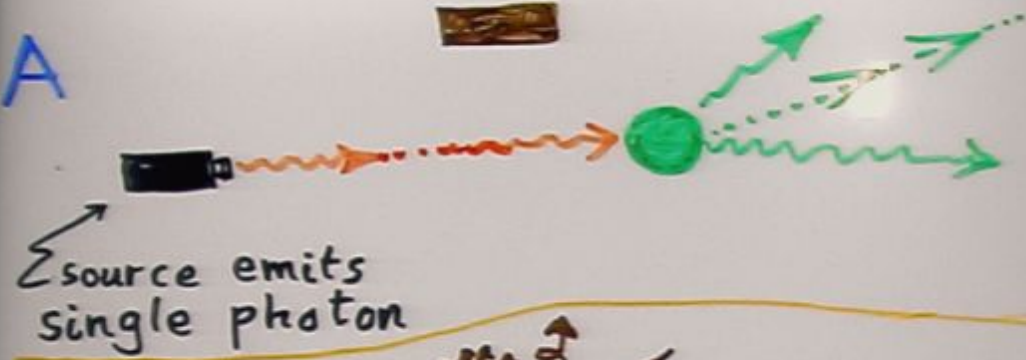


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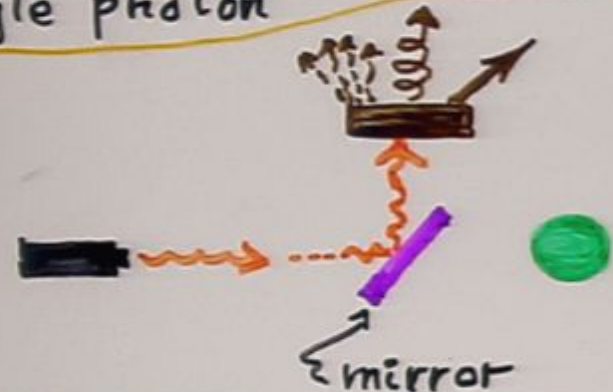


Quantum Electrodynamics

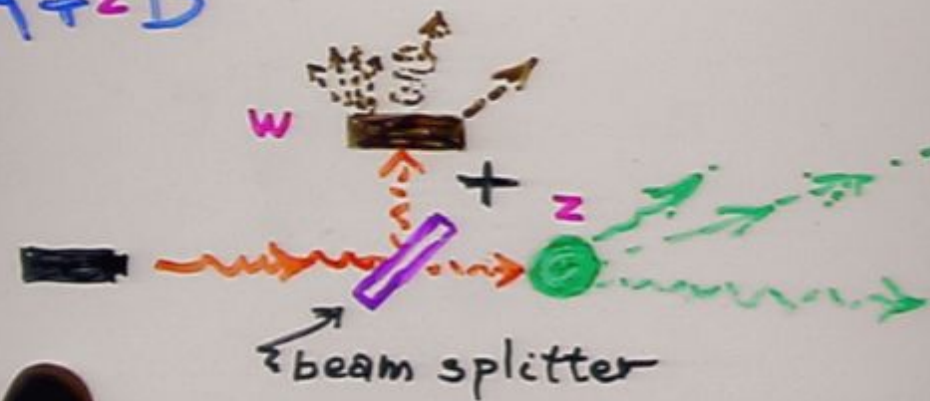
A



B

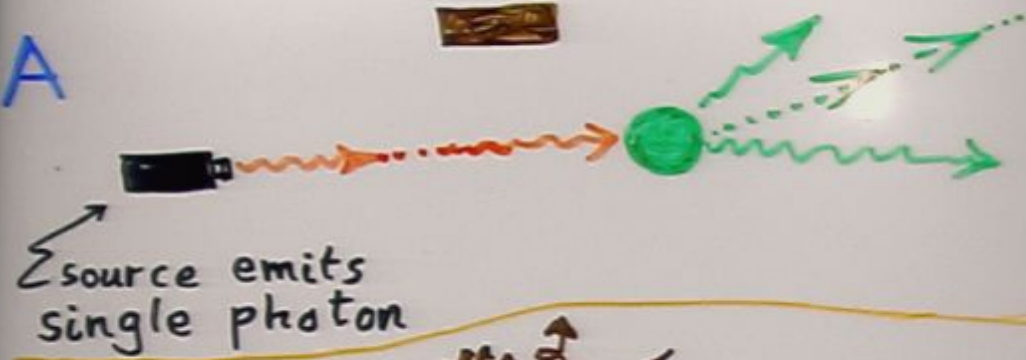


$wA + zB$

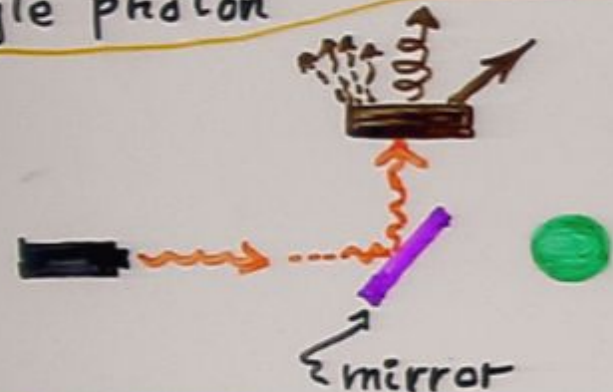


Quantum Linearity

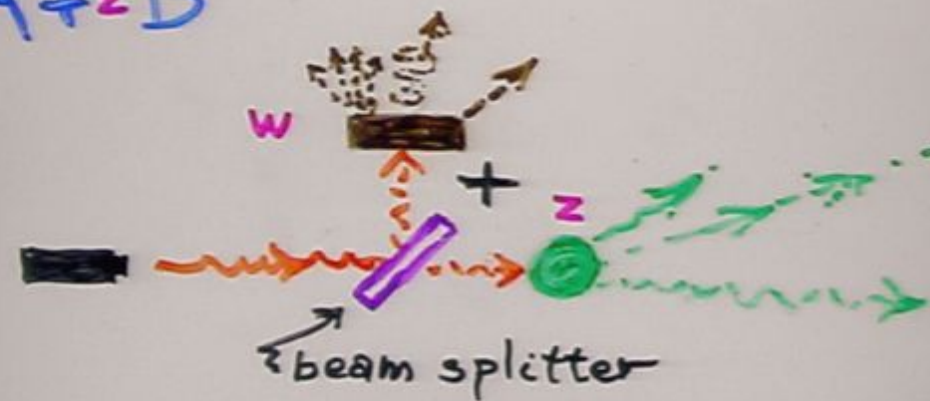
A



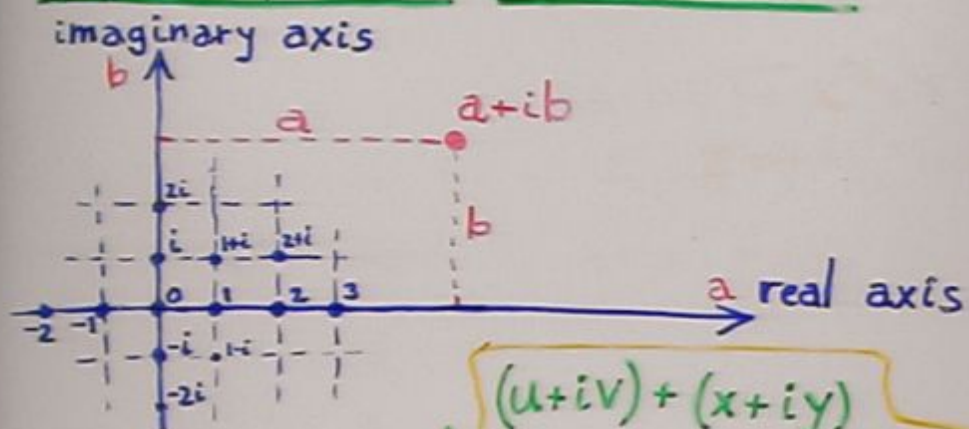
B



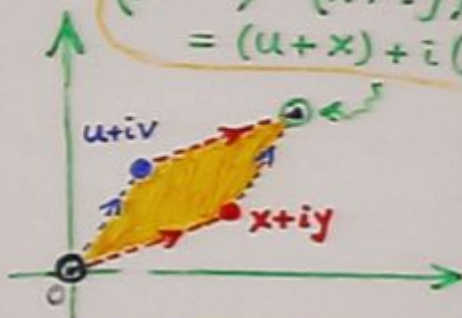
$wA + zB$



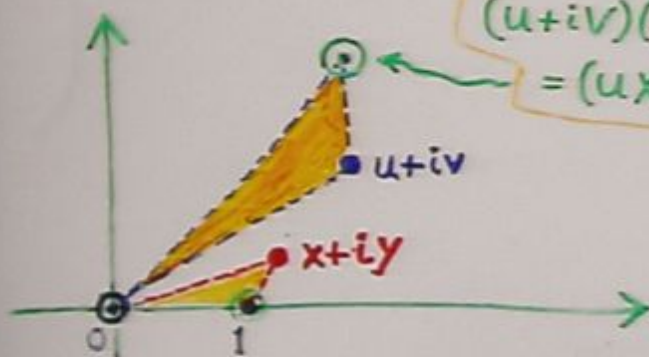
Complex Numbers



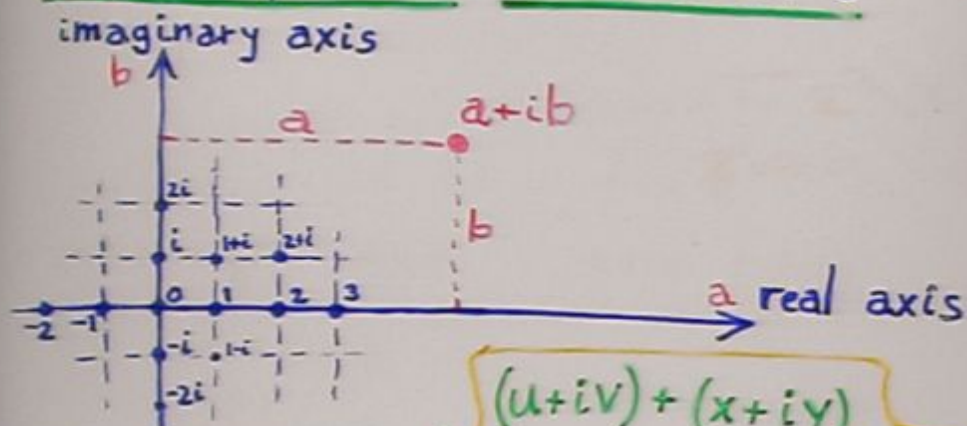
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



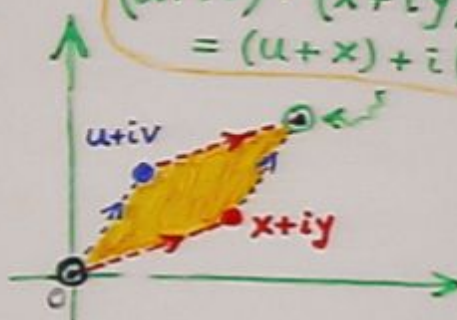
$$(u+iv)(x+iy) = (ux-vy) + i(vx+uy)$$



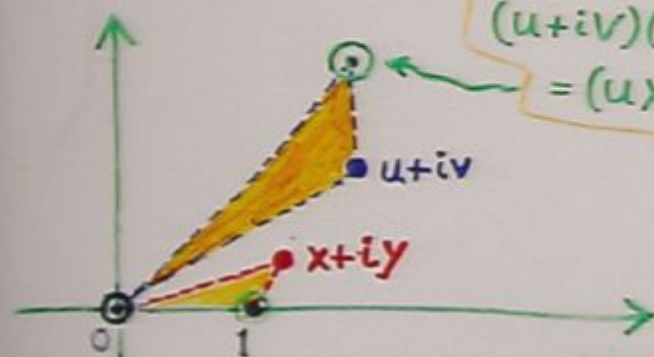
Complex Numbers



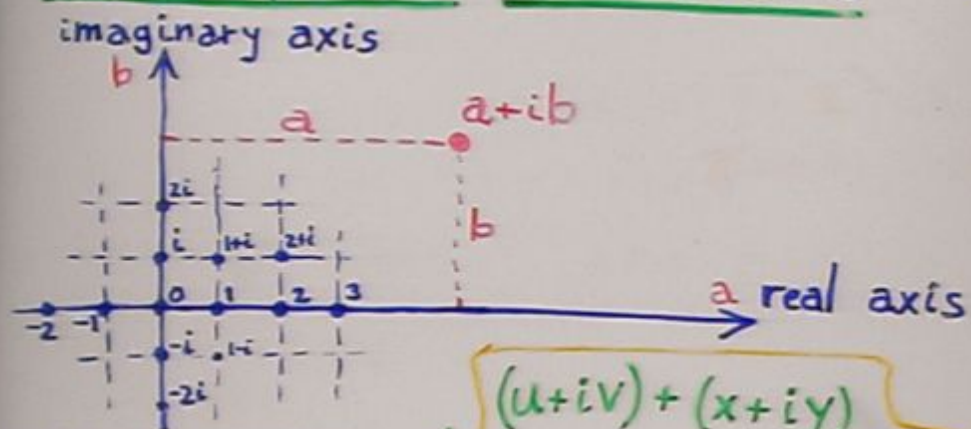
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



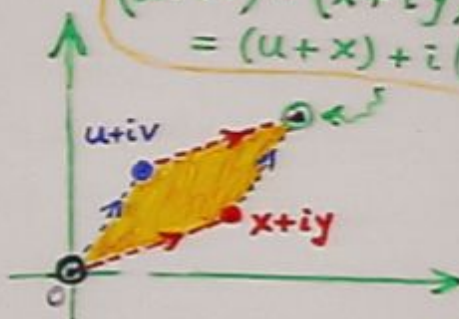
$$(u+iv)(x+iy) = (ux - vy) + i(vx + uy)$$



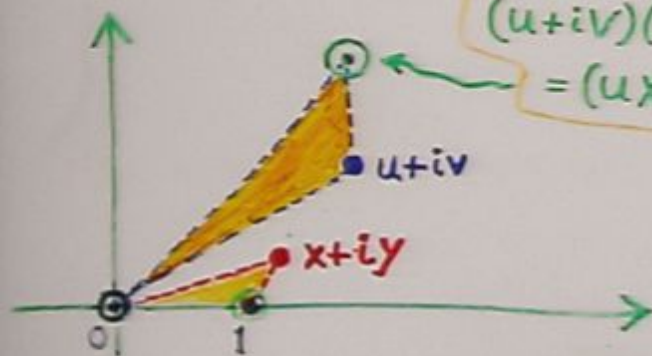
Complex Numbers



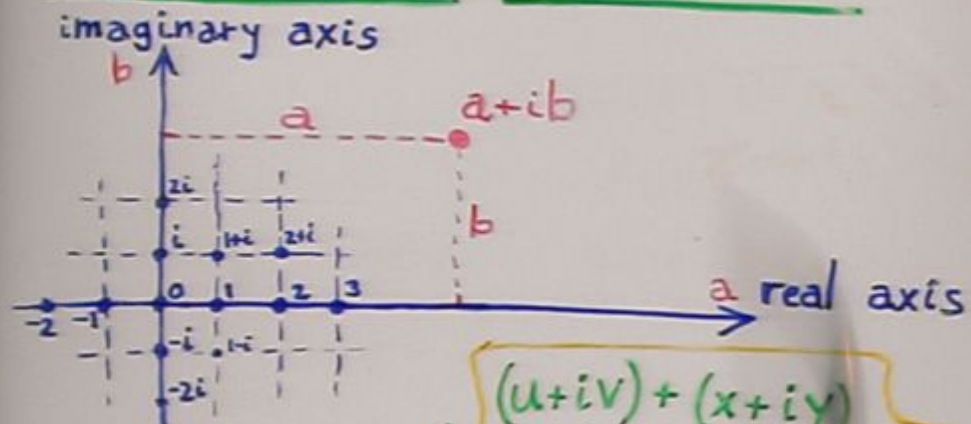
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



$$(u+iv)(x+iy) = (ux - vy) + i(vx + uy)$$



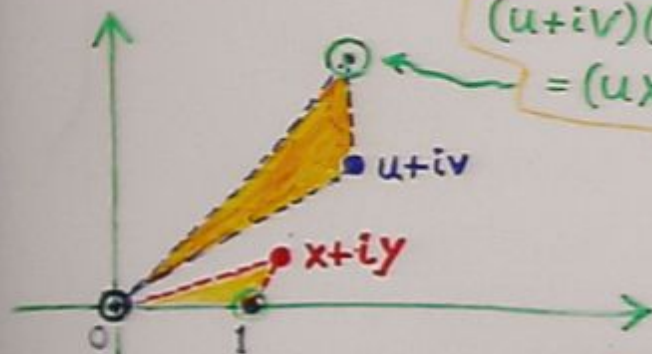
Complex Numbers



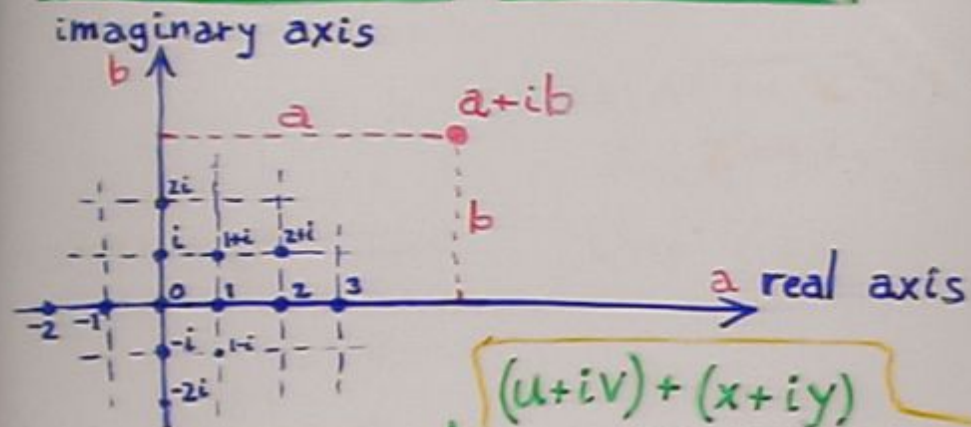
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



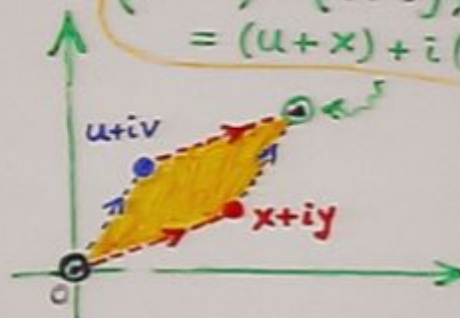
$$(u+iv)(x+iy) = (ux - vy) + i(vx + uy)$$



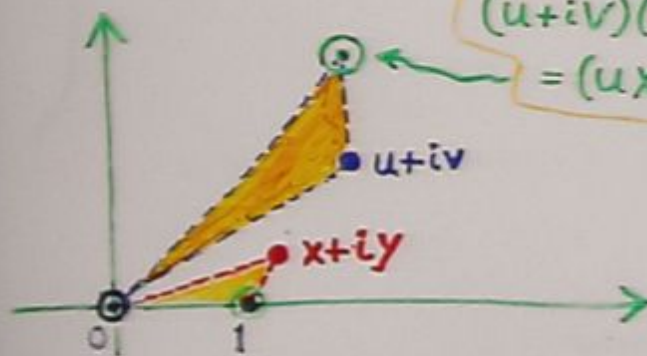
Complex Numbers



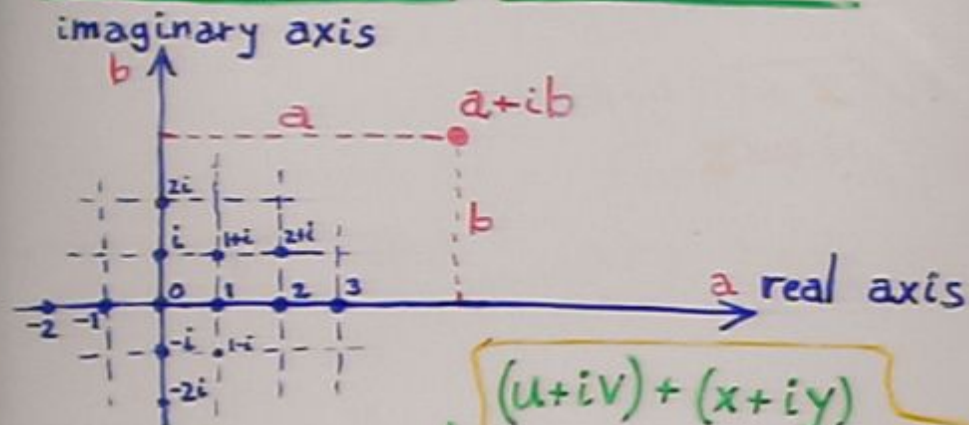
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



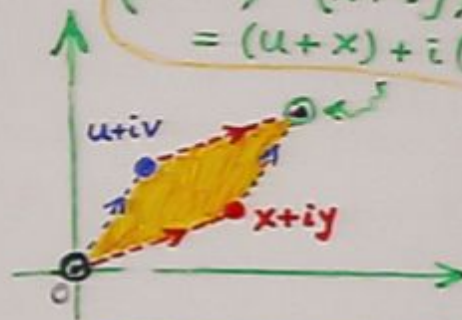
$$(u+iv)(x+iy) = (ux - vy) + i(vx + uy)$$



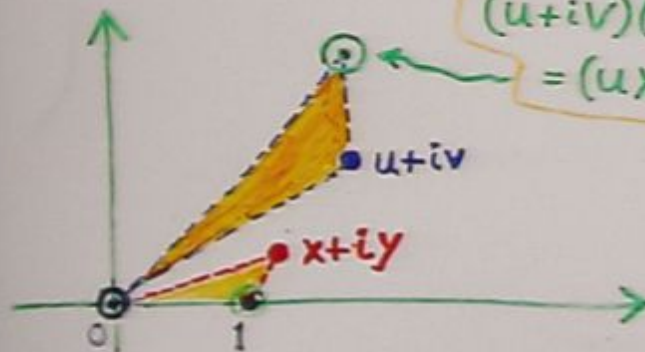
Complex Numbers



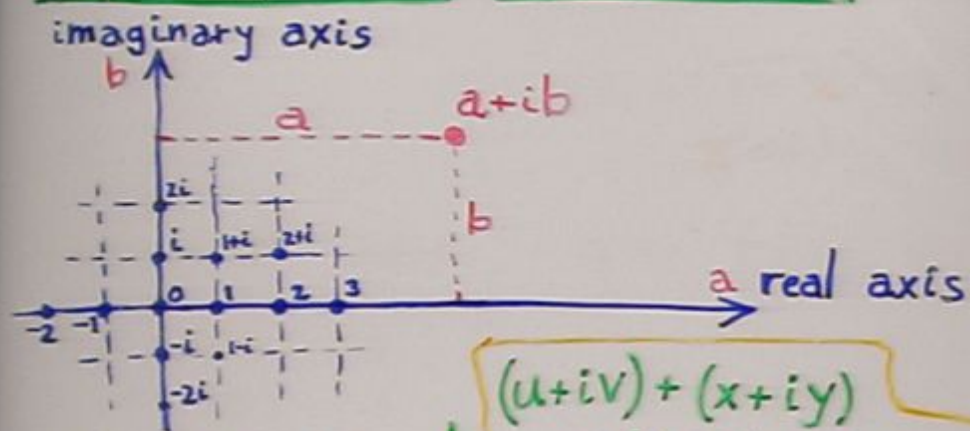
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



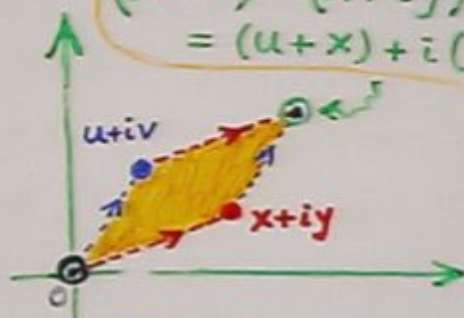
$$(u+iv)(x+iy) = (ux-vy) + i(vx+uy)$$



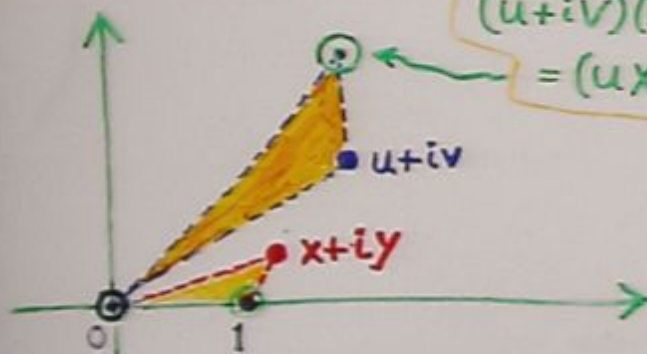
Complex Numbers



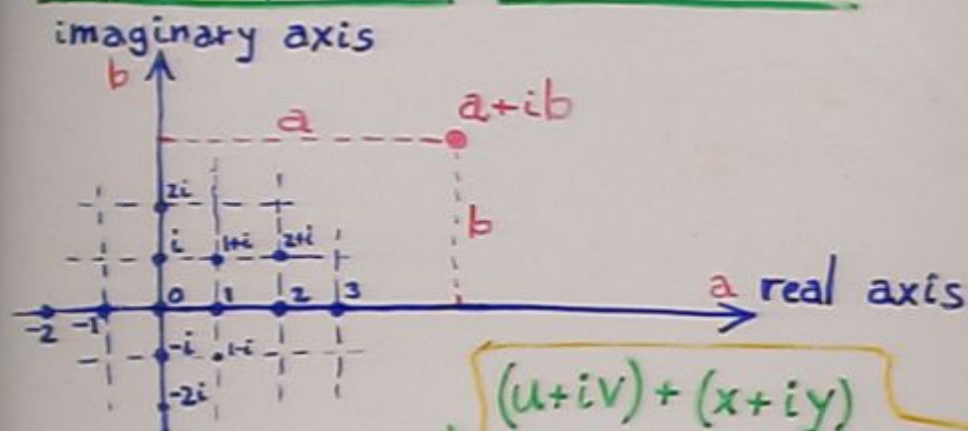
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



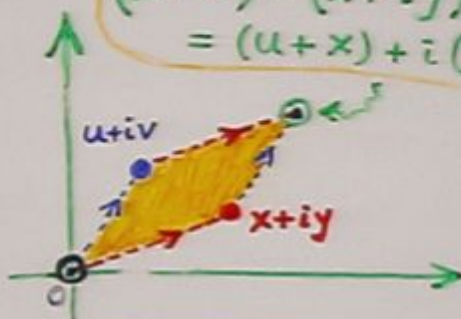
$$(u+iv)(x+iy) = (ux-vy) + i(vx+uy)$$



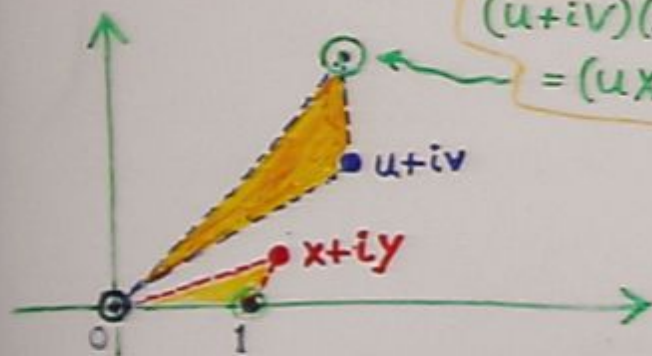
Complex Numbers



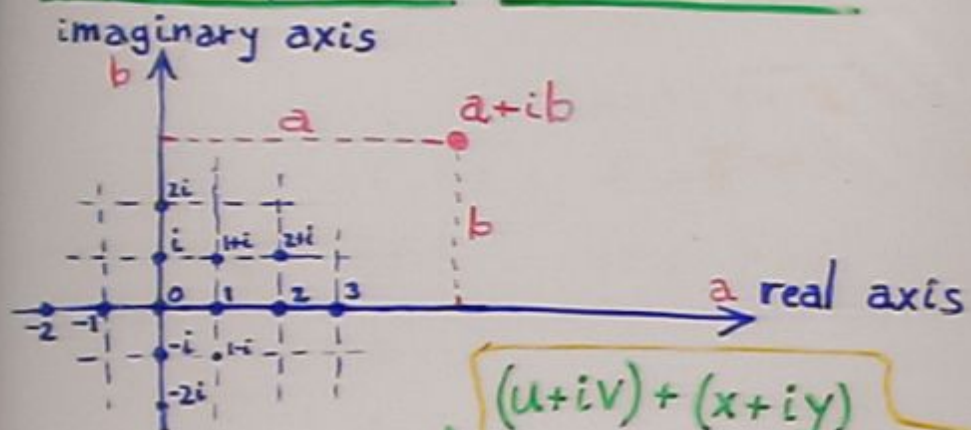
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



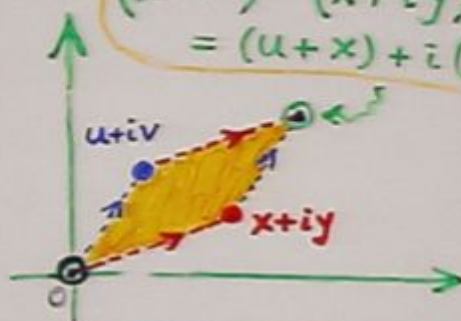
$$(u+iv)(x+iy) = (ux-vy) + i(vx+uy)$$



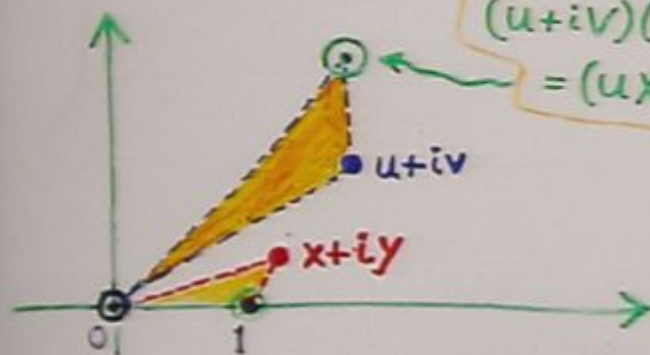
Complex Numbers



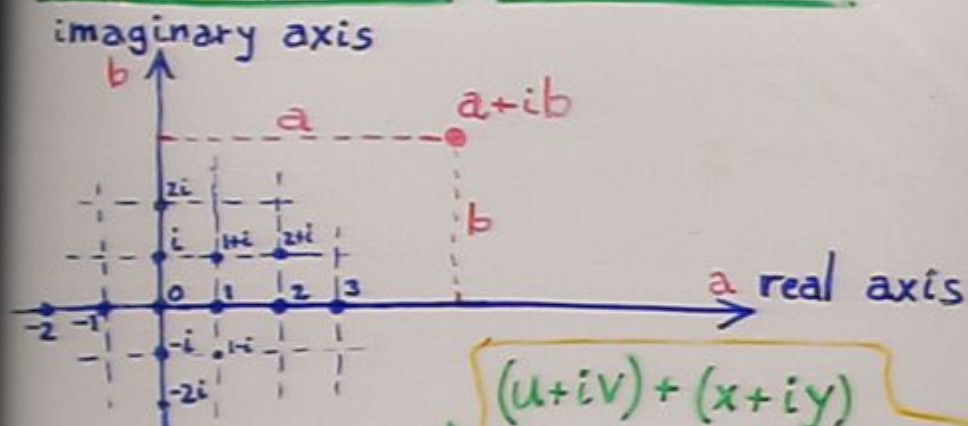
$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



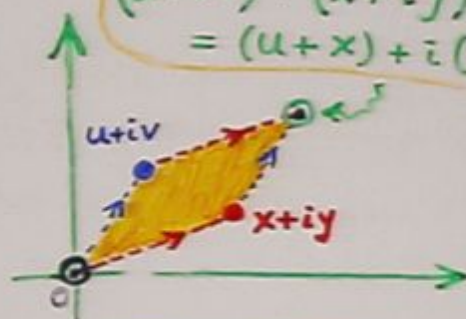
$$(u+iv)(x+iy) = (ux - vy) + i(vx + uy)$$



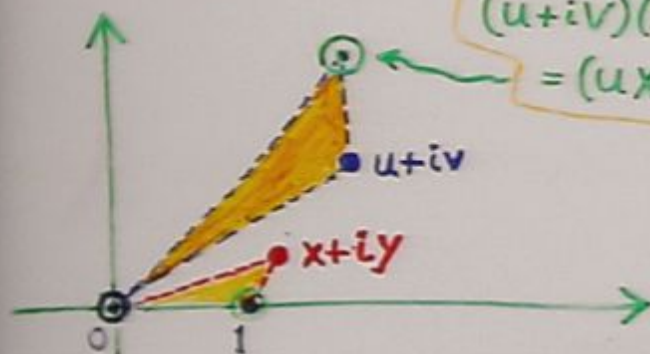
Complex Numbers



$$(u+iv) + (x+iy) = (u+x) + i(v+y)$$



$$(u+iv)(x+iy) = (ux-vy) + i(vx+uy)$$

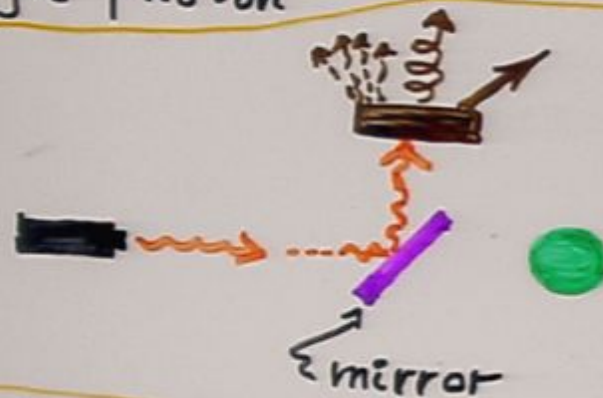


Quantum Linearity

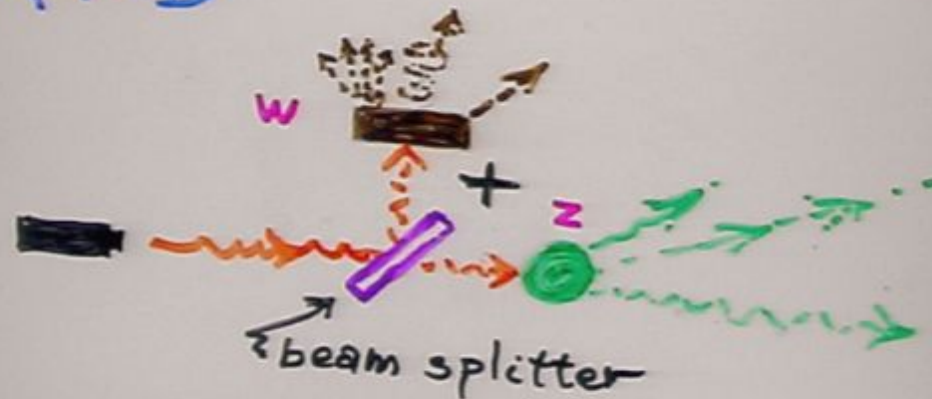
A



B

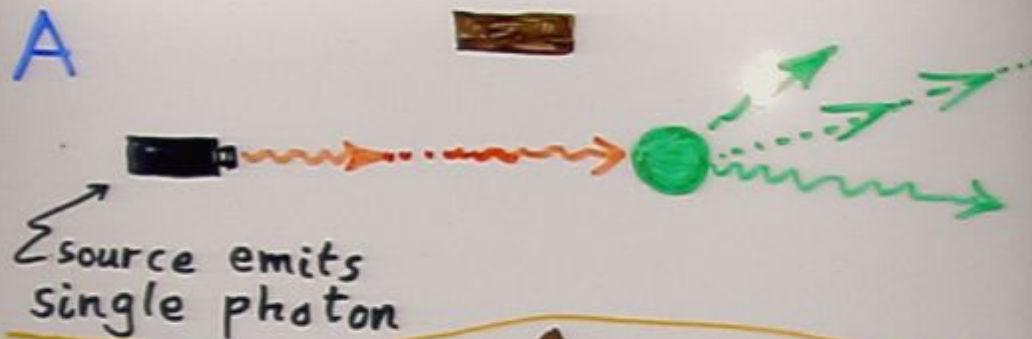


$$wA + zB$$

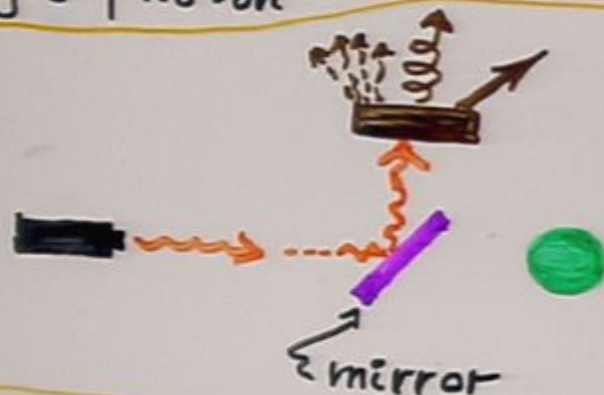


Quantum Linearity

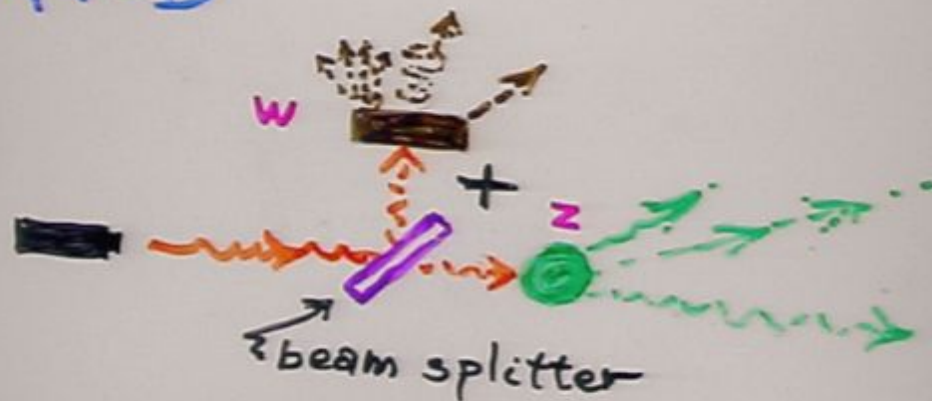
A



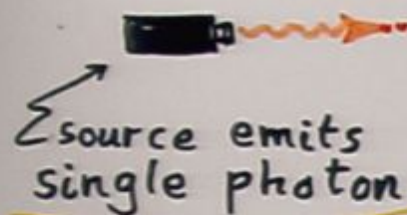
B



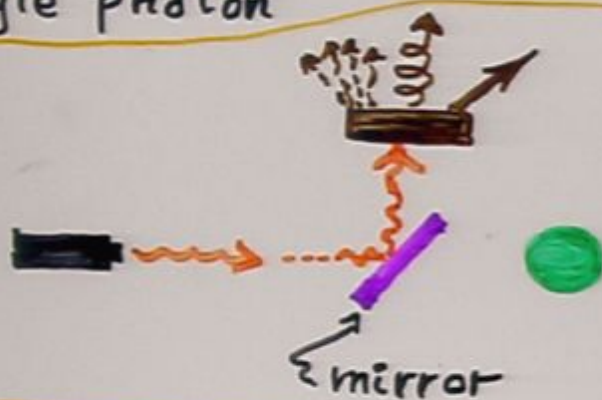
$$wA + zB$$



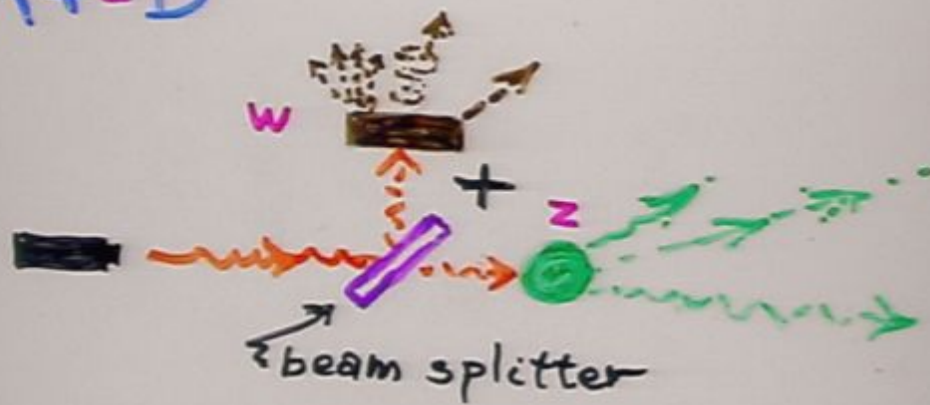
A



B



$wA + zB$



Quantum-mechanical spin

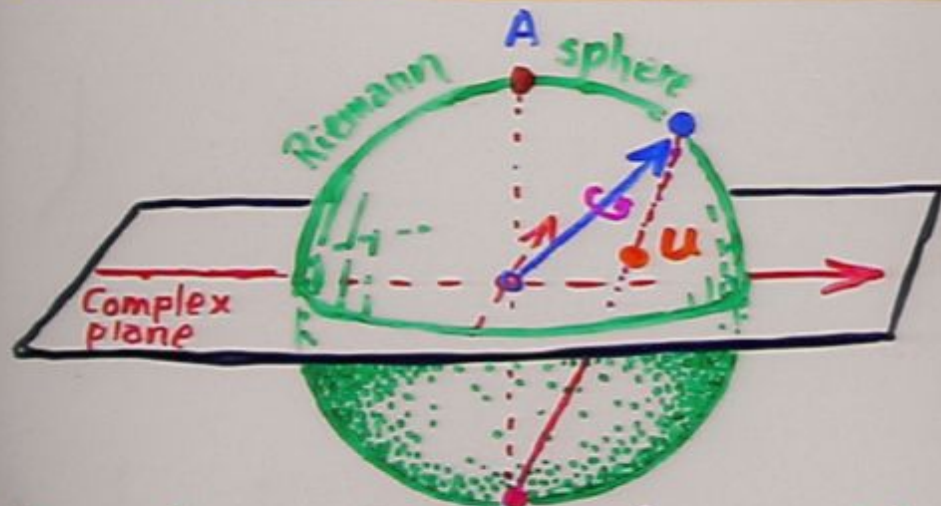
[— for spin $\frac{1}{2}$
eg. electron, proton, neutron
quark, ...]

Basis states

A: 

B: 

$wA + zB$: 

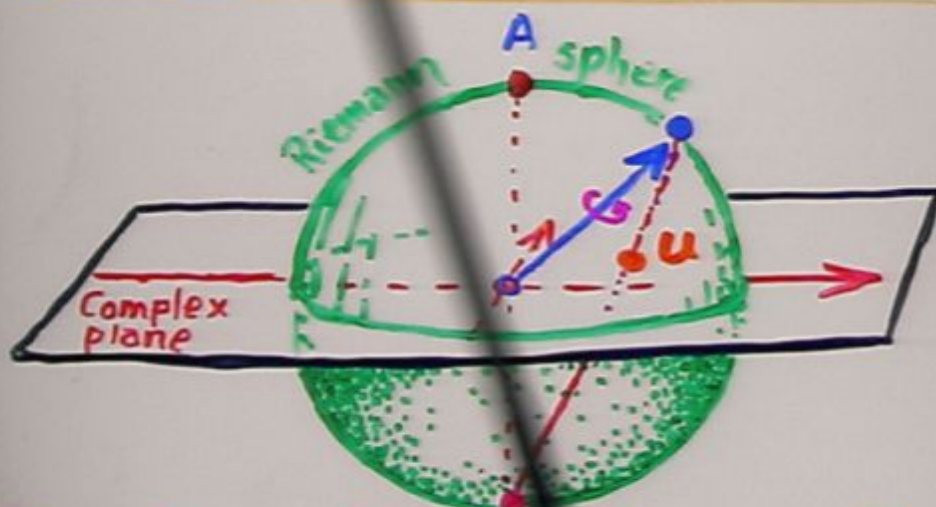
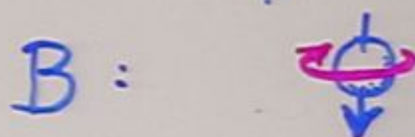
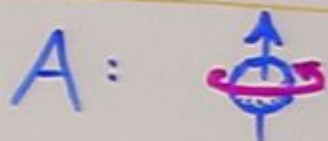


Complex ratio: $z/u = u$

Quantum-mechanical spin

— for spin $\frac{1}{2}$
eg. electron, proton, neutron, quark, ...

Basis states



Complex ratio: $\frac{z}{w} = u$

Quantum-mechanical spin

[— for spin $\frac{1}{2}$
eg. electron, proton, neutron
quark, ...]

Basis states

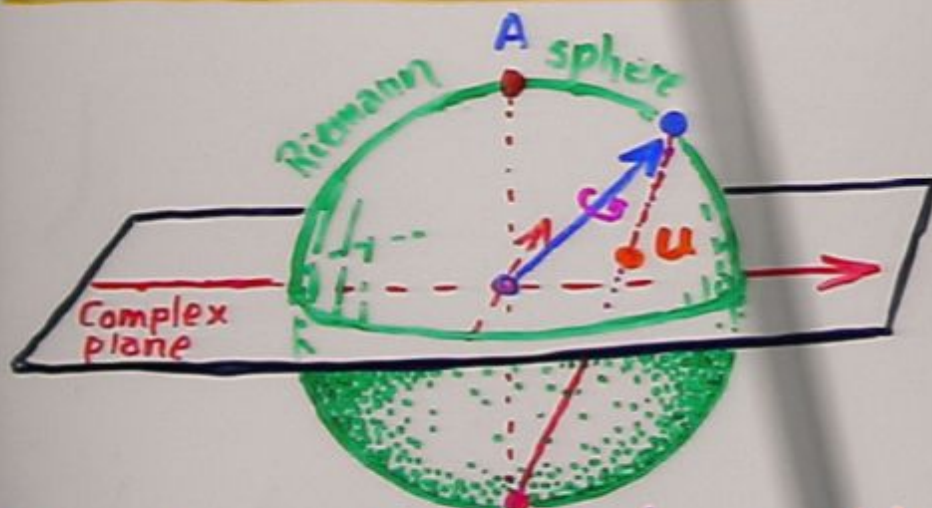
A:



B:



$wA + zB$:



Complex ratio: $z/w = u$

Quantum-mechanical spin

[— for spin $\frac{1}{2}$
eg. electron, proton, neutron
quark, ...]

Basis states

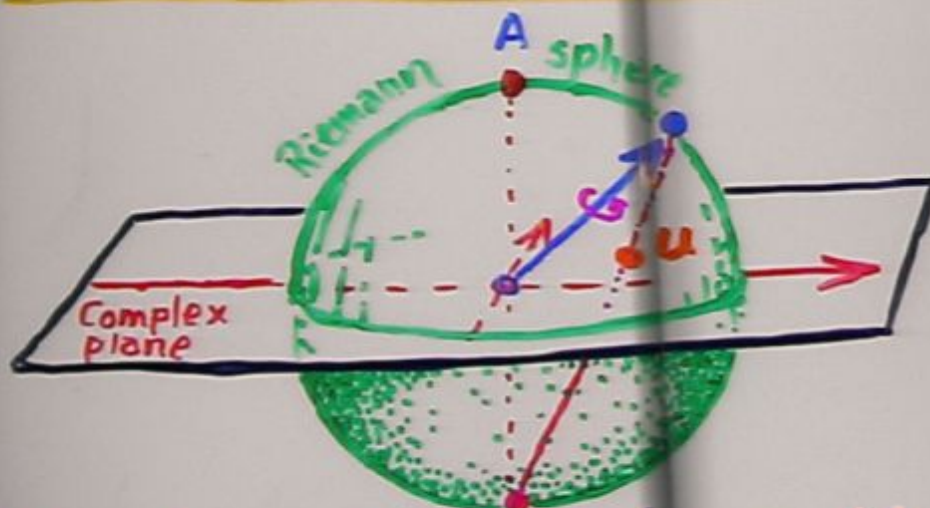
A:



B:



$wA + zB$:



Complex ratio: $z/w = u$

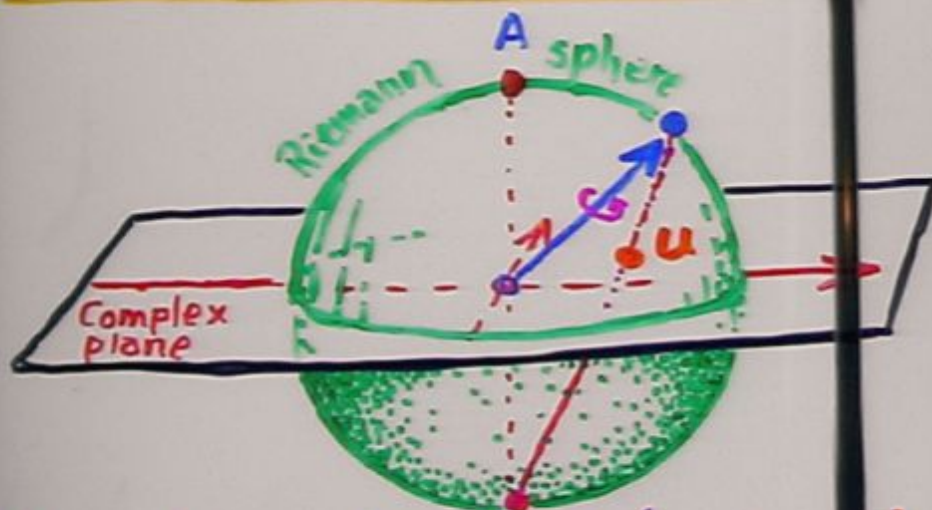
Quantum-mechanical spin

— for spin $\frac{1}{2}$
eg. electron, proton, neutron
quark, ...

Basis states A : 

B : 

$wA + zB$: 



Complex ratio: $z/w = u$

Quantum-mechanical
spin — for spin

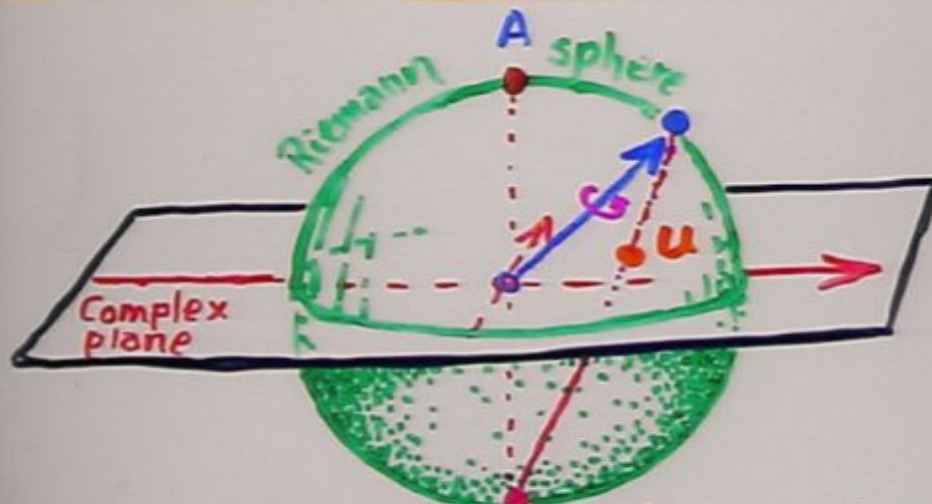
— for spin
e.g. electron, proton, neutron
quark, ...

Basis states

A:



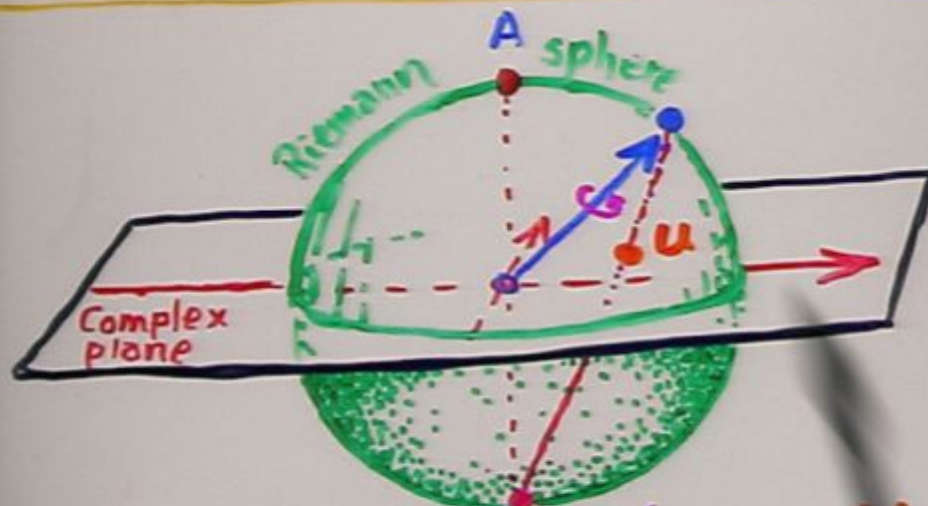
B :

 $wA + zB :$ 

Complex ratio: $z/w = u$

Quantum-mechanical spin [— for spin $\frac{1}{2}$ eg. electron, proton, neutron quark, ...]

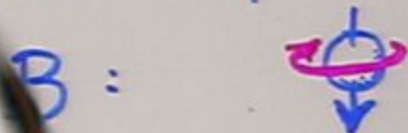
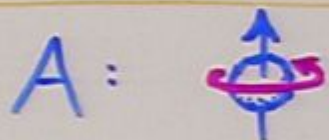
Basis states A: 
 B: 
 $wA + zB$: 



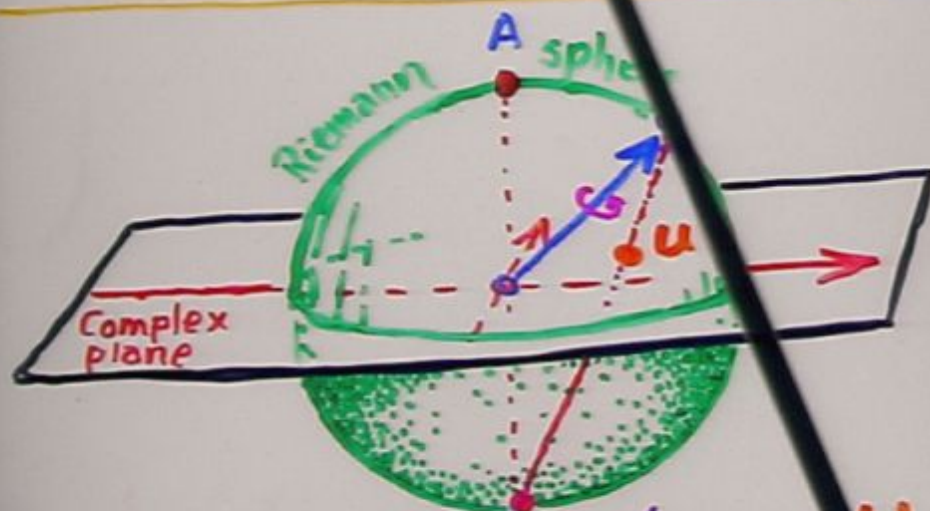
Complex ratio: $z/w = u$

Quantum-mechanical Spin [— for spin $\frac{1}{2}$ eg. electron, proton, neutron quark, ...]

Basis states



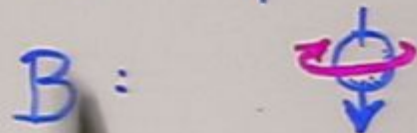
$wA + zB$:



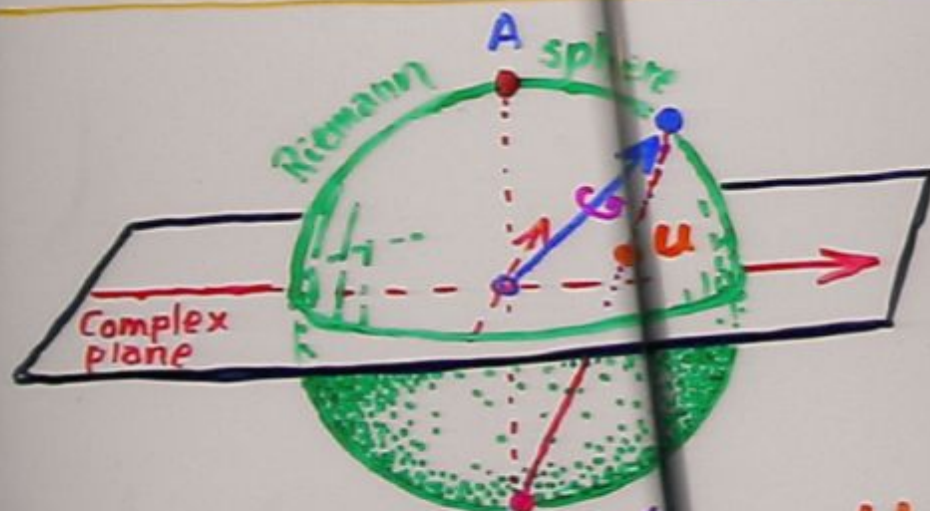
Complex ratio: $z/w = U$

Quantum-mechanical Spin [— for spin $\frac{1}{2}$ eg. electron, proton, neutron quark, ...]

Basis states



$wA + zB$:



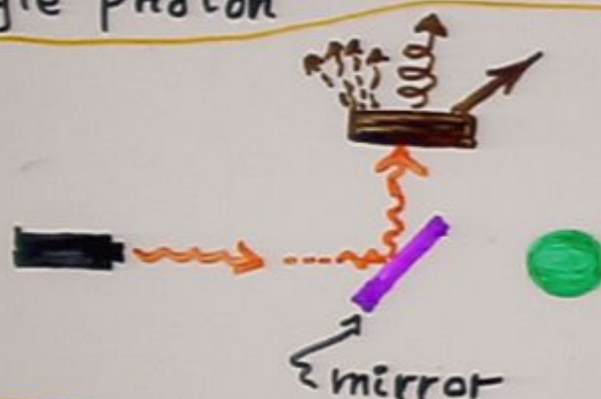
Complex ratio: $\frac{z}{w} = u$

Quantum Linearity

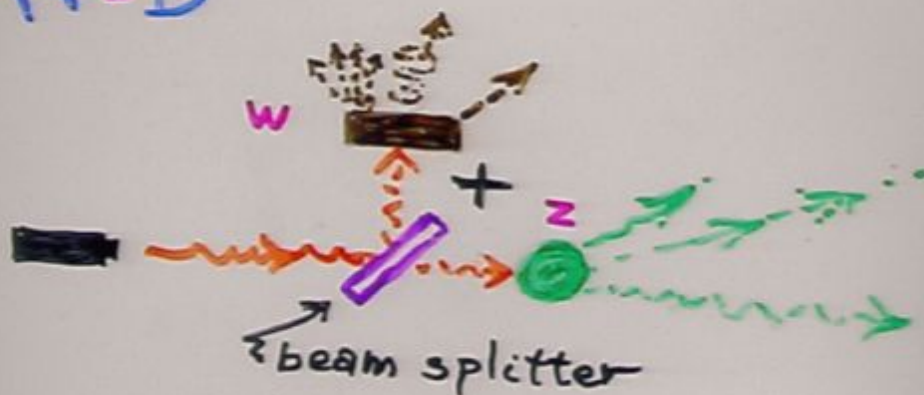
A



B



$wA + zB$



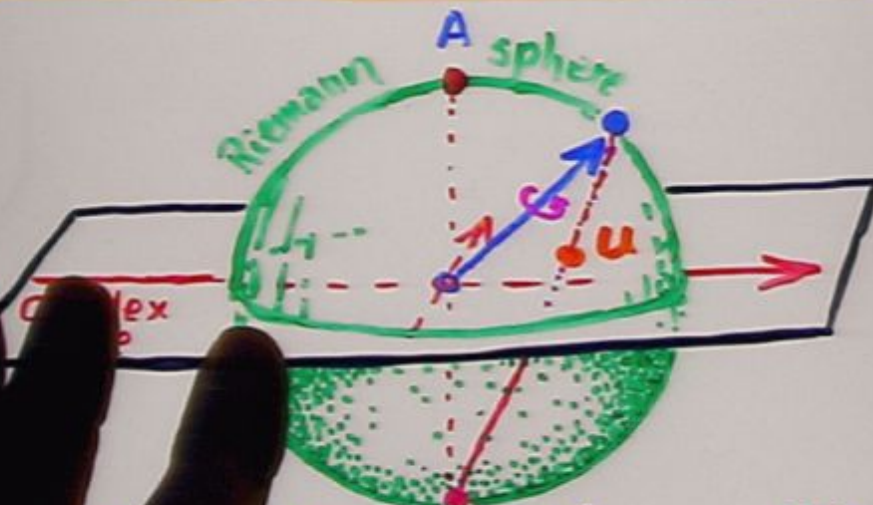
Quantum-mechanical
spin — for spin

— for spin :
eg. electron, proton, neutron
quark, ...

Basis states

A: 

B :

 $wA + zB :$ 

ratio: $z/w = u$

Quantum-mechanical spin

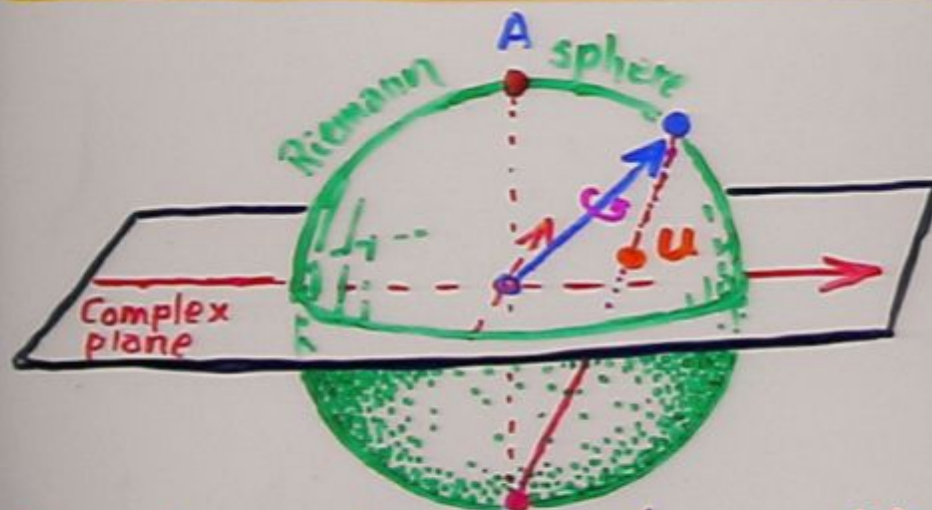
— for spin $\frac{1}{2}$
eg. electron, proton, neutron
quark, ...

Basis states

A: 

B: 

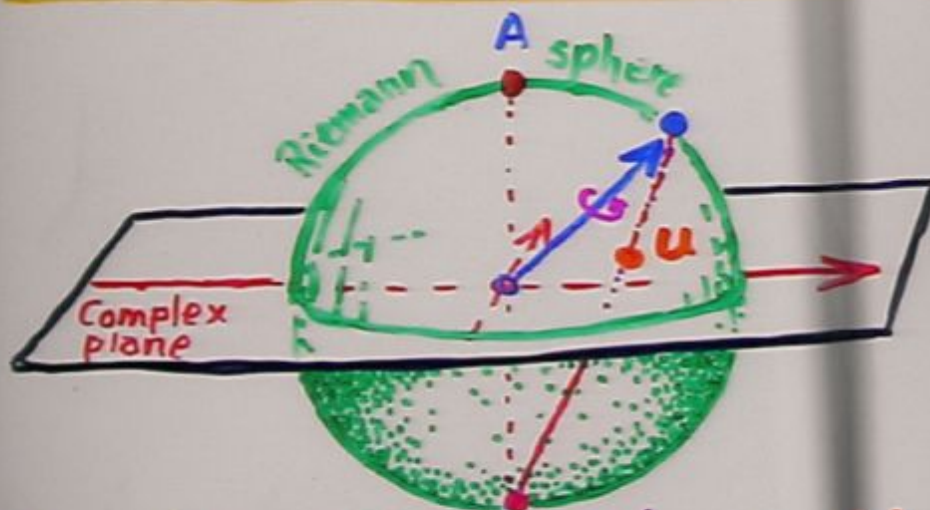
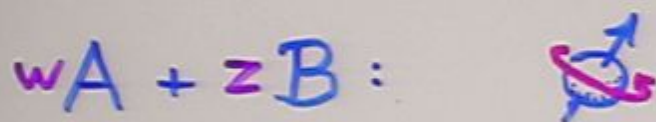
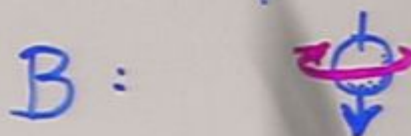
$wA + zB$: 



Complex ratio: $z/w = u$

Quantum-mechanical Spin [— for spin] eg. electron, proton, neutron quark, ...

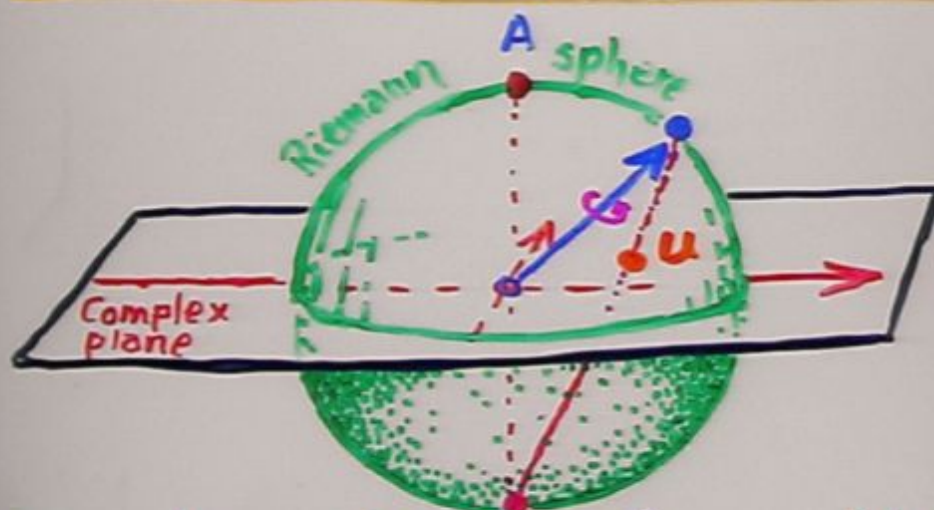
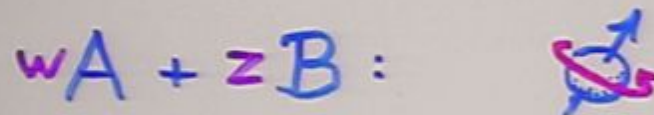
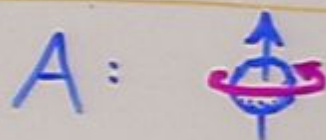
Basis states



Complex ratio: $\frac{z}{w} = u$

Quantum-mechanical Spin [— for spin $\frac{1}{2}$ eg. electron, proton, neutron quark, ...]

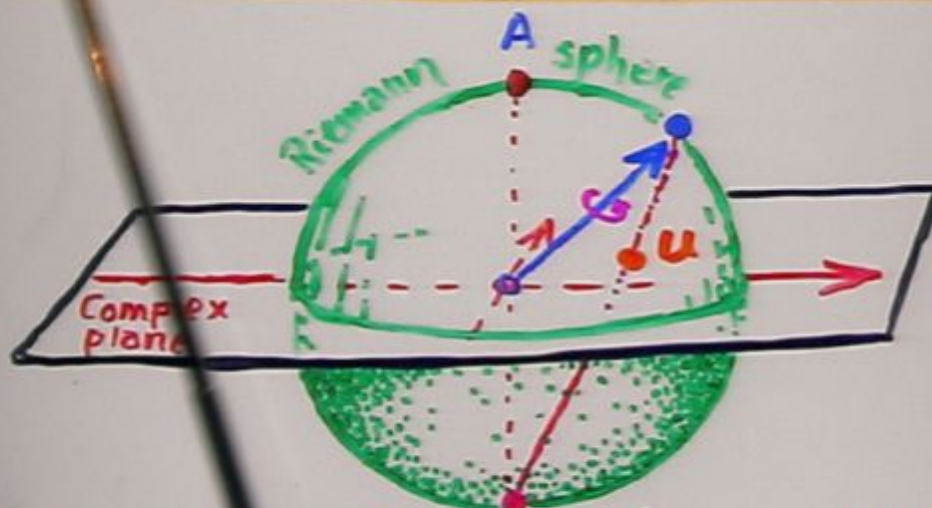
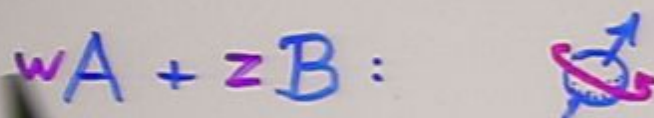
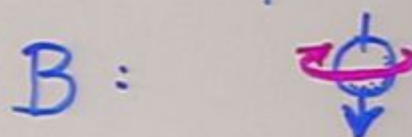
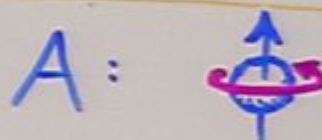
Basis states



Complex ratio: $z/w = u$

Quantum-mechanical Spin [— for spin $\frac{1}{2}$ eg. electron, proton, neutron quark, ...]

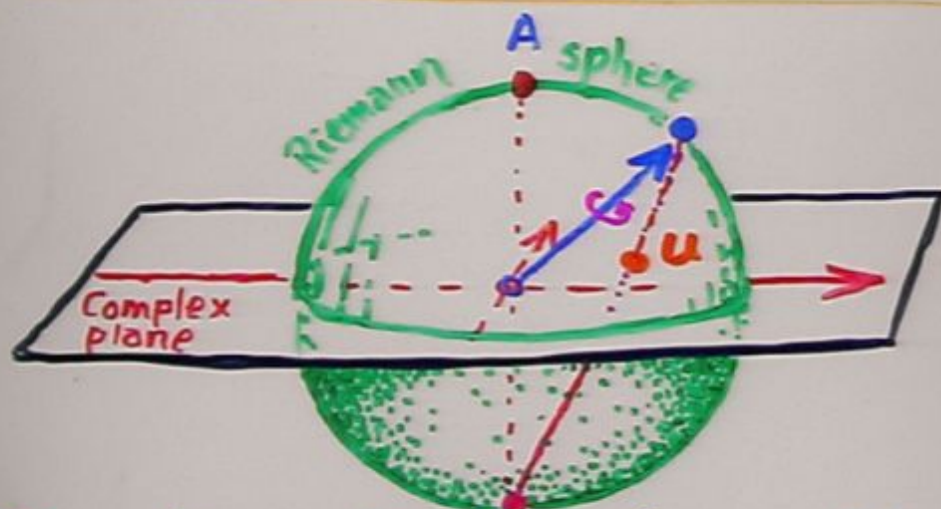
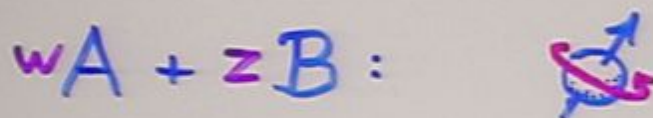
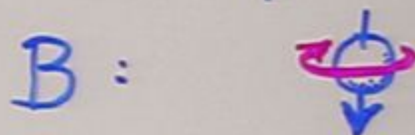
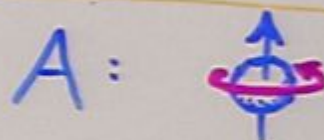
Basis states



Complex ratio: $\frac{z}{w} = u$

Quantum-mechanical Spin [— for spin $\frac{1}{2}$ eg. electron, proton, neutron, quark, ...]

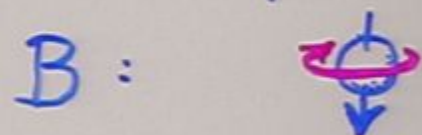
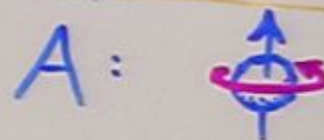
Basis states



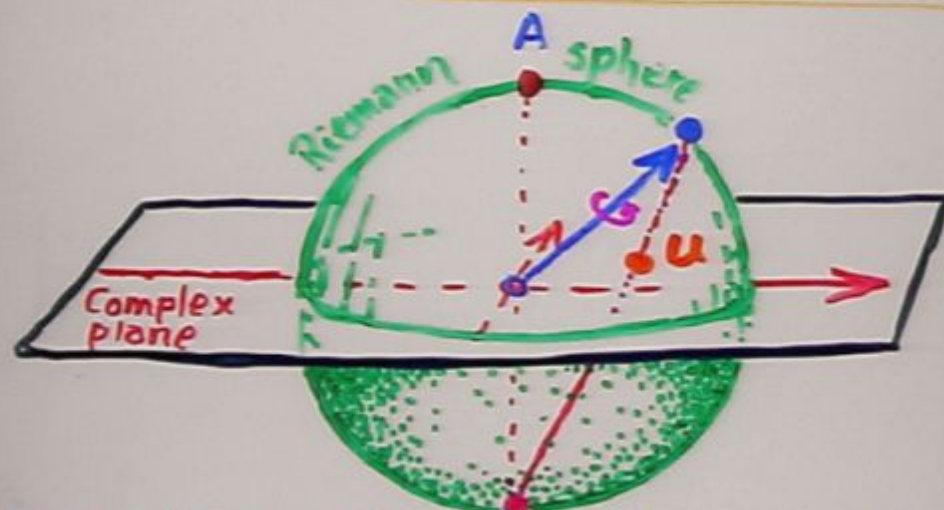
Complex ratio: $\frac{z}{w} = u$

Spin [— for spin $\frac{1}{2}$
eg. electron, proton, neutron
+ quark, ...

Basis states



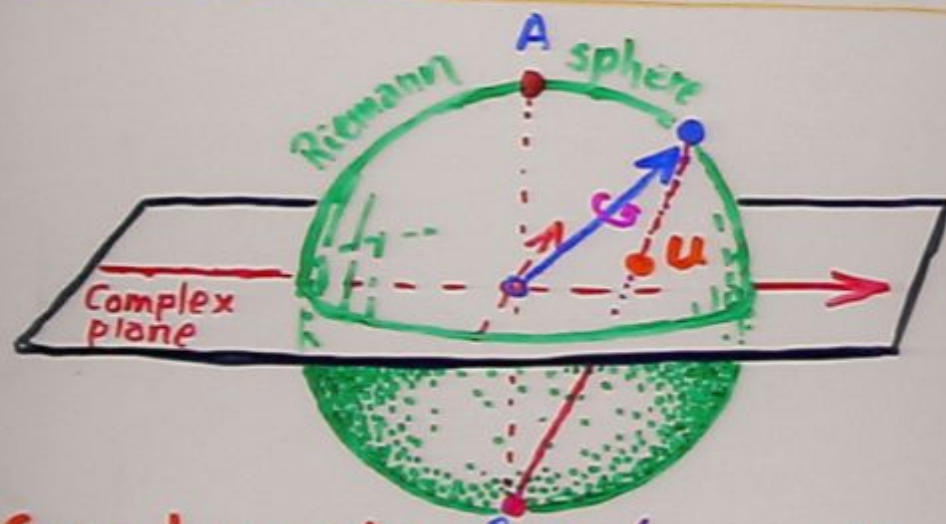
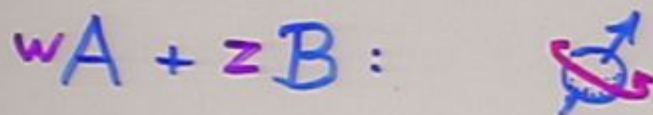
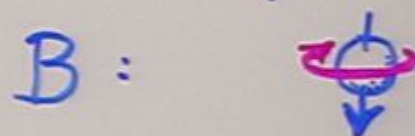
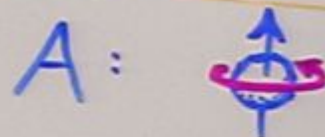
$wA + zB$:



Complex ratio: $z/w = U$

Spin [— for spin $\frac{1}{2}$
eg. electron, proton, neutron,
quark, ...

Basis states



Complex ratio: $z/w = u$

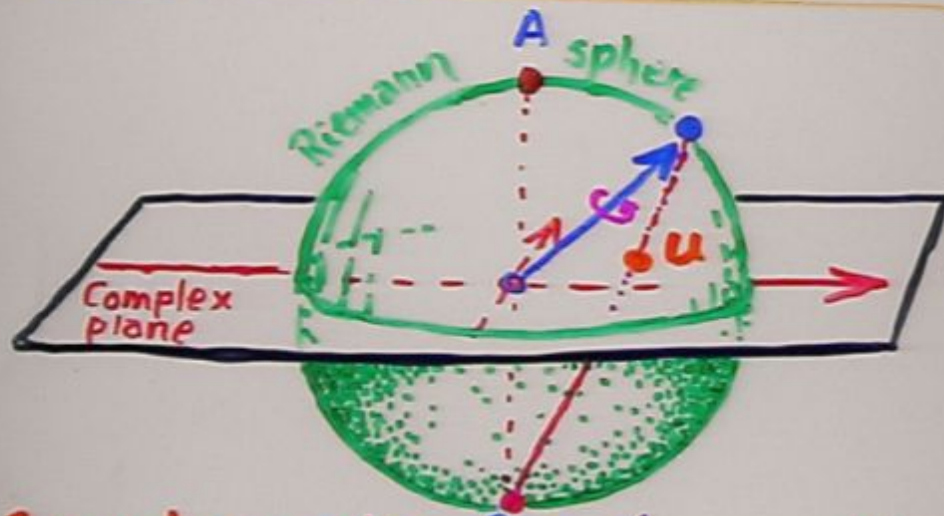
Spin [— for spin $\frac{1}{2}$
eg. electron, proton, neutron, quark, ...

— for spin $\frac{1}{2}$
eg. electron, proton, neutron, quark, ...

Basis states A : 

A: 

B :

 $wA + zB :$ 

Complex ratio: $z/w = u$

quark, ...

Basis states

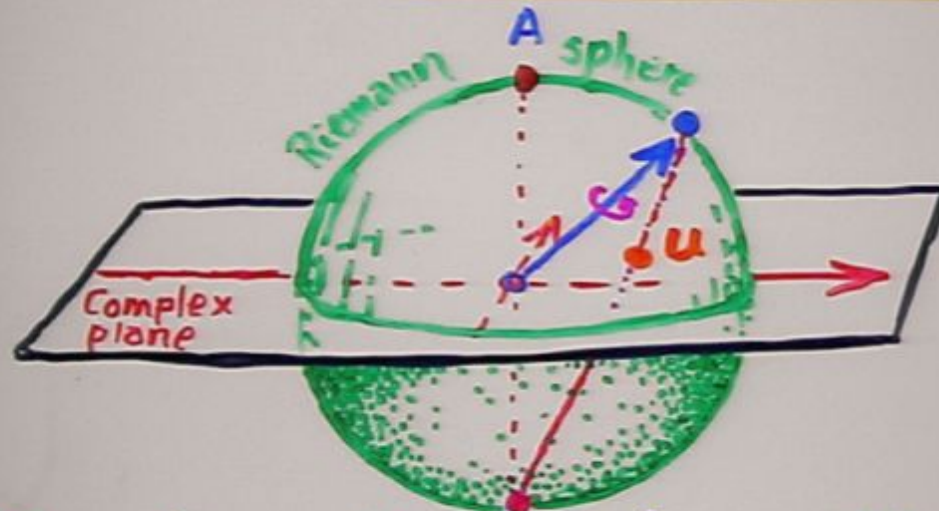
A:



B:



$wA + zB$:



Complex ratio: $z/w = u$

quark, ...

Basis states

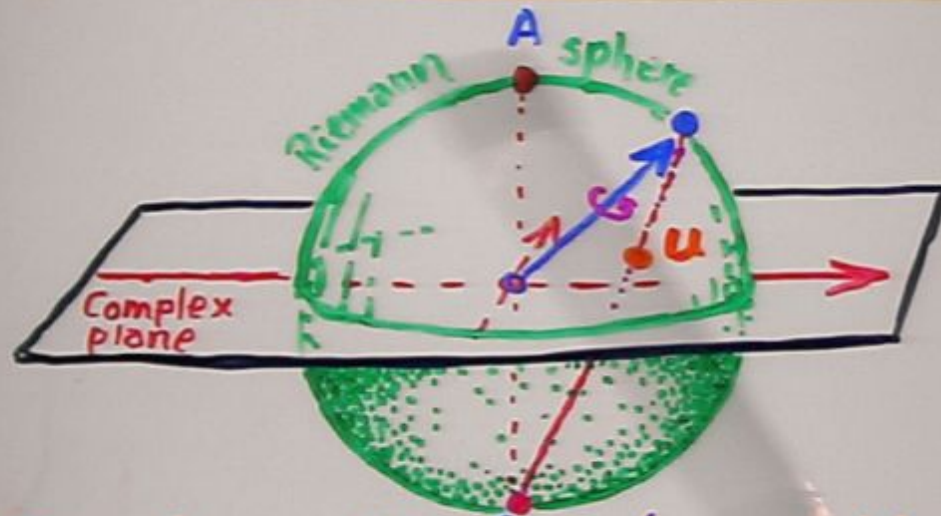
A:



B:



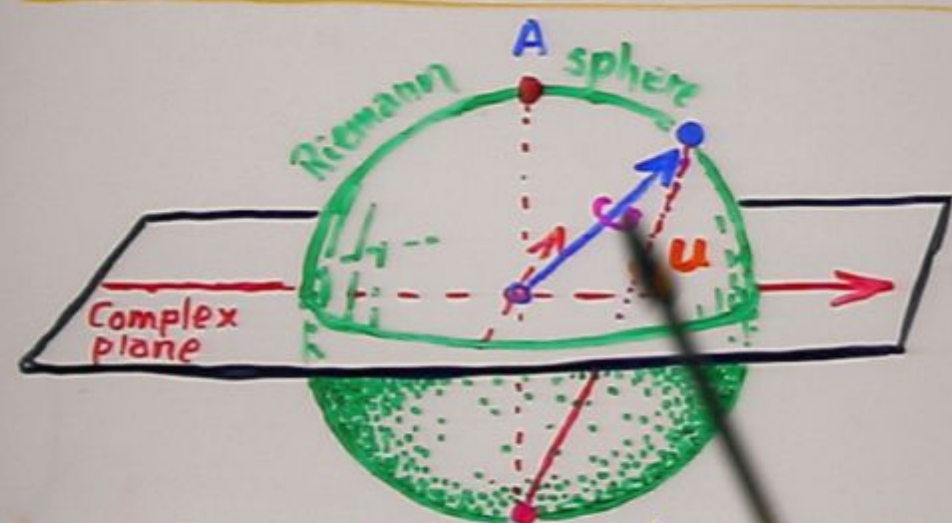
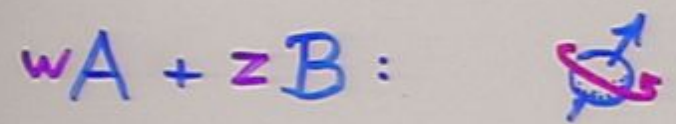
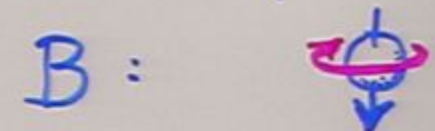
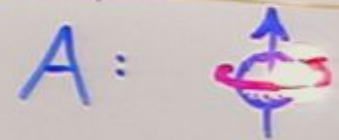
$wA + zB$:



Complex ratio: $z/w = u$

quark, ...

Basis states



Complex ratio: $z/w = u$

Spin

— for spin $\frac{1}{2}$
eg. electron, proton, neutron
quark, ...

Basis states

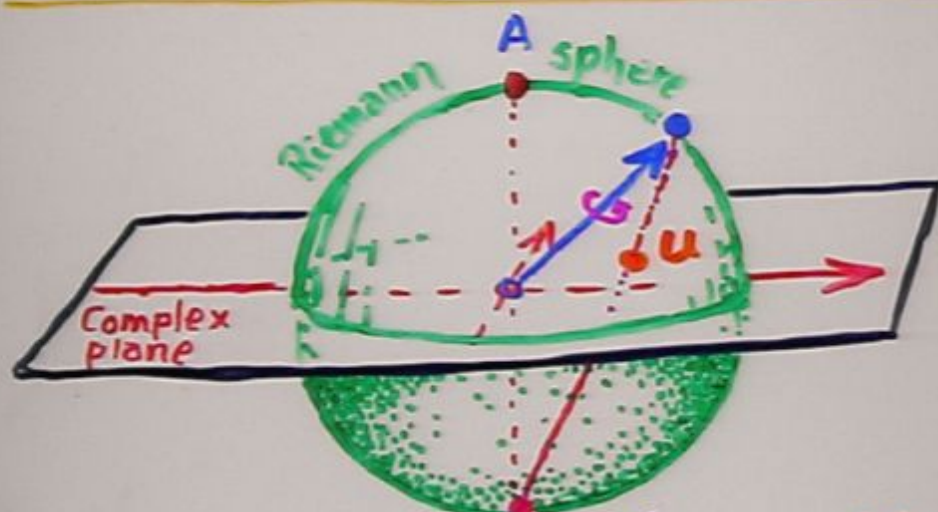
A:



B:



$wA + zB$:



Complex ratio: $z/w = u$

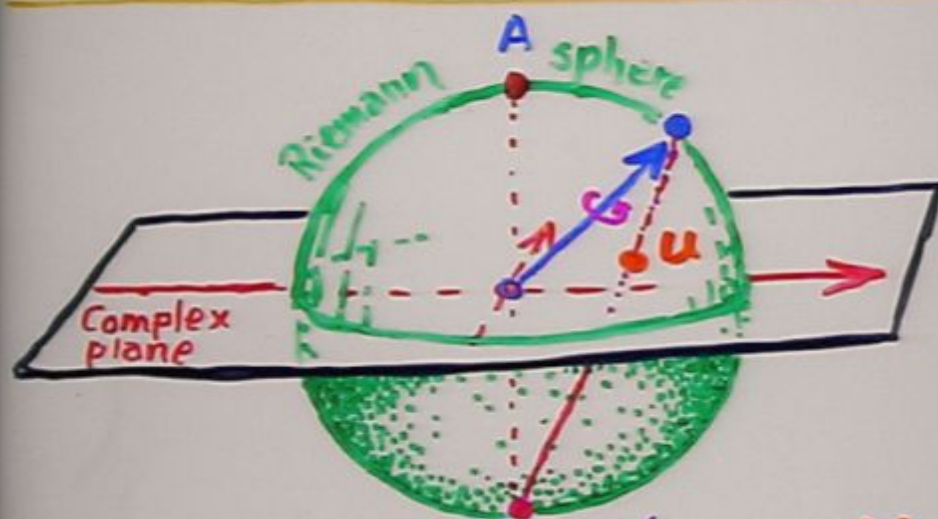
eg. electron, proton, neutron
quark, ...

Basis states

A: 

B: 

$wA + zB$: 



Complex ratio: $z/w = u$

"Schrödinger's



source emits
single photon



detector

"Schrödinger's



source emits
single photon



detector

"Schrödinger's



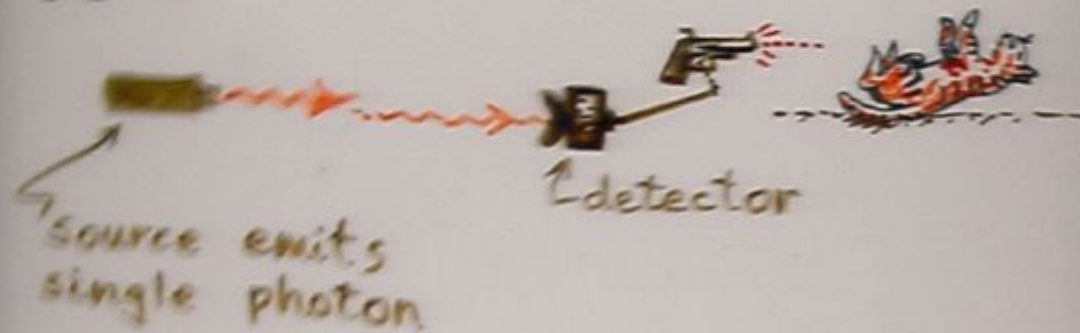
source emits
single photon



detector

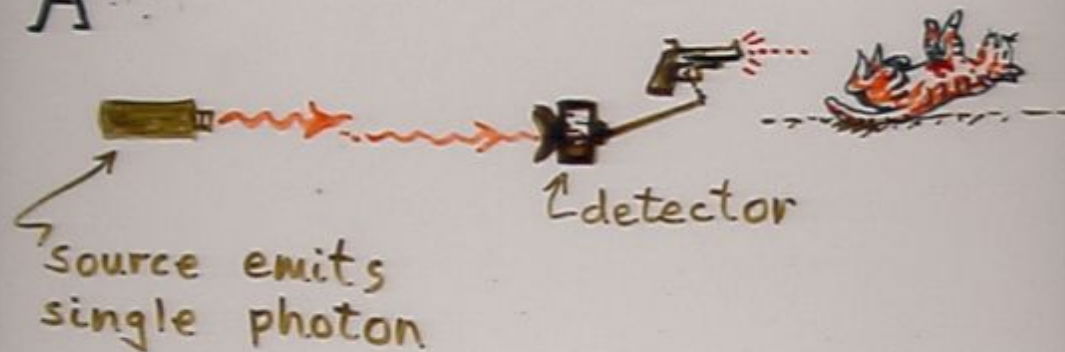
"Schrödinger's cat"

A

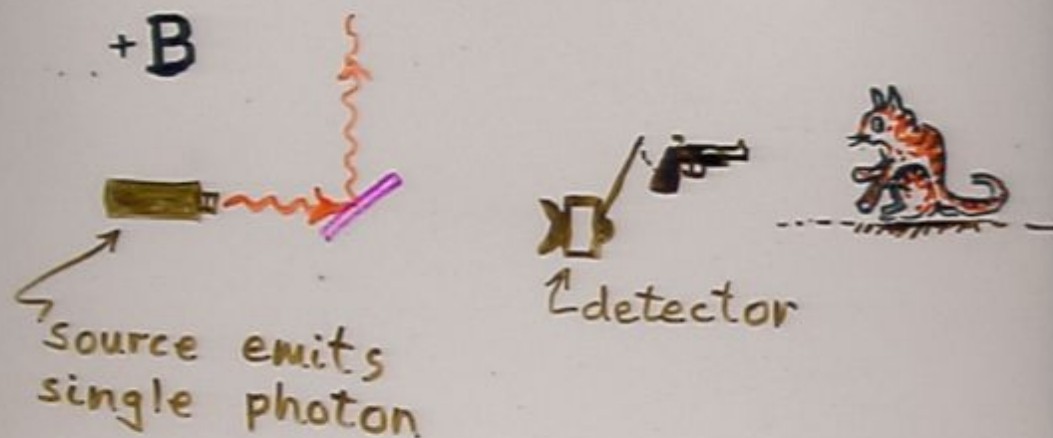


"Schrödinger's cat"

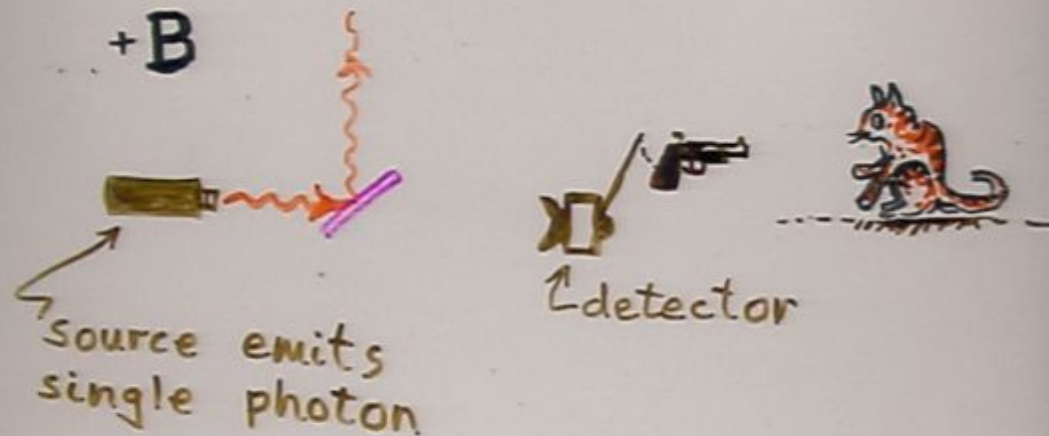
A



"Schrödinger's cat"

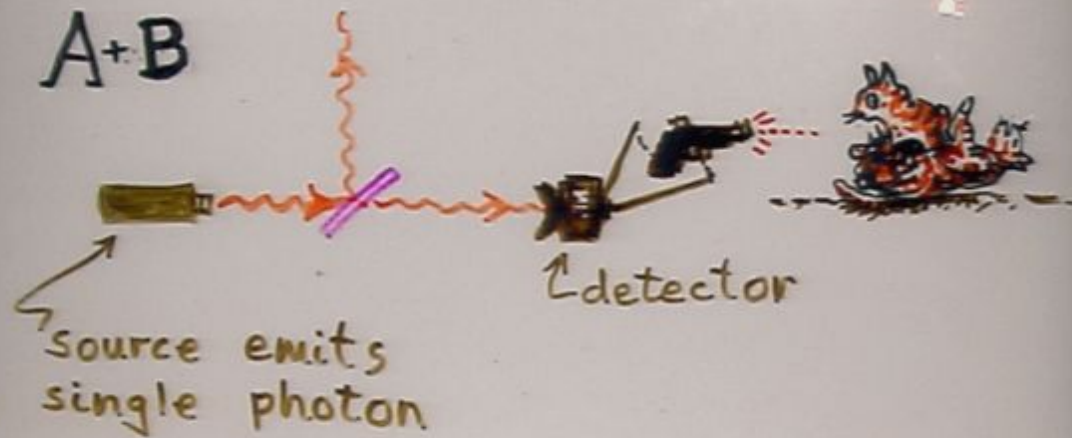


"Schrödinger's cat"



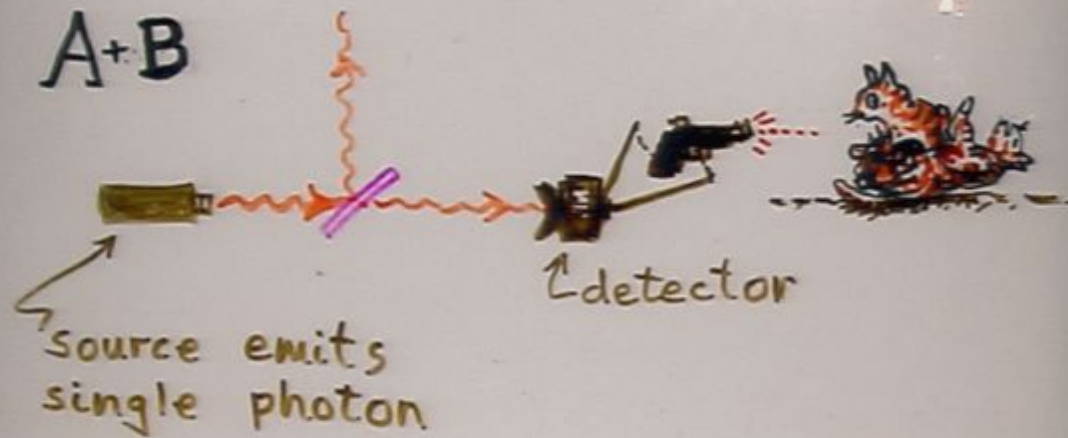
"Schrödinger's Cat"

$A+B$

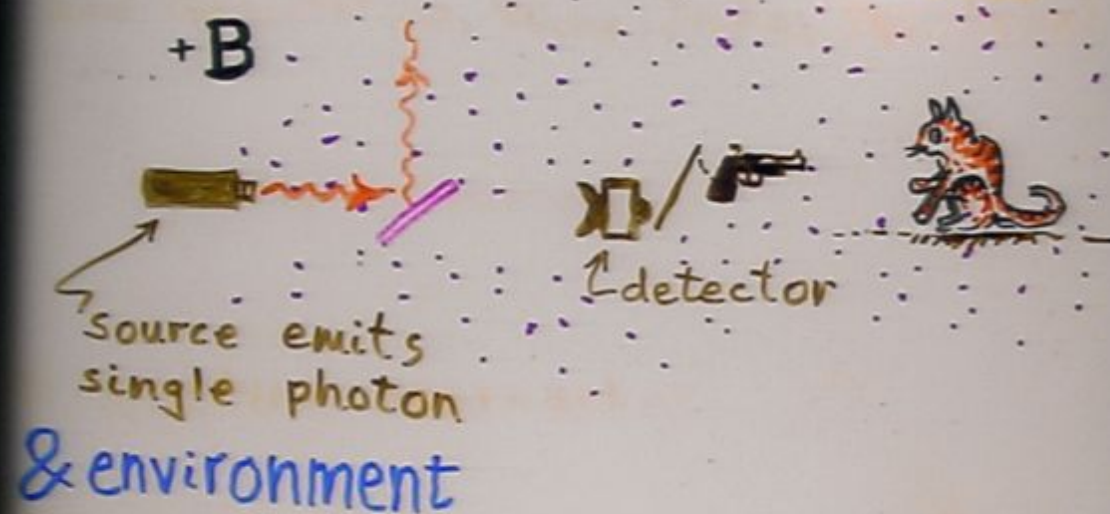


"Schrödinger's Cat"

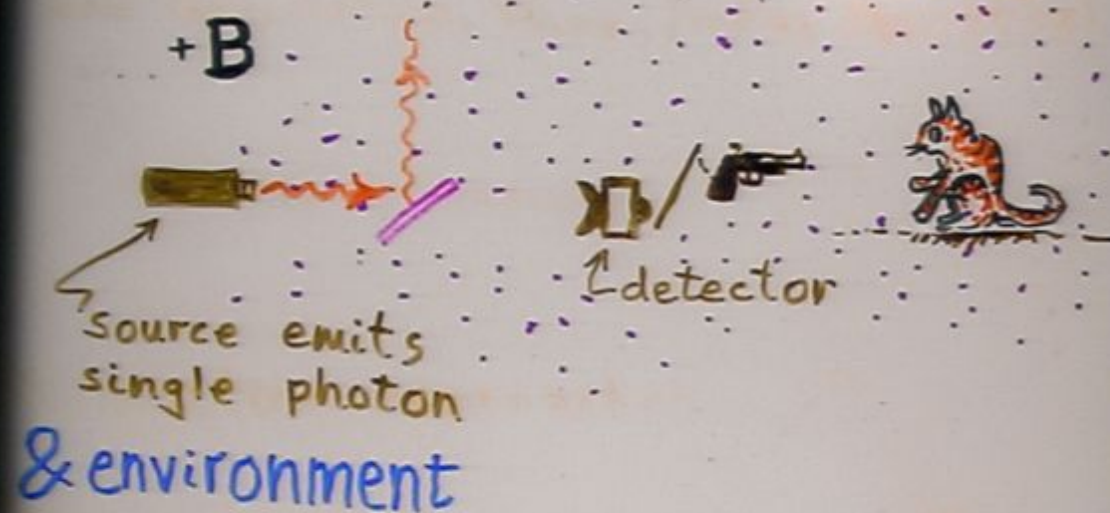
$A+B$



"Schrödinger's Cat"

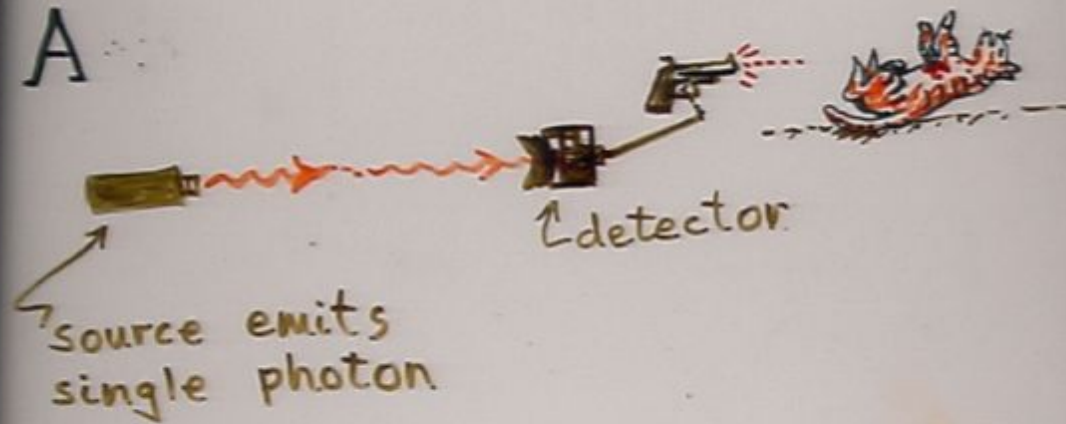


"Schrödinger's cat"



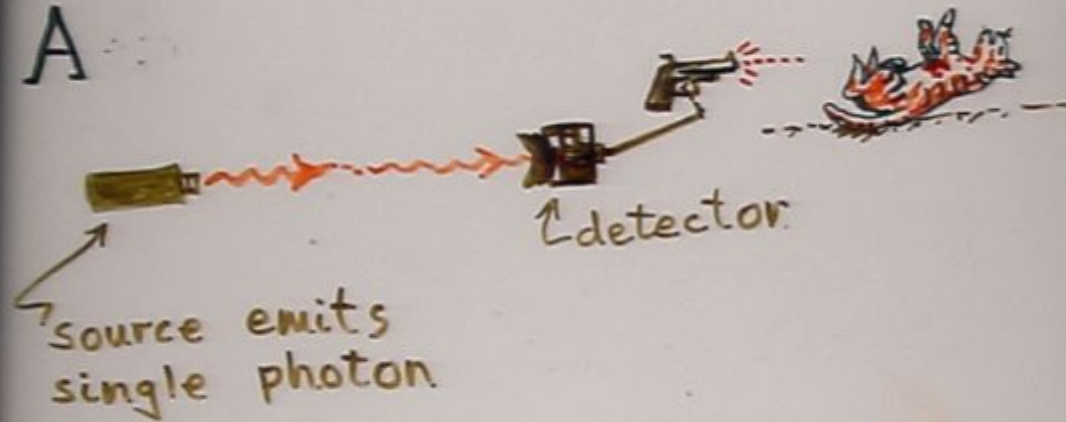
Schrödinger's cat

A

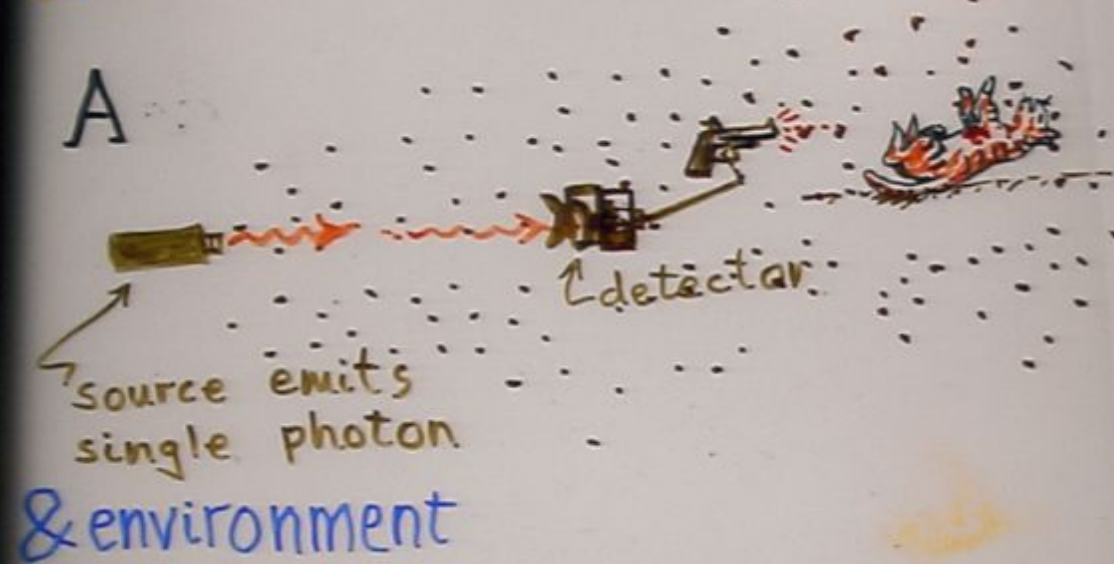


Schrödinger's cat

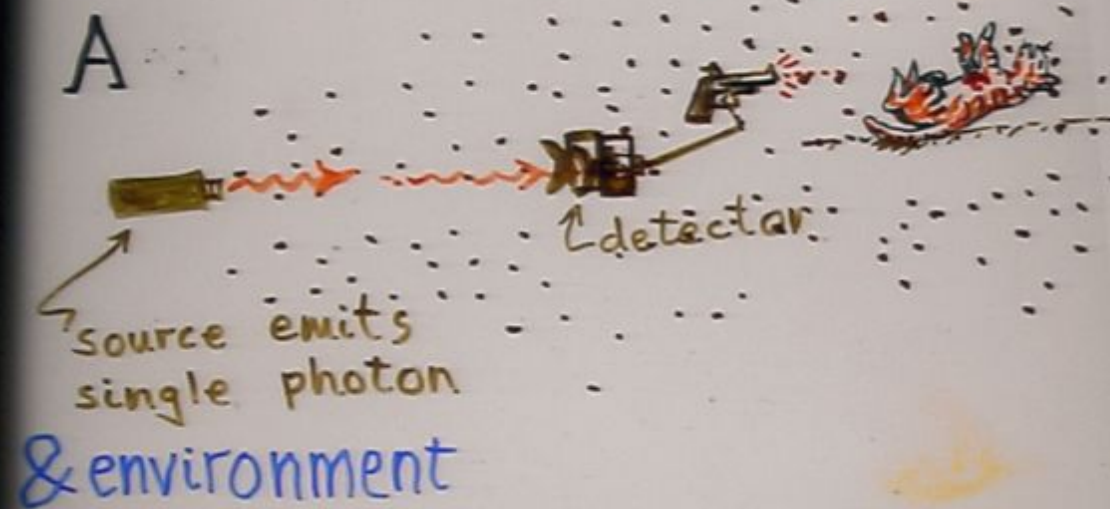
A



Schrödinger's cat

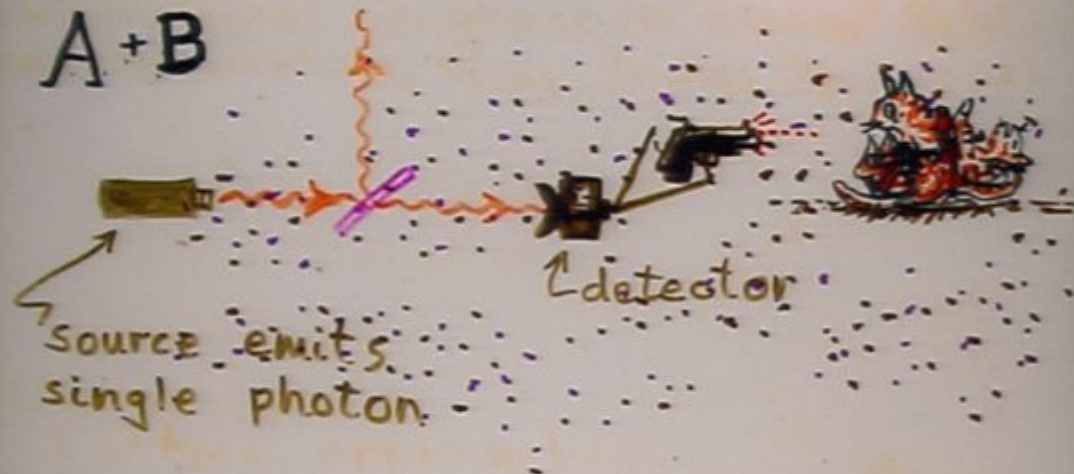


Schrödinger's cat



"Schrödinger's cat"

$A+B$



& environment

"Schrödinger's cat"

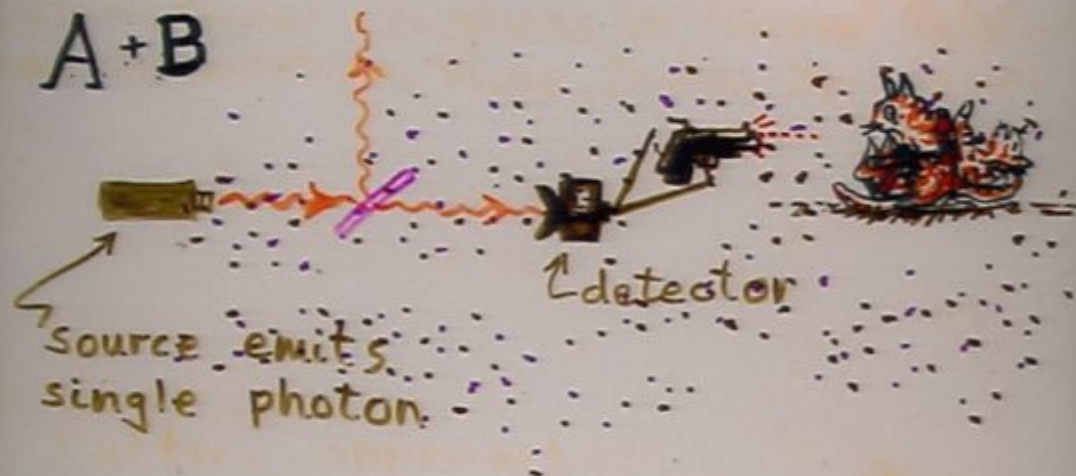
$A+B$



& environment

"Schrödinger's cat"

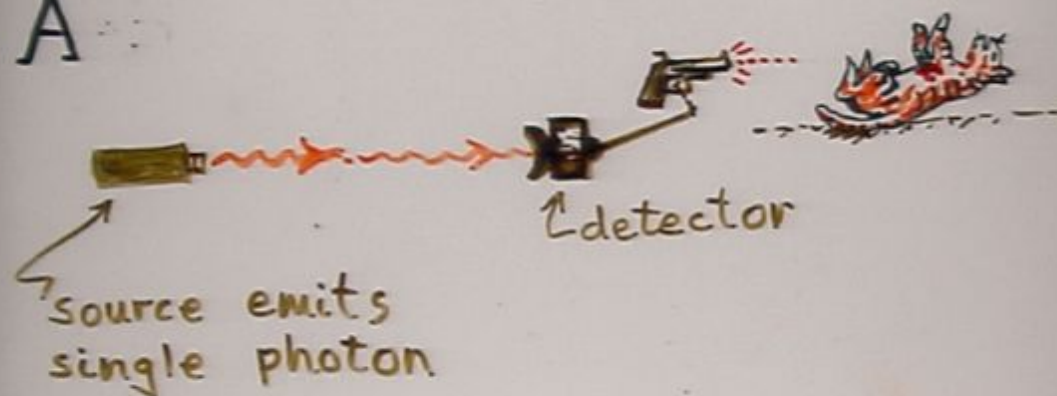
$A+B$



& environment

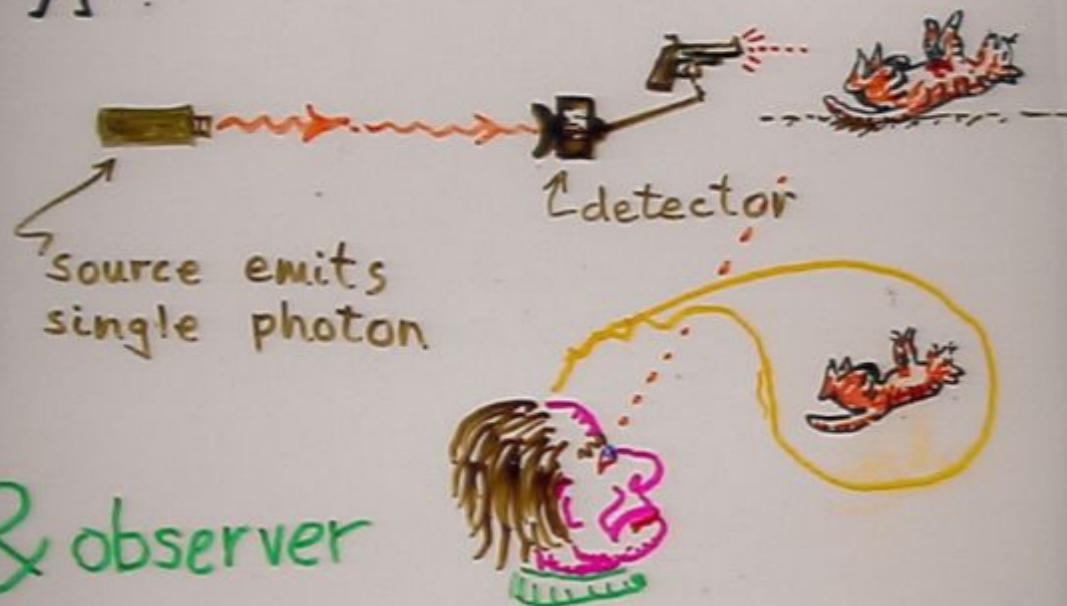
"Schrödinger's cat"

A



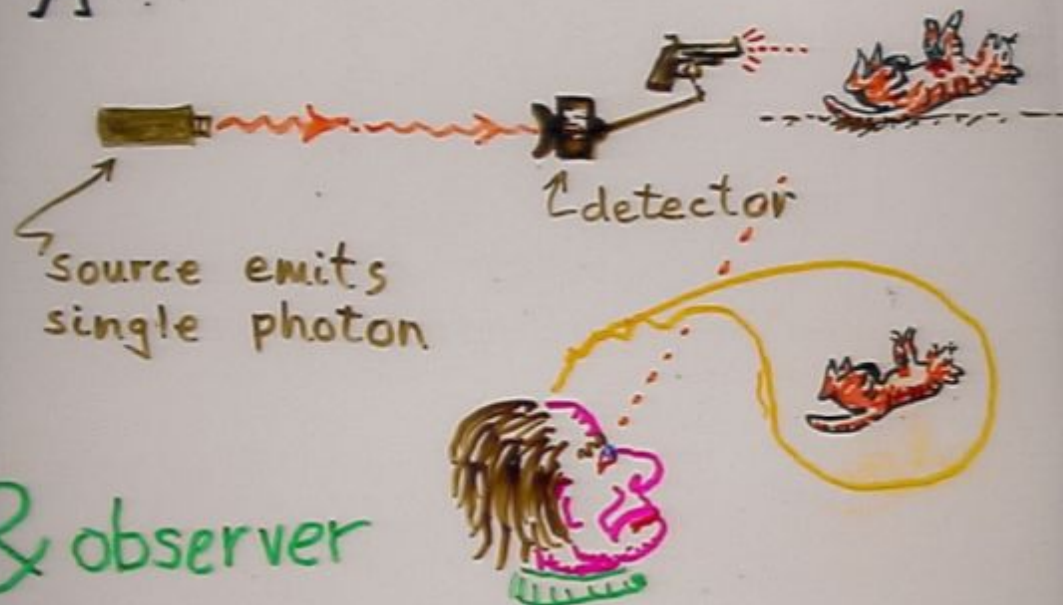
"Schrödinger's cat"

A



"Schrödinger's cat"

A



"Schrödinger's cat"

$A+B$



& environment
& observer



"Schrödinger's cat"

$A+B$

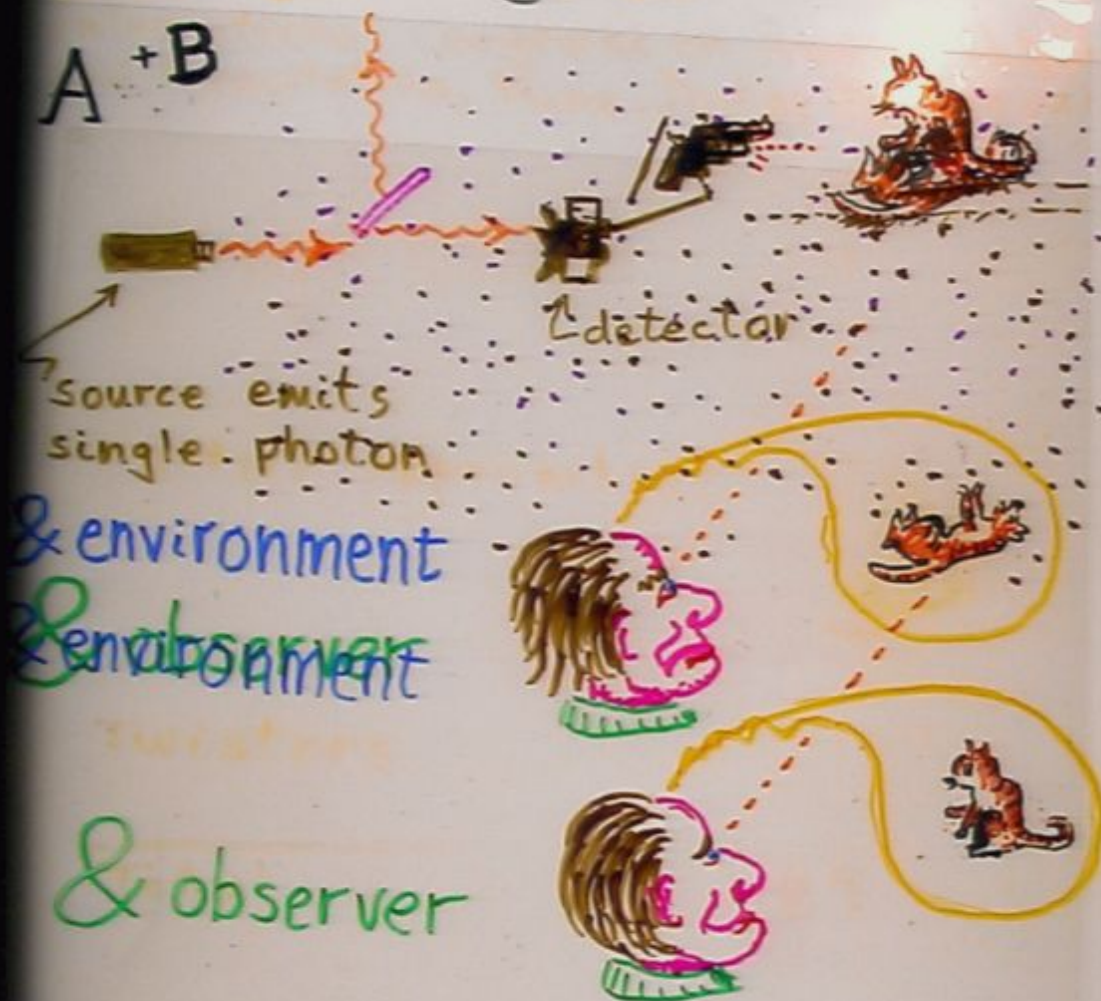


& environment
& observer



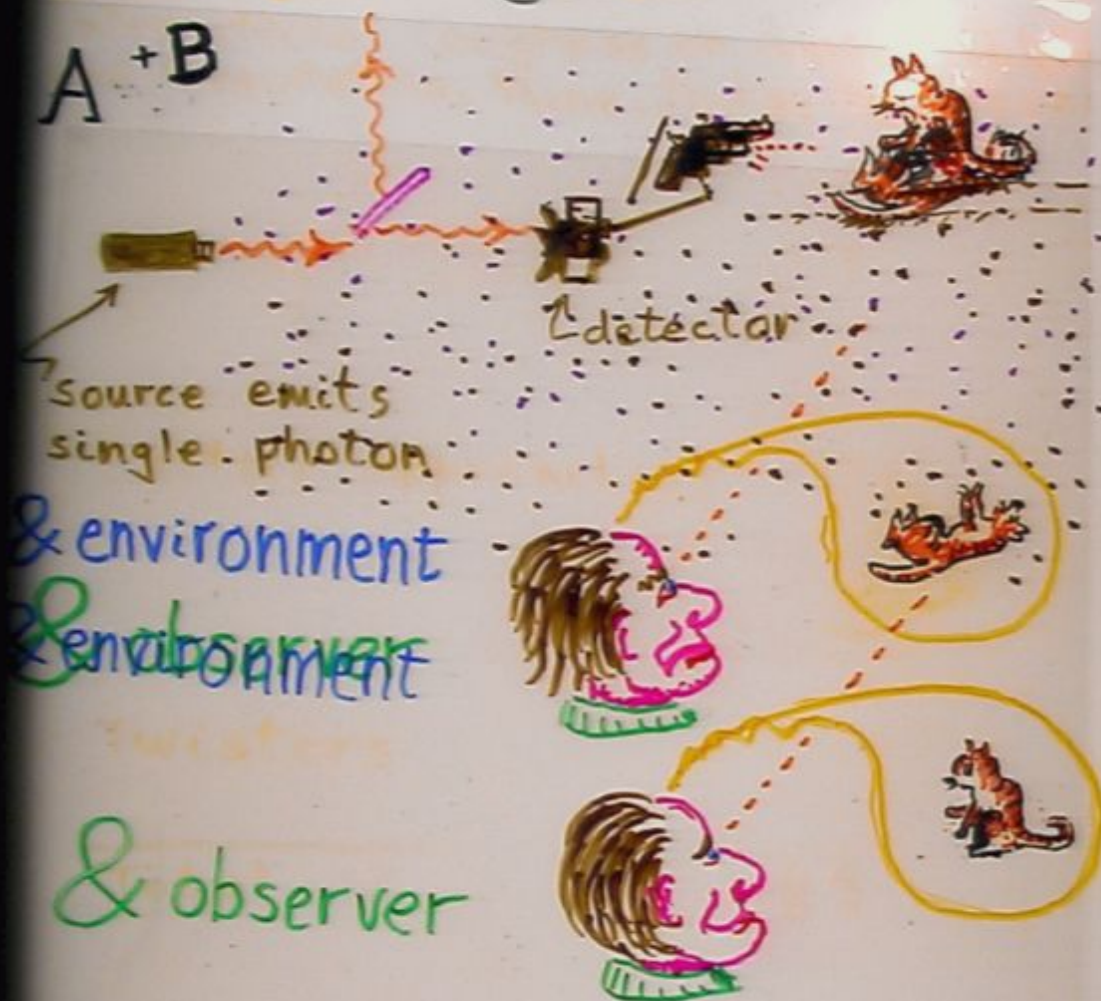
Schrödinger's cat

$A + B$



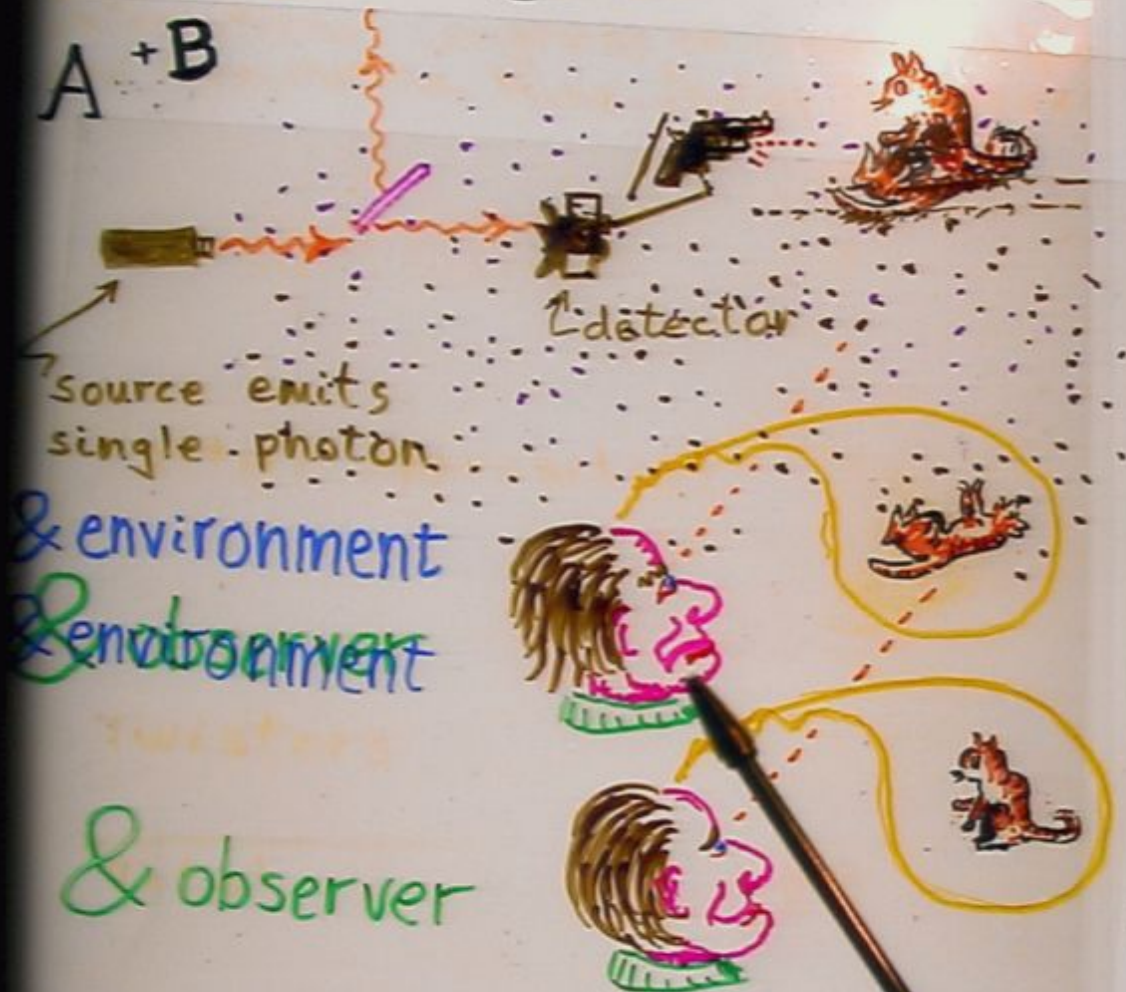
Schrödinger's cat

$A + B$



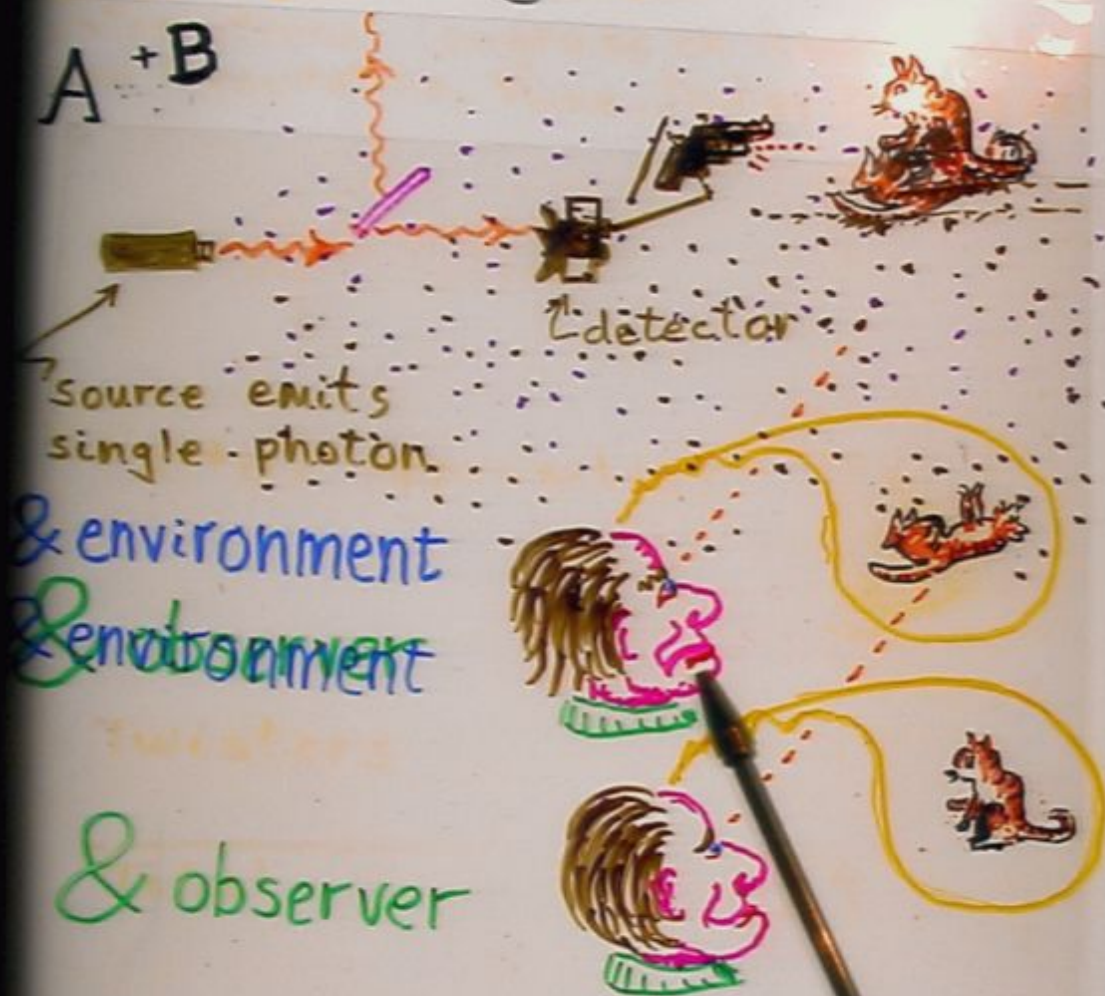
Schrödinger's cat

A + B



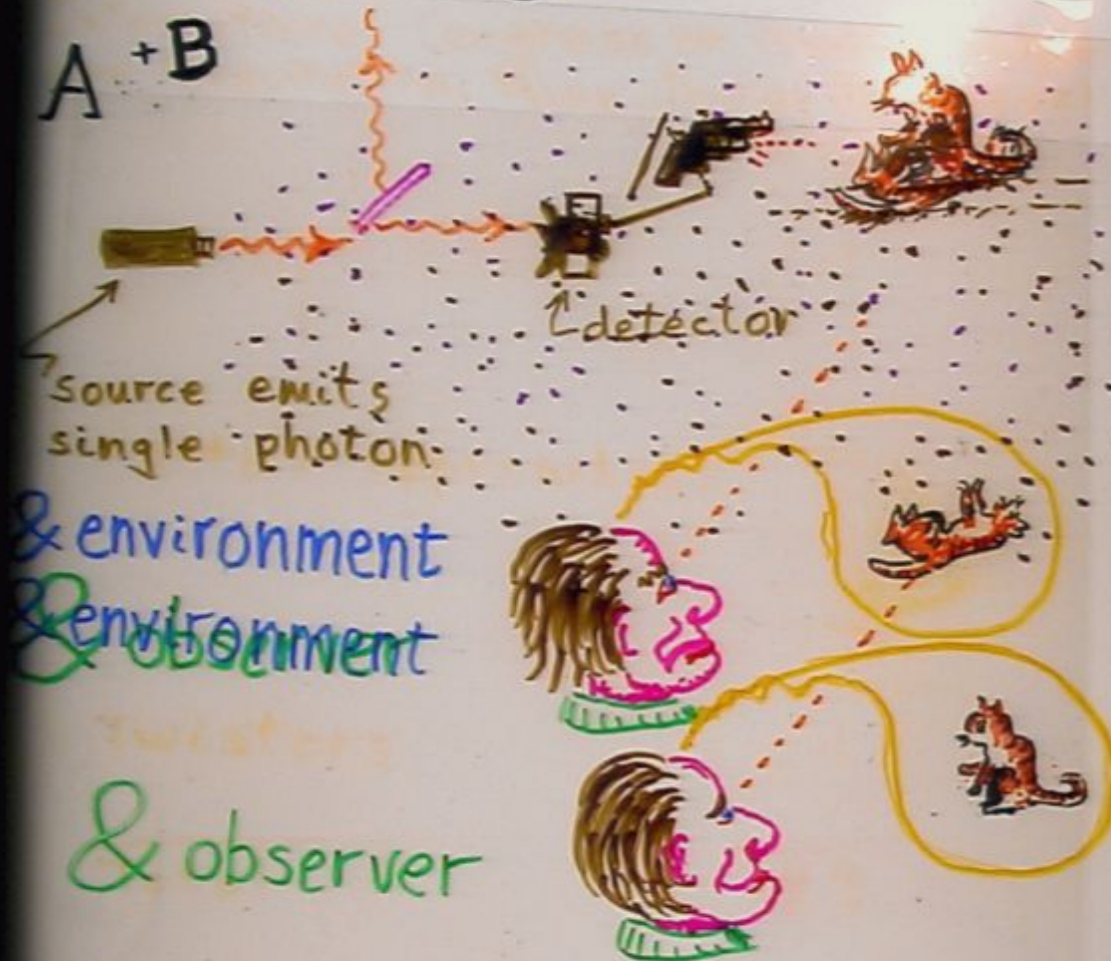
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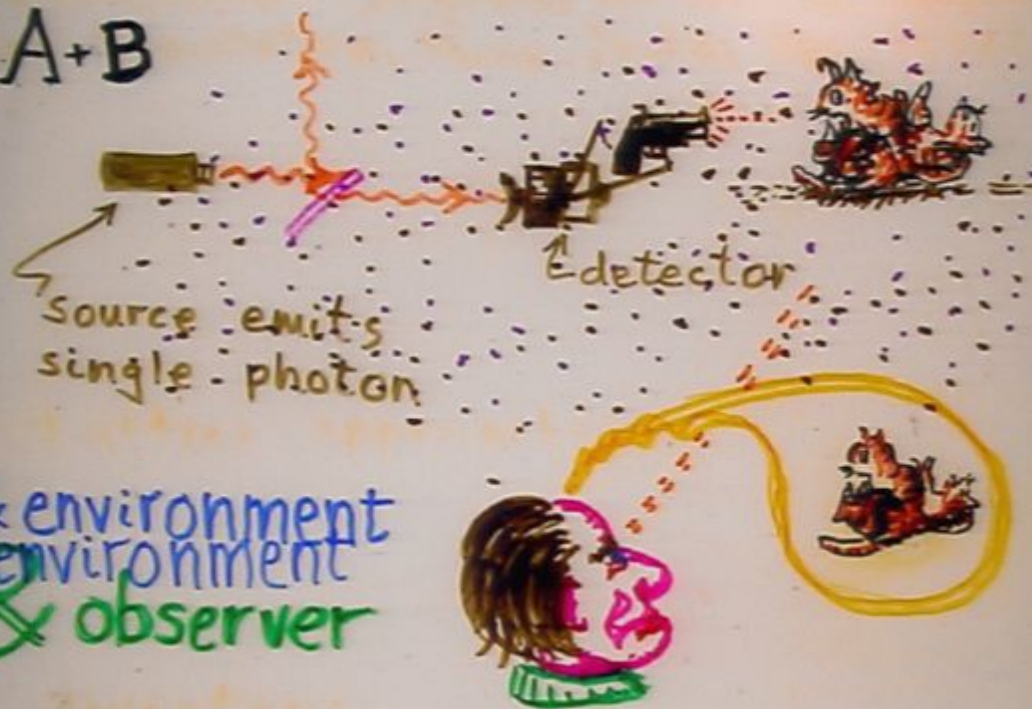
Schrödinger's cat

A + B



"Schrödinger's cat"

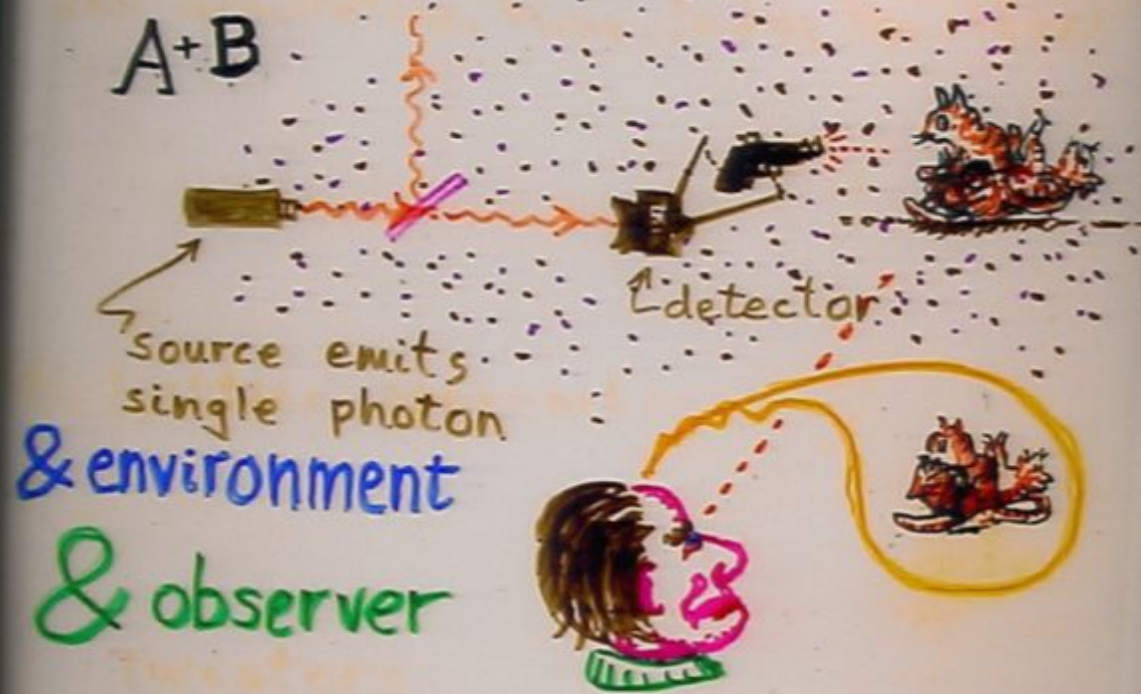
A+B



& environment
& environment
& observer

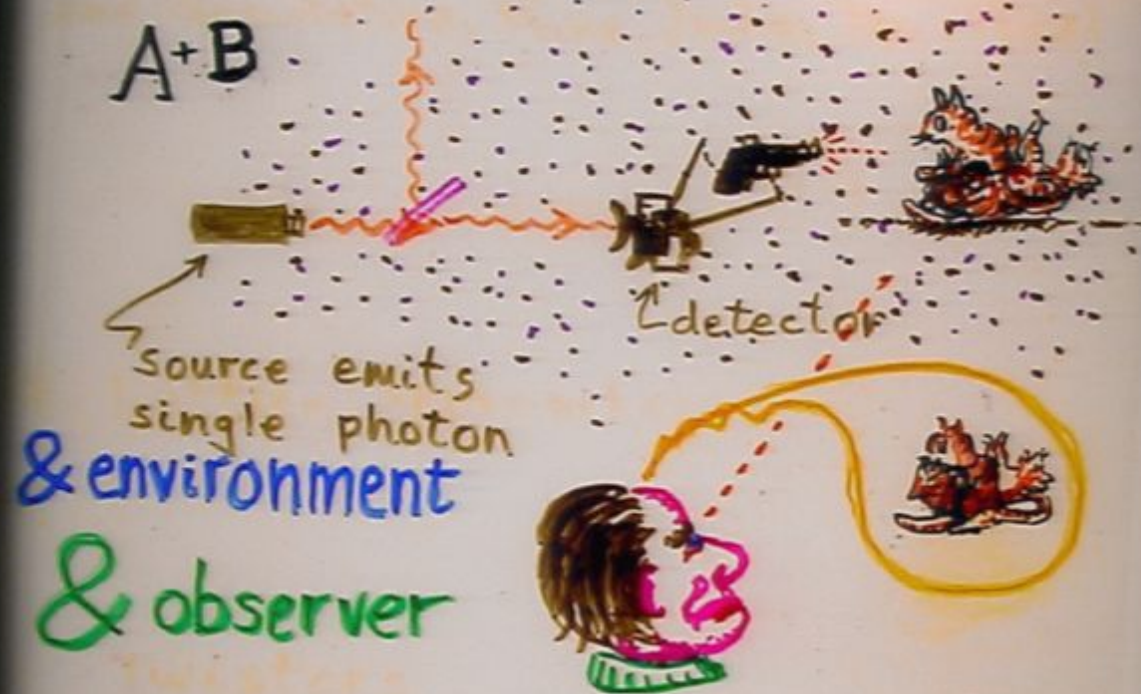
"Schrödinger's cat"

$A+B$



"Schrödinger's cat"

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"Schrödinger's"

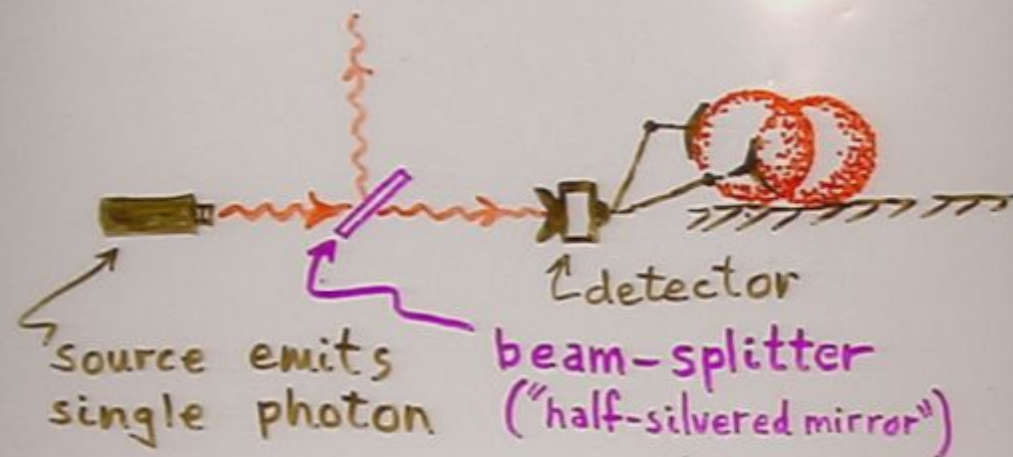


source emits
single photon



detector

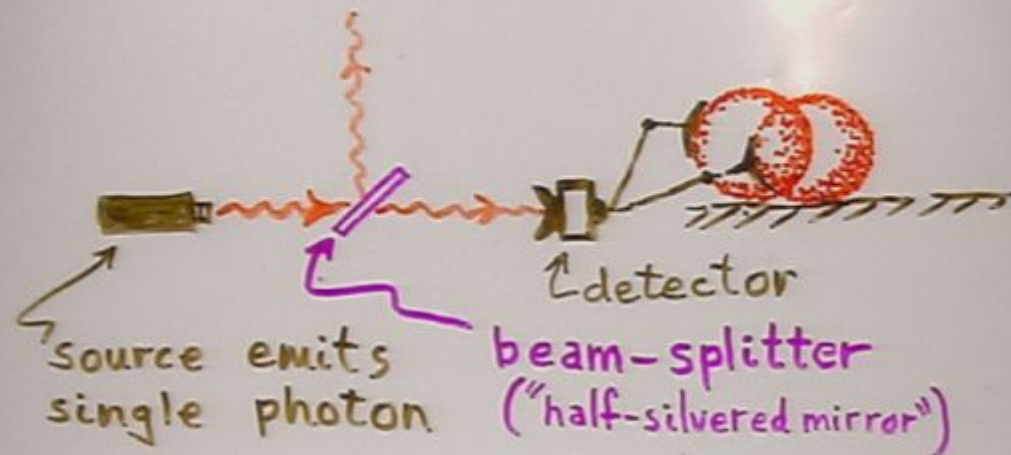
"Schrödinger's lump"



Gravitational **O**bjective **R**eduction theory tells us that the superposition is unstable, reducing to one location or the other in a time scale $\sim \hbar/E_G$

where E_G = gravitational self-energy of difference between the two mass distributions

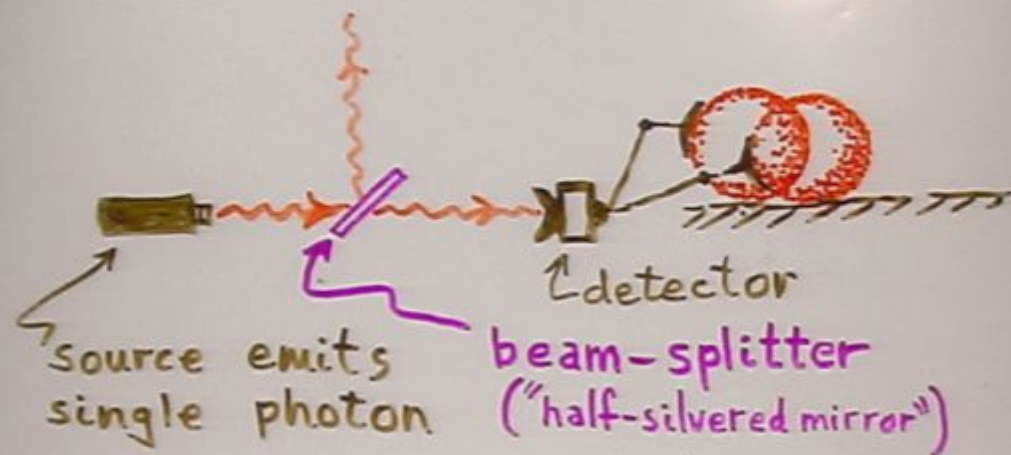
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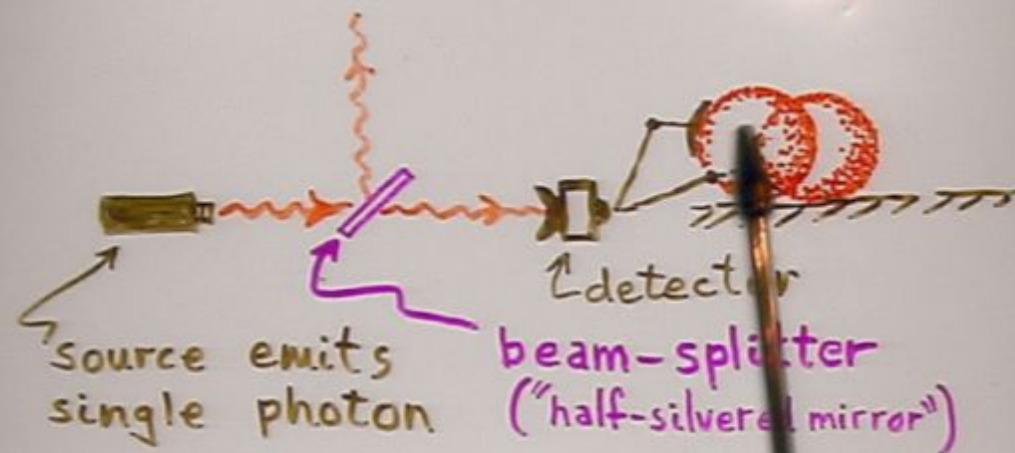
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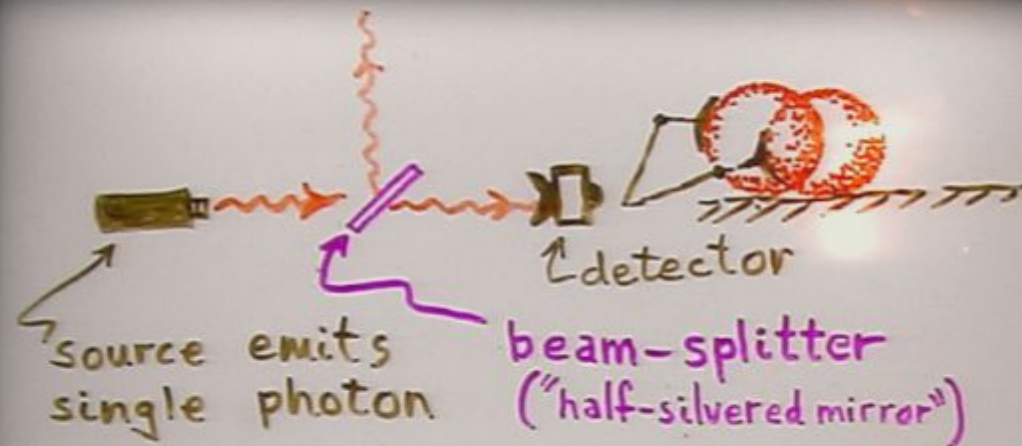
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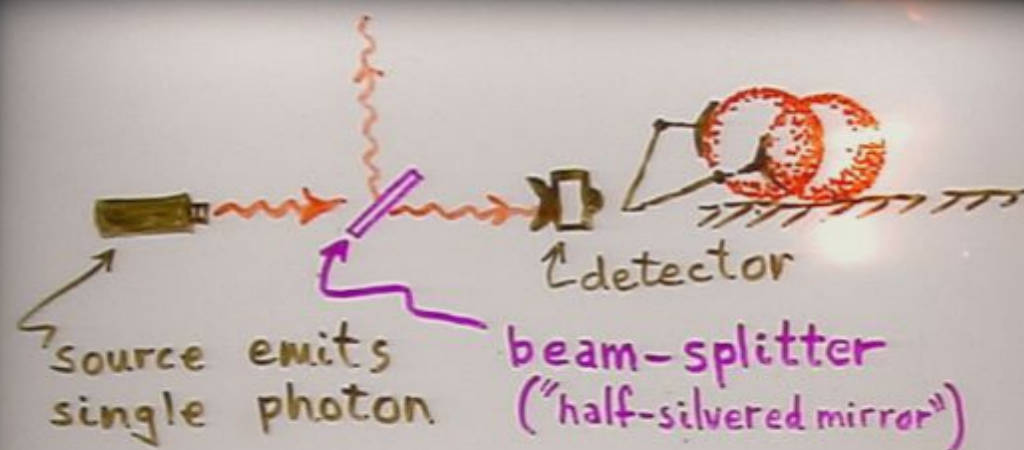
Gravitational ~~O~~ ~~R~~ theory tells us that the superposition is unstable, reducing to one location or the other in a time scale $\sim \hbar/E_G$

where E_G = gravitational self-energy



Gravitational $\text{O} \begin{matrix} \text{b} \\ \text{j} \\ \text{e} \\ \text{c} \\ \text{i} \\ \text{v} \\ \text{e} \end{matrix} \text{R} \text{eduction}$
 theory tells us that
 the superposition 
 is unstable, reducing to one
 location or the other in
 a time scale $\sim \hbar/E_G$

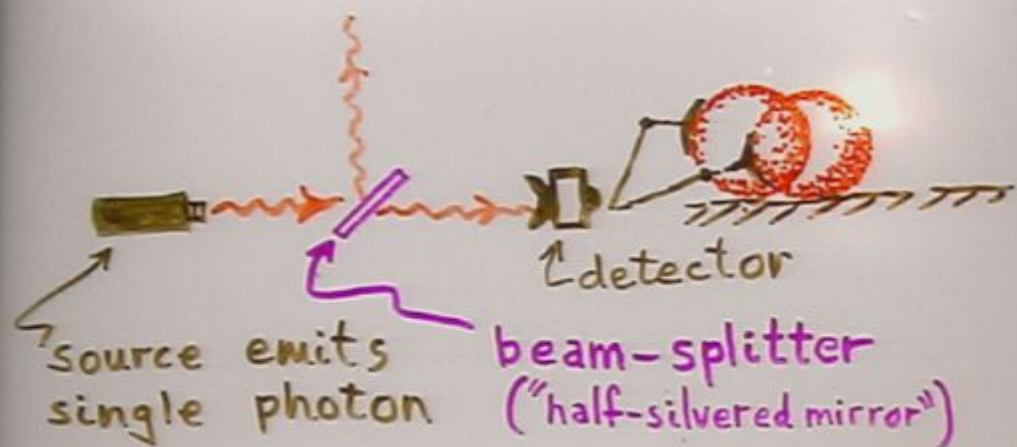
where E_G = gravitational self-energy
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 ($\approx$ energy of displacement of one in grav'l field of the other)



Gravitational $\text{O} \begin{matrix} \text{b} \\ \text{j} \\ \text{e} \\ \text{c} \\ \text{i} \\ \text{v} \\ \text{e} \end{matrix} \text{R} \begin{matrix} \text{e} \\ \text{d} \\ \text{u} \\ \text{c} \\ \text{i} \\ \text{o} \\ \text{n} \end{matrix}$ theory tells us that the superposition is unstable, reducing to one location or the other in a time scale $\sim \hbar/E_G$

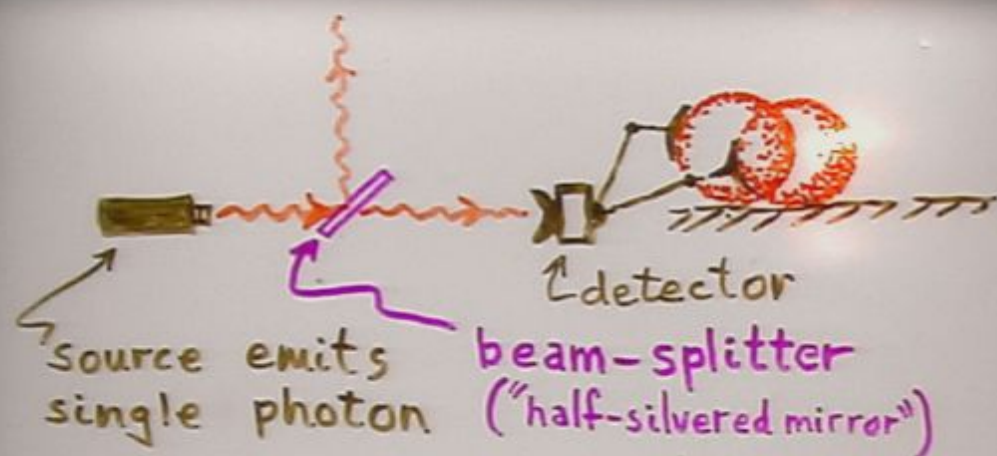
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Schrodinger's Cat

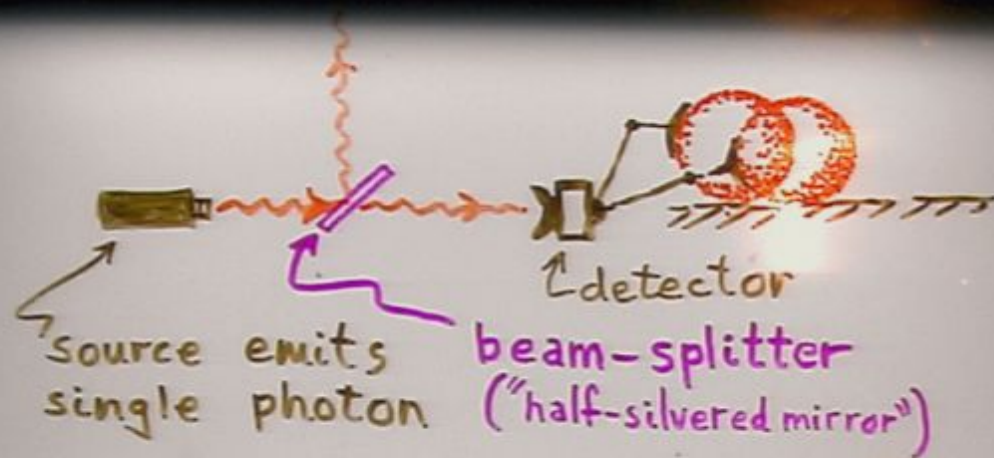


Gravitational $\bigcirc$ Reduction
 theory tells us that
 the superposition is unstable, reducing to one location or the other in a time scale $\sim \hbar/E_G$

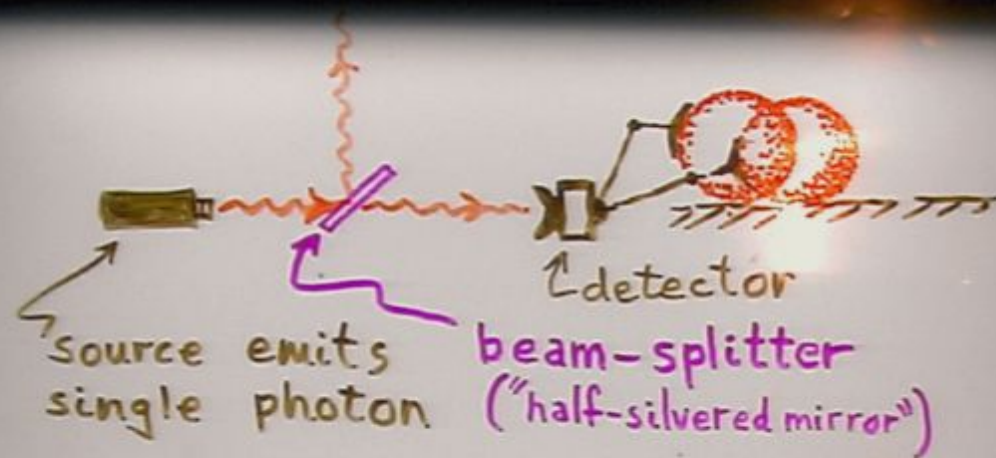
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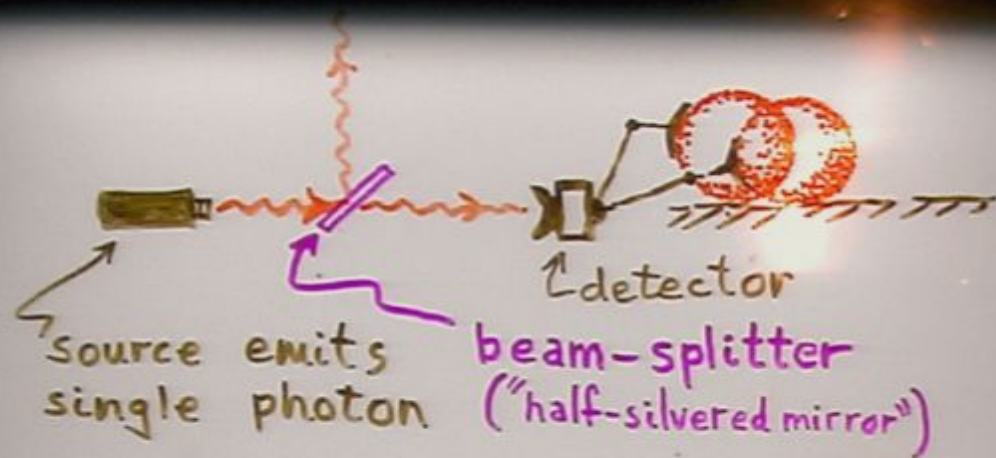
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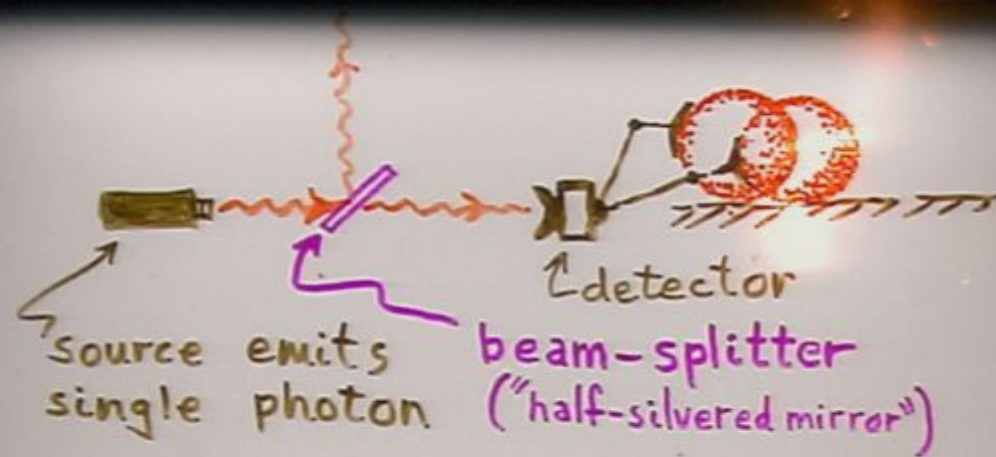
Gravitational OR theory tells us that the superposition is unstable, reducing to one location or the other in a time scale $\sim \hbar/E_G$ where E_G = gravitational self-energy of difference between the two mass distributions ($\approx$ energy of displacement of one in grav'l field of the other)



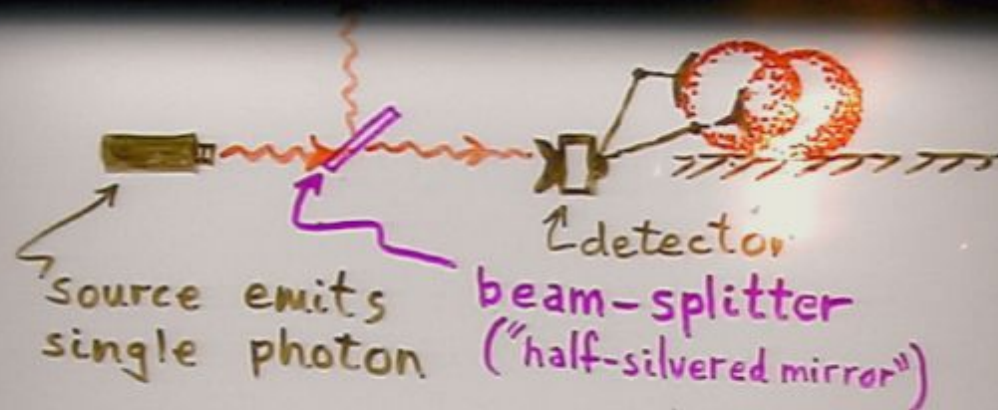
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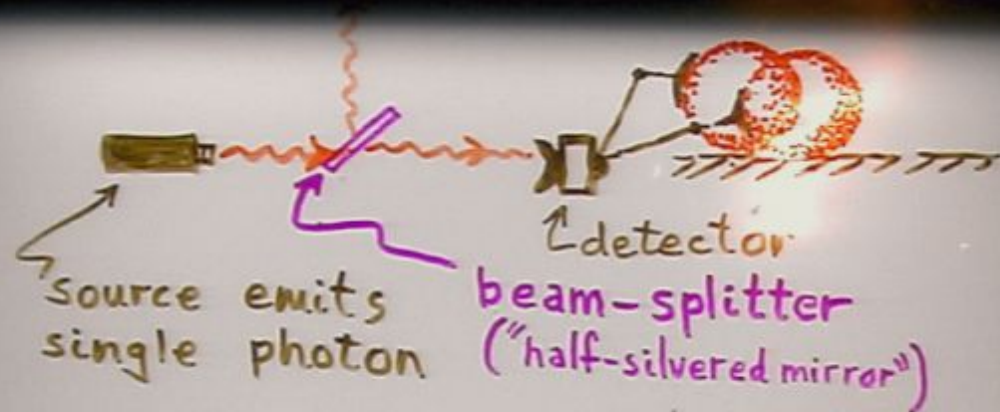


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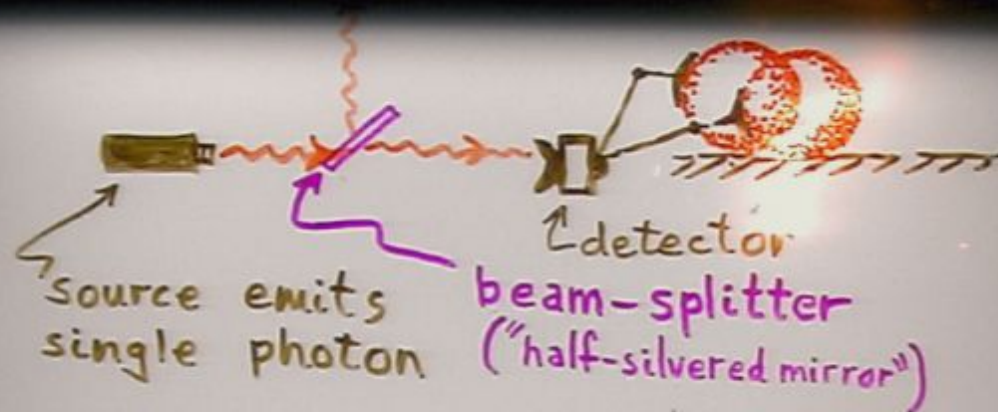


Gravitational **O** **R** theory tells us that _{bjective} ^{eduction} the superposition is unstable, reducing to one location or the other in a time scale $\sim \hbar/E_G$

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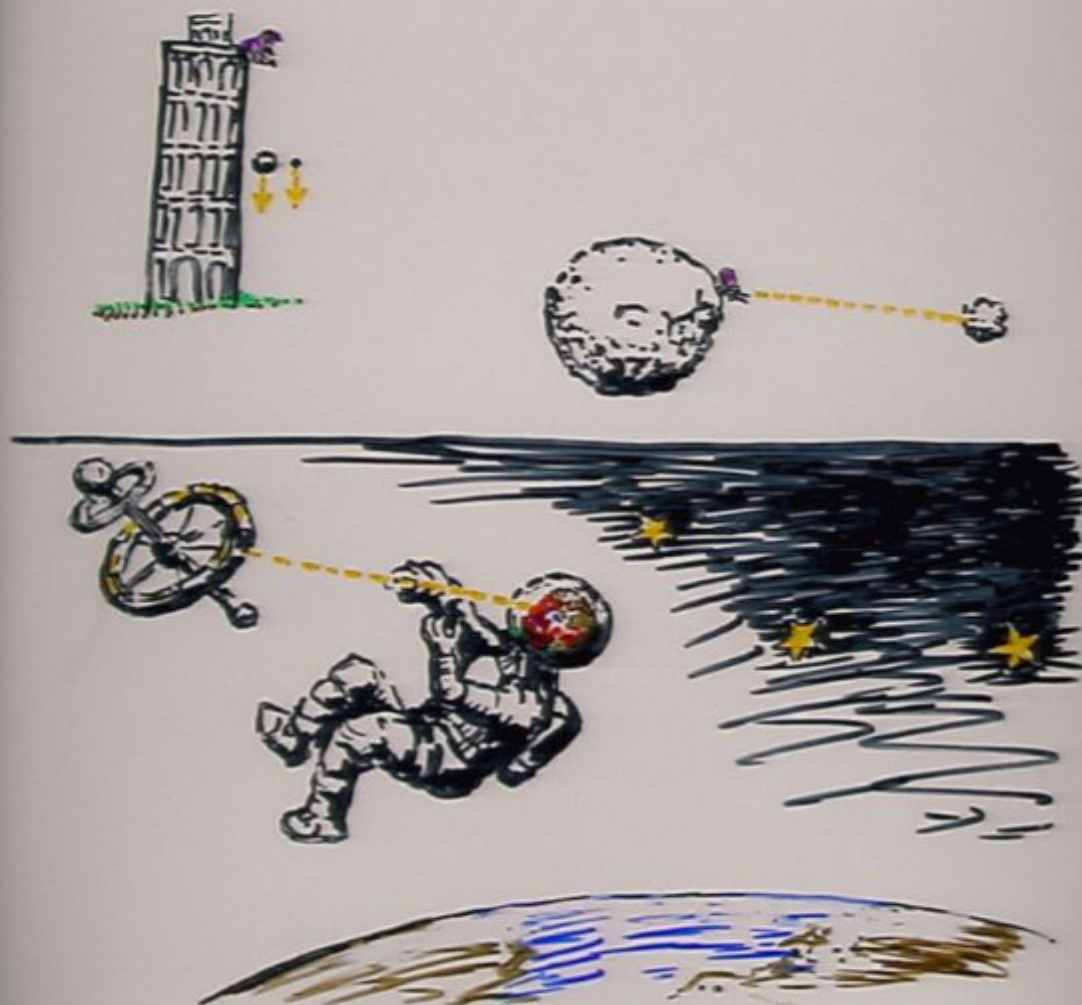
Gravitational **O** **R** theory tells us that _{bjective} ^{eduction} the superposition is unstable, reducing to one location or the other in a time scale $\sim \hbar/E_G$ where E_G = gravitational self-energy of difference between the two mass distributions ($\approx$ energy of displacement of one in grav'l field of the other)



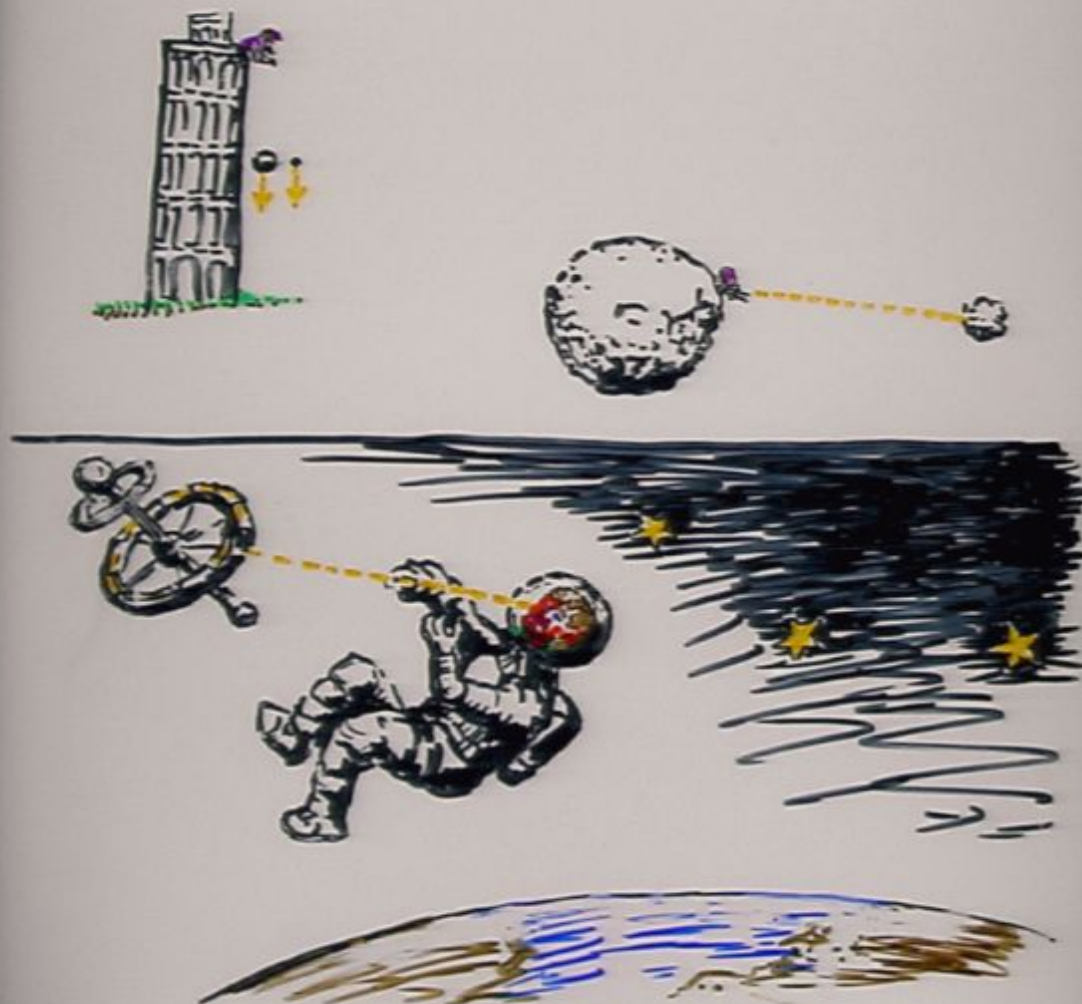
Gravitational OR Objective Reduction
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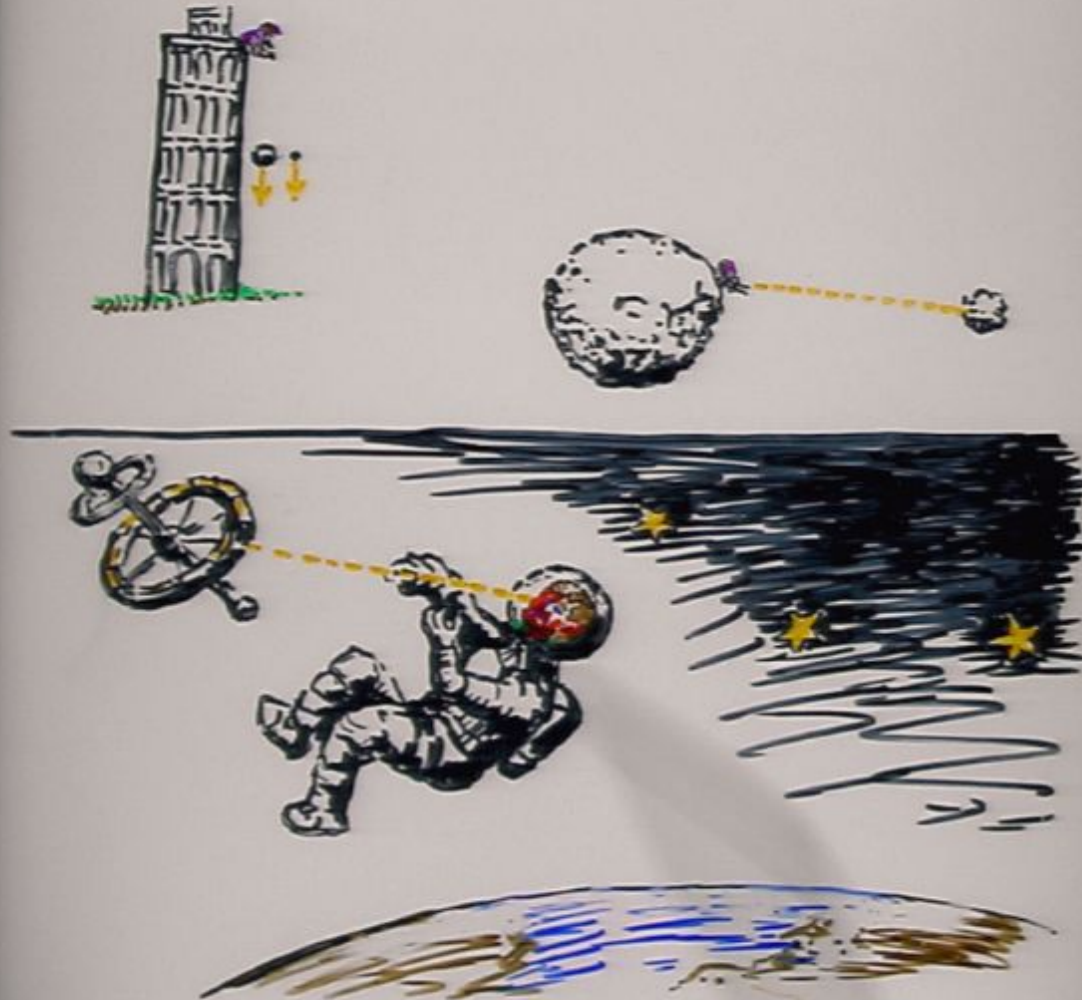
Galilei - Einstein Principle of Equivalence



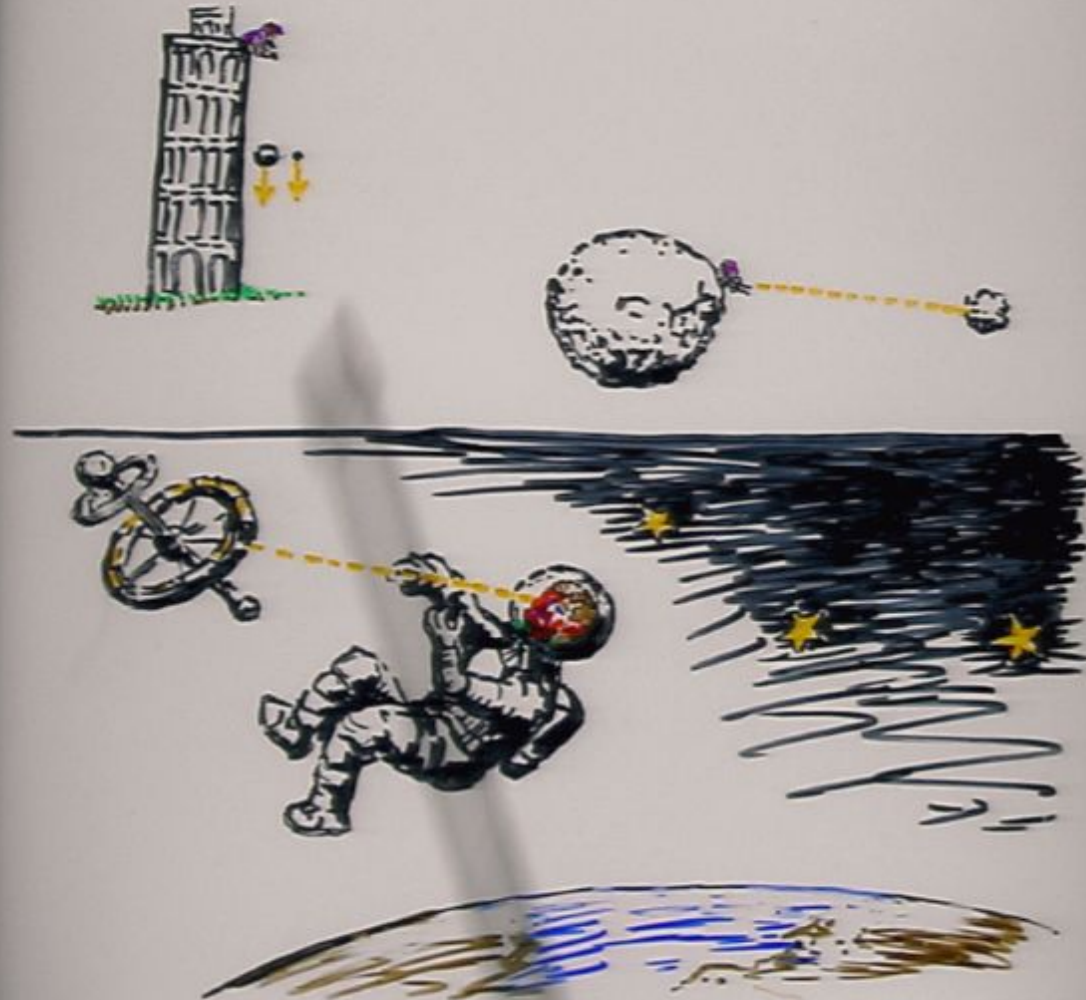
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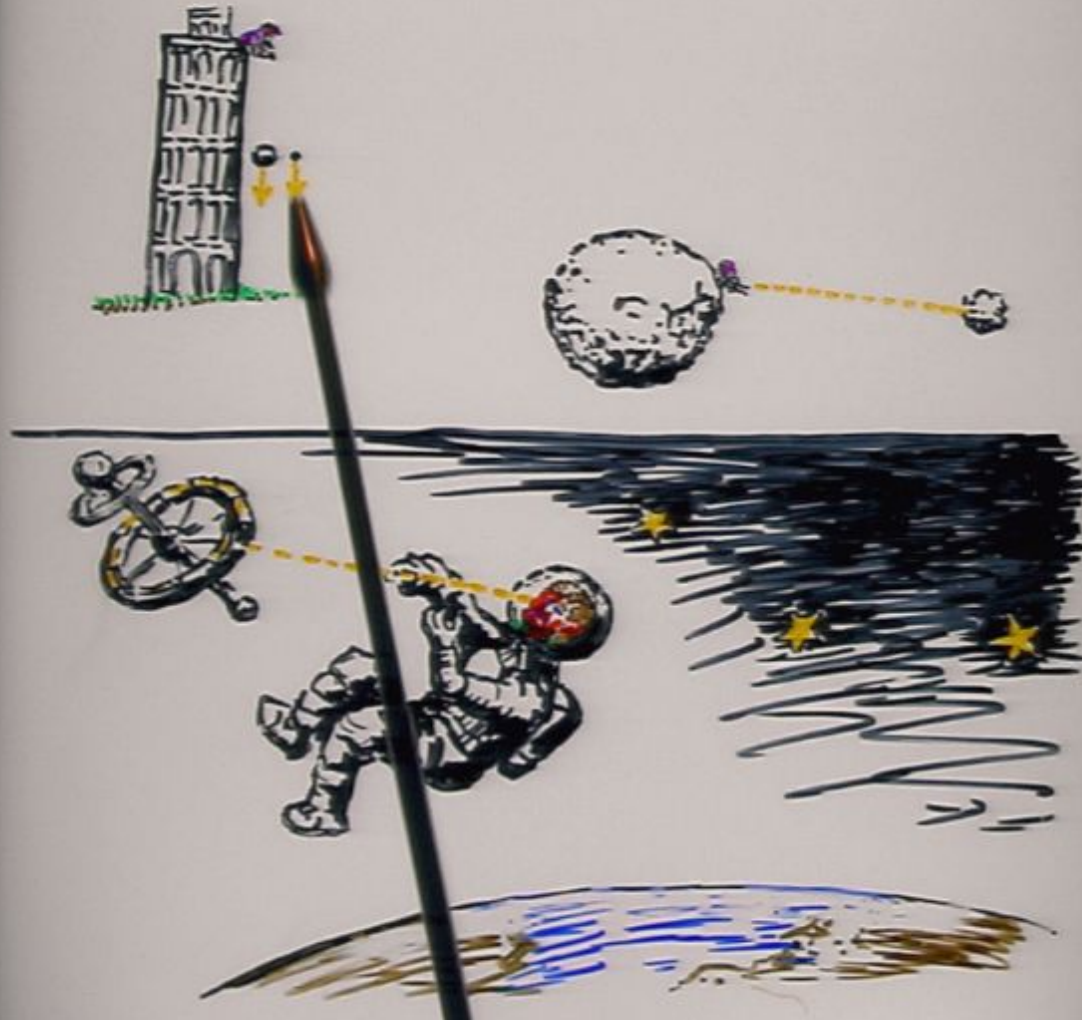
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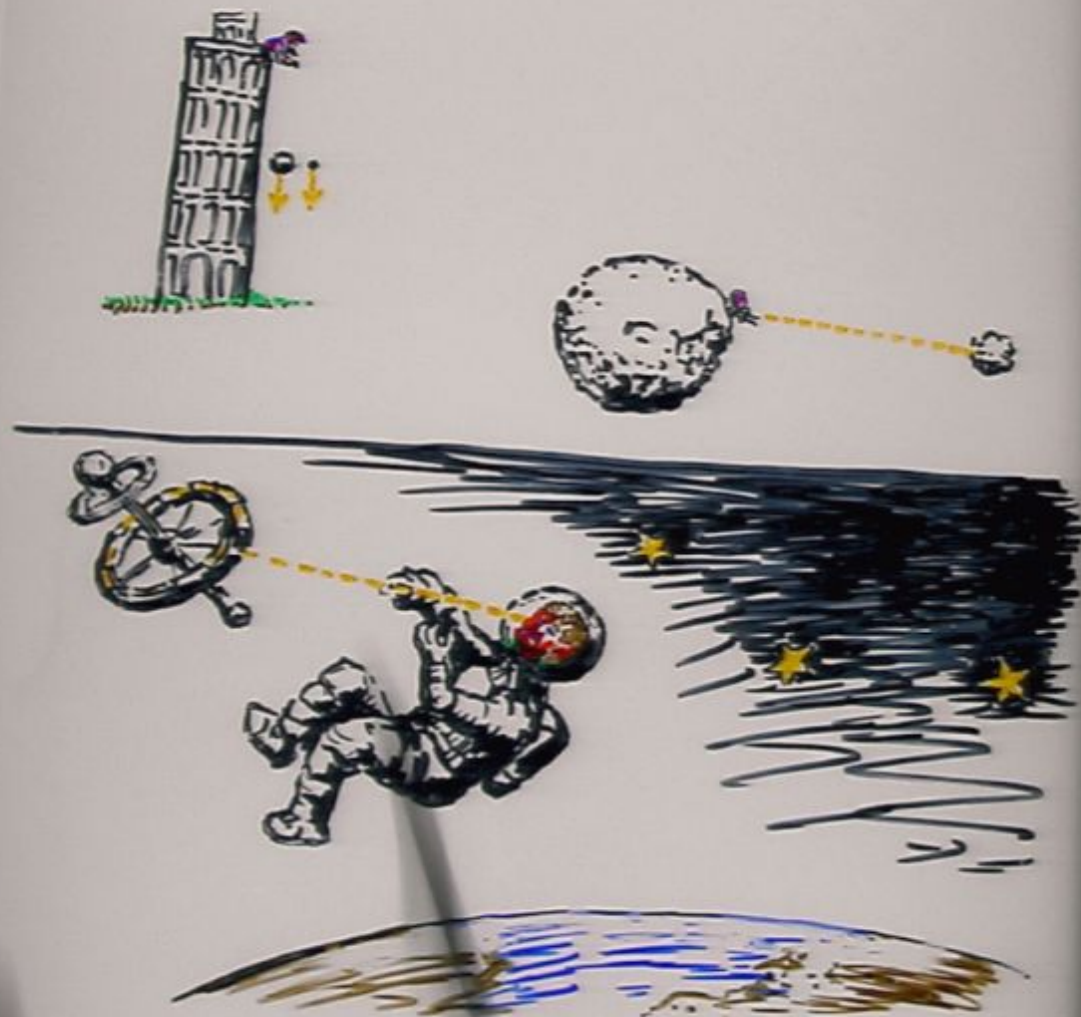
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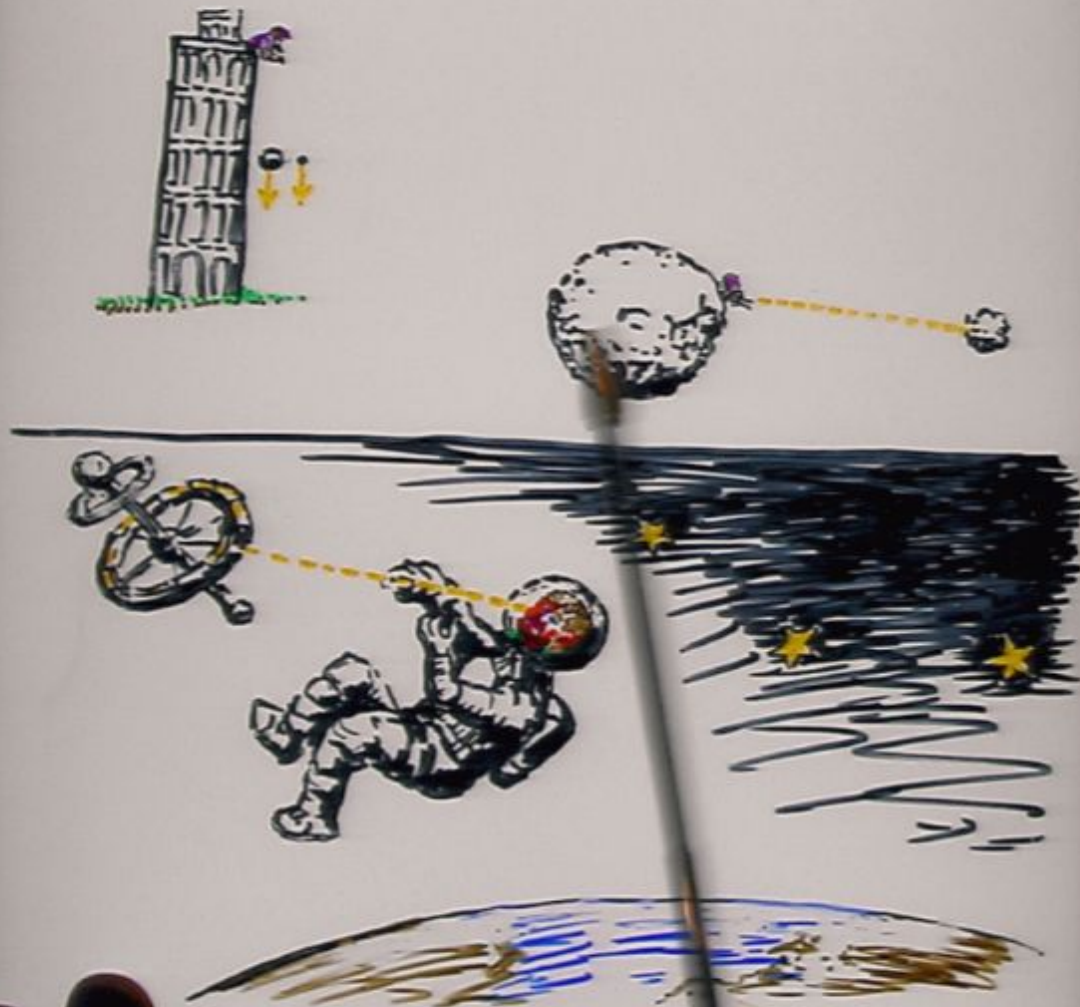
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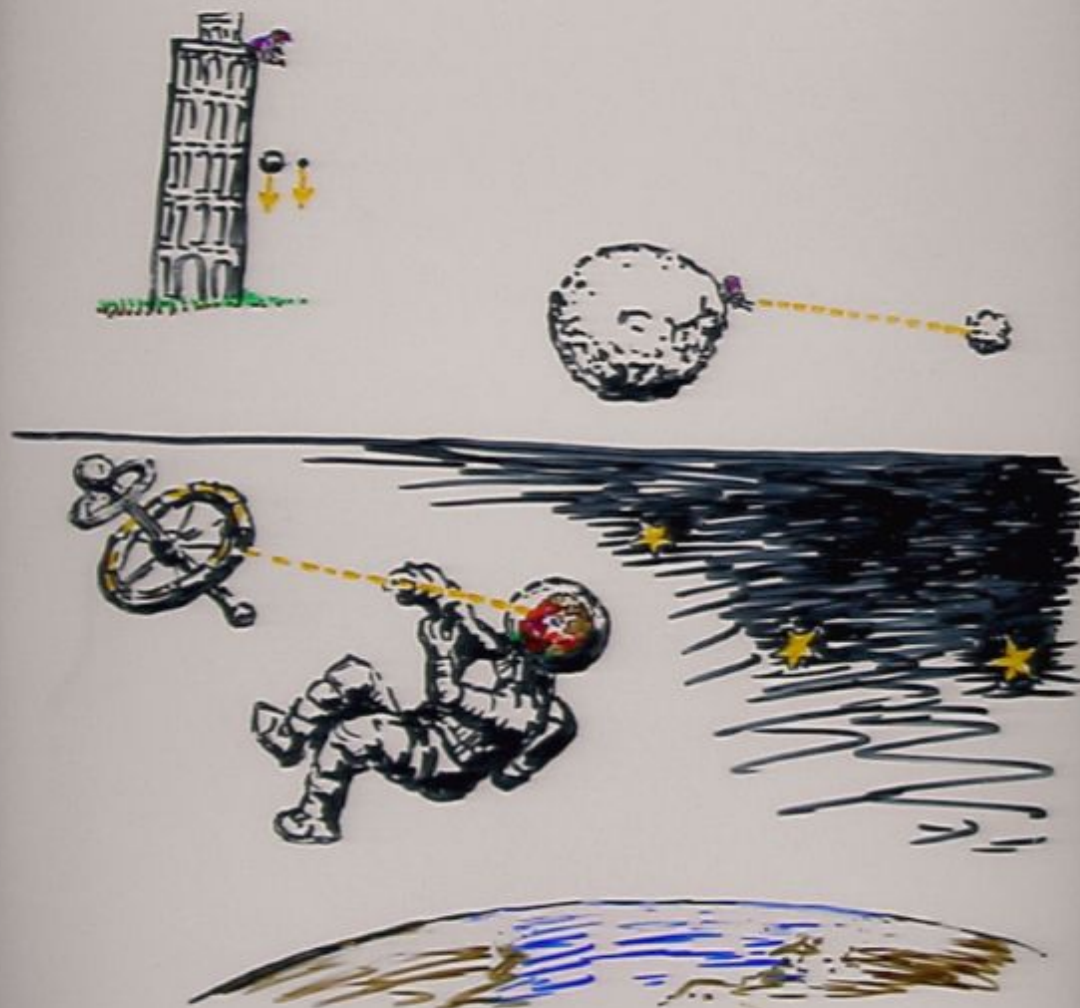
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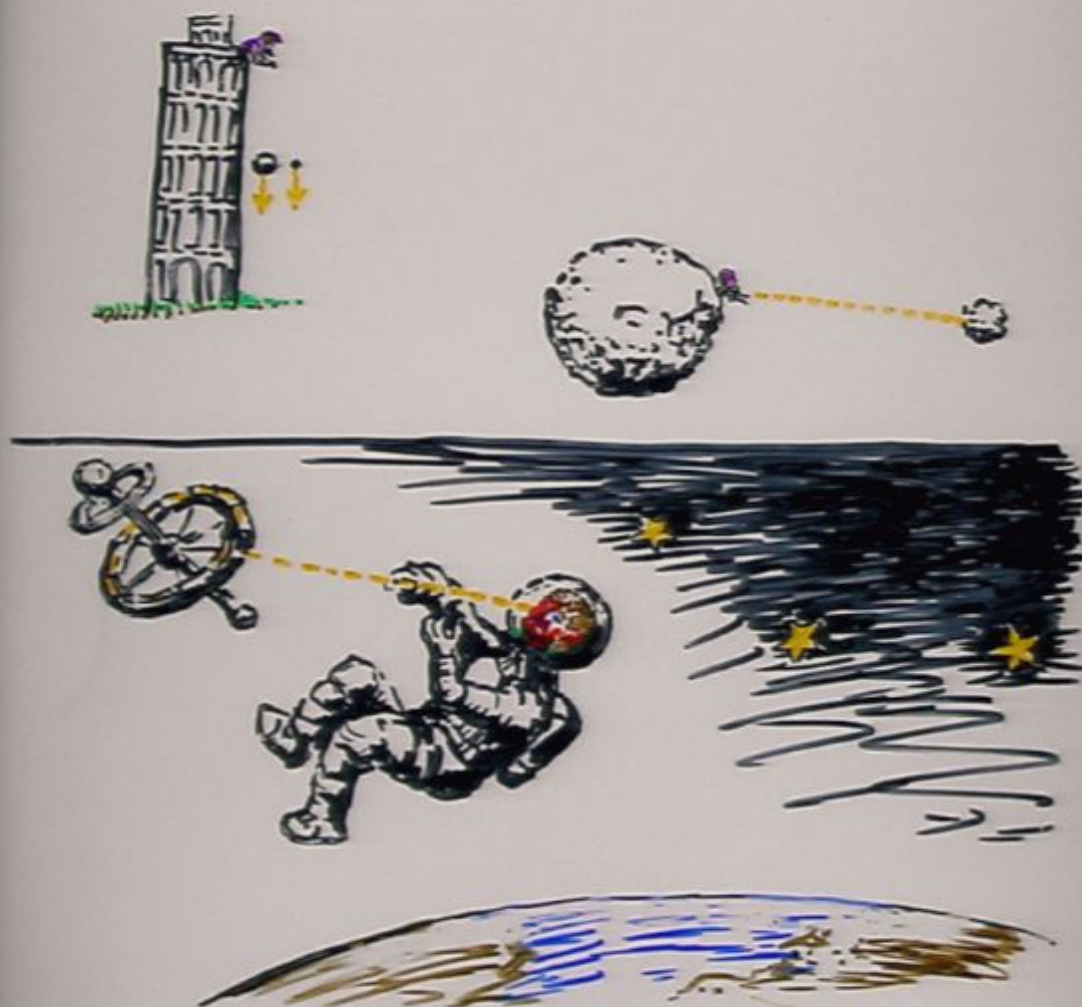
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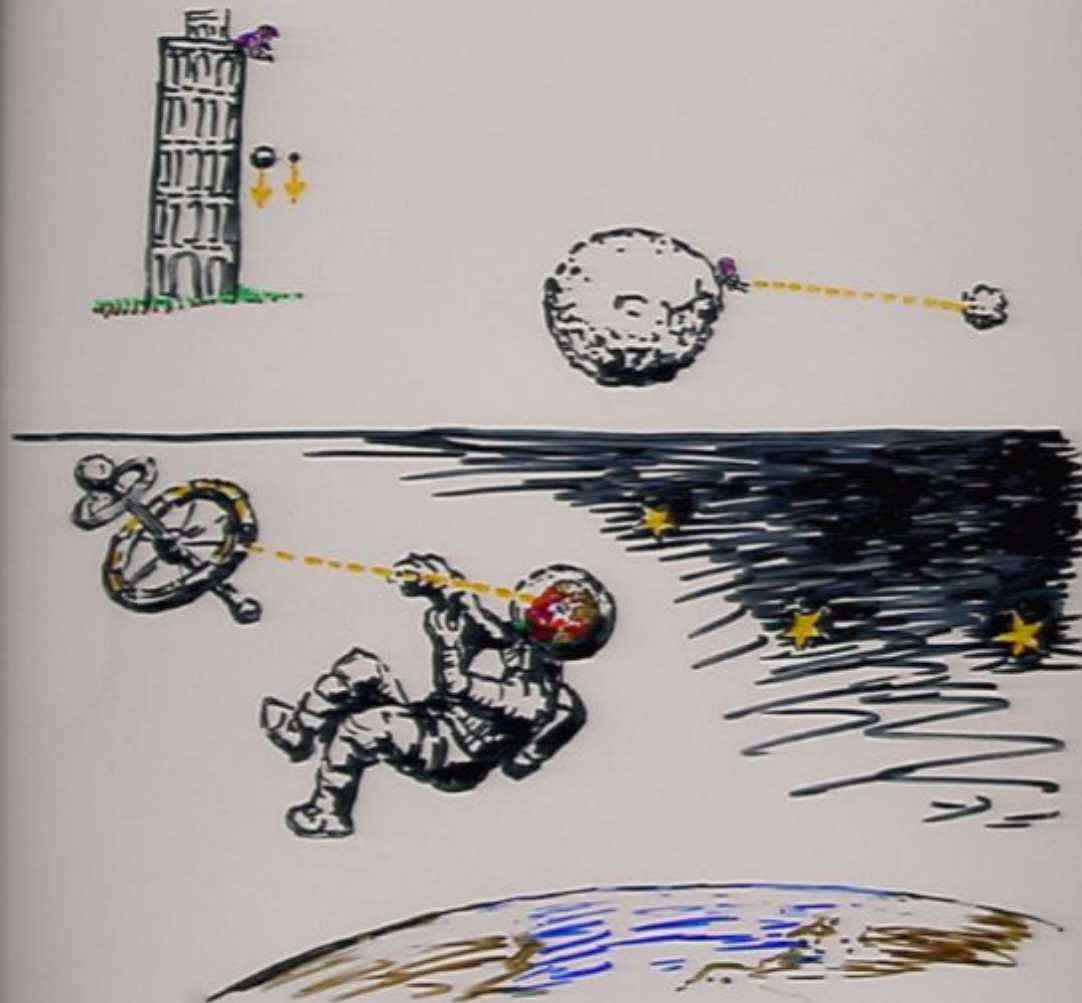
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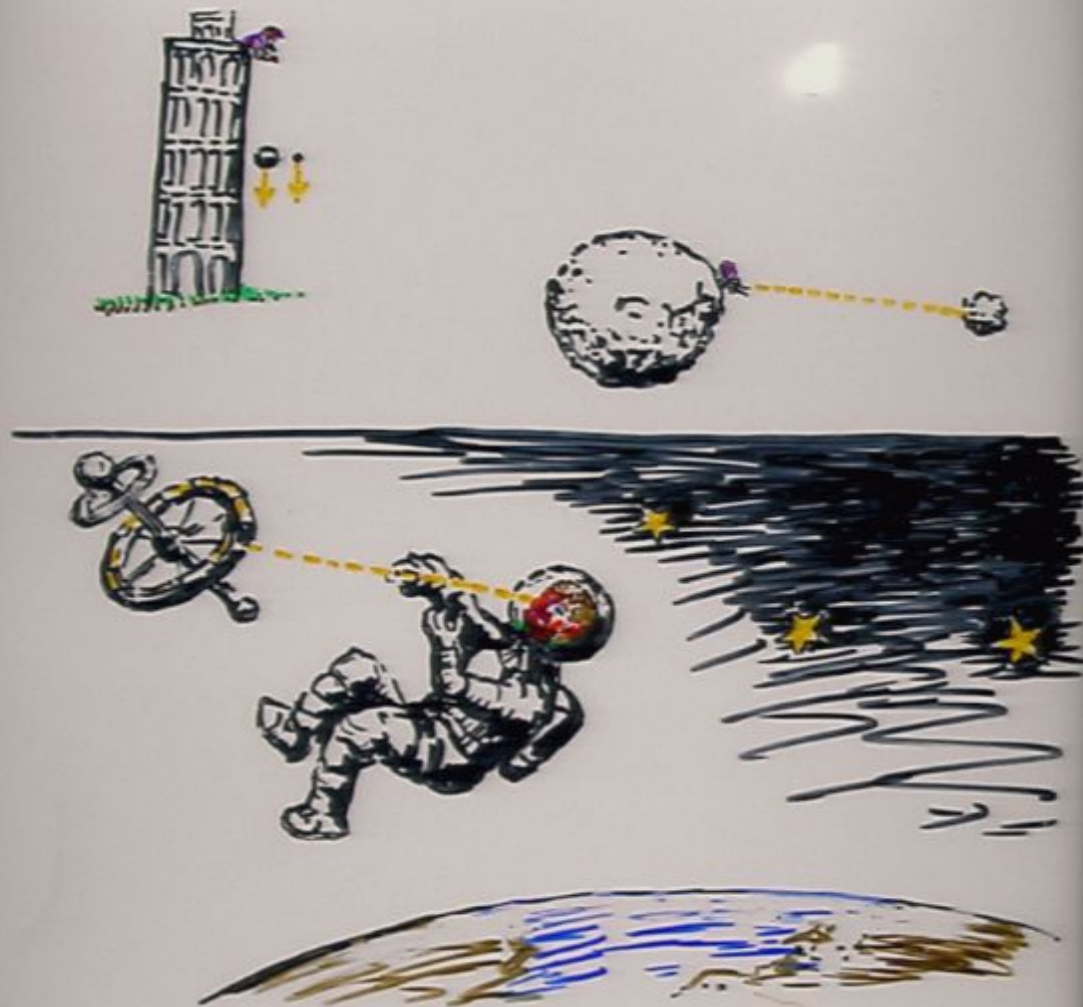


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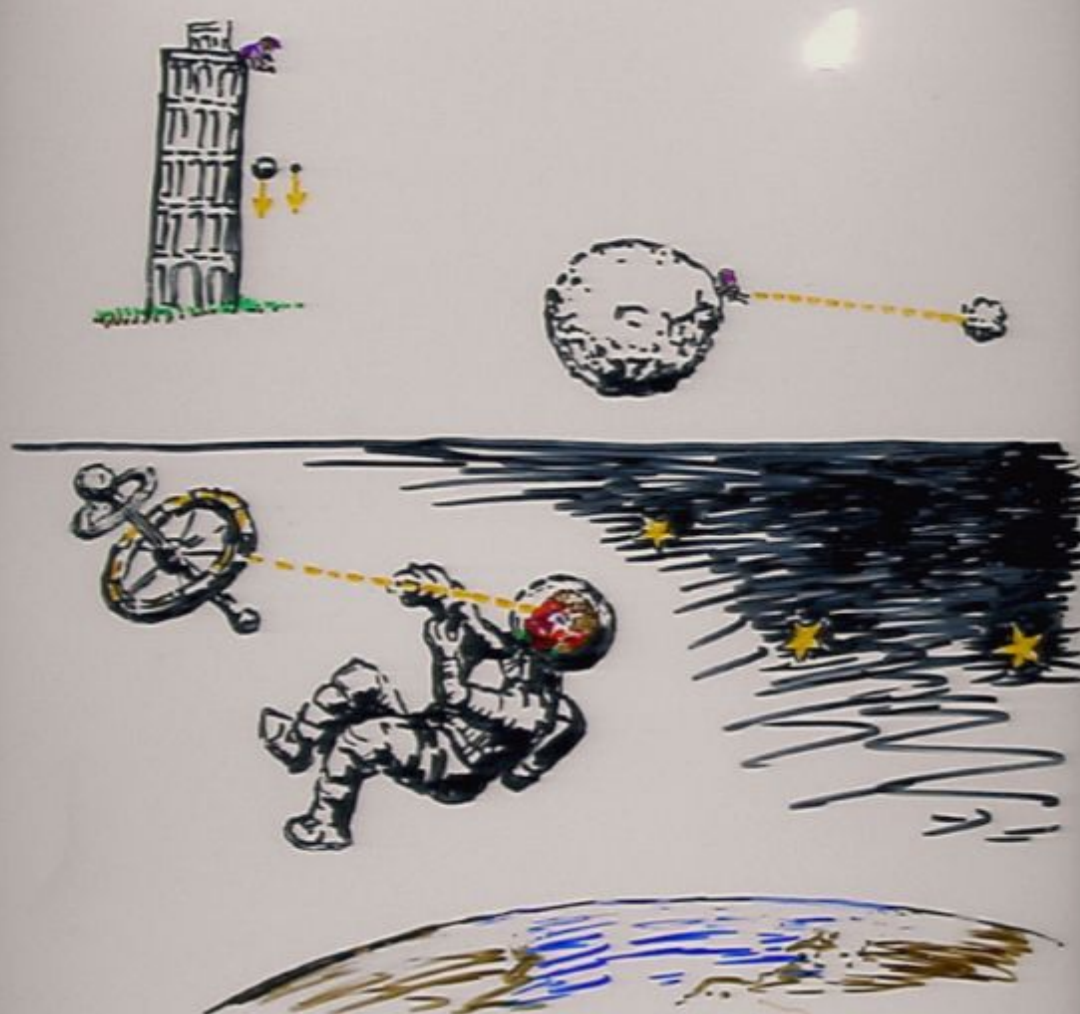


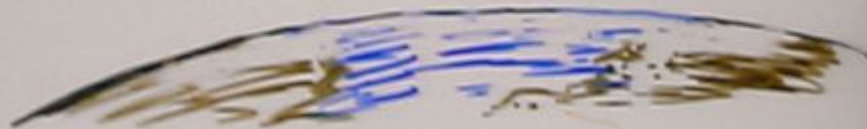
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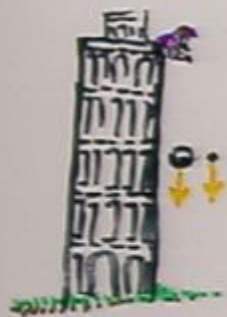




Principle of Equivalence





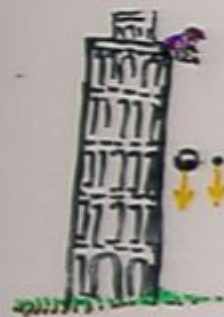


Galilei - Einstein

Principle of Equivalence

Principle of General Covariance

No physical meaning
to be attached to
any particular labelling
of space-time points



Galilei - Einstein

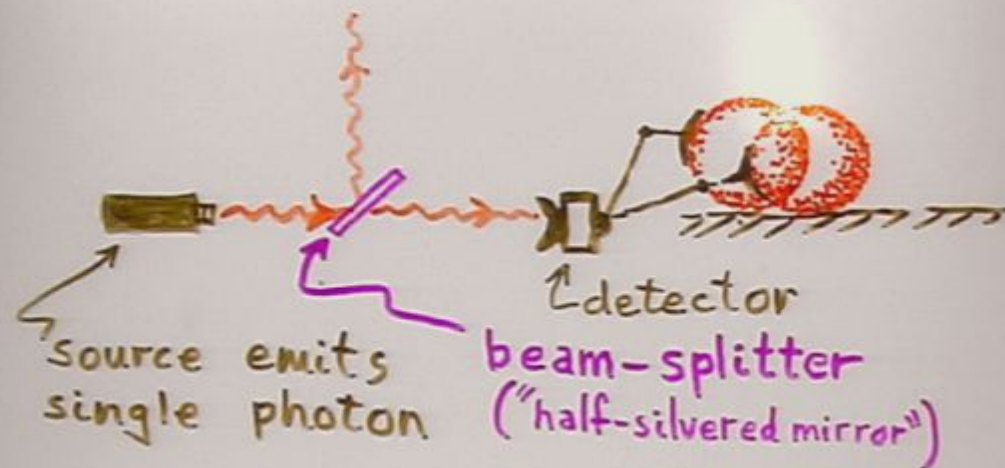
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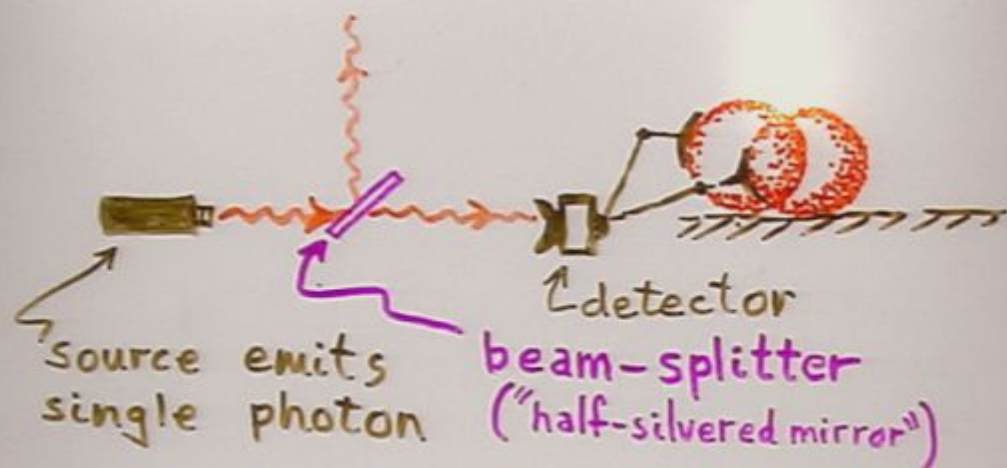


Schrödinger's lump



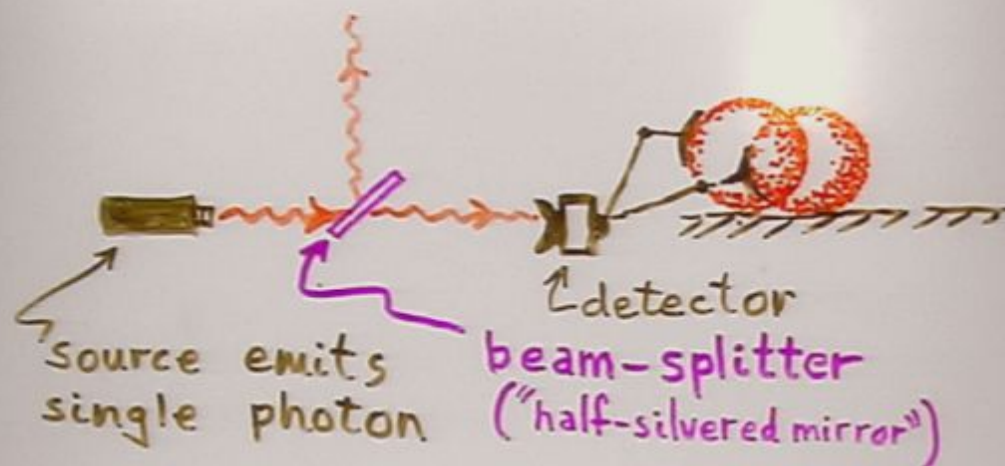
Gravitational **O** **R** theory tells us that
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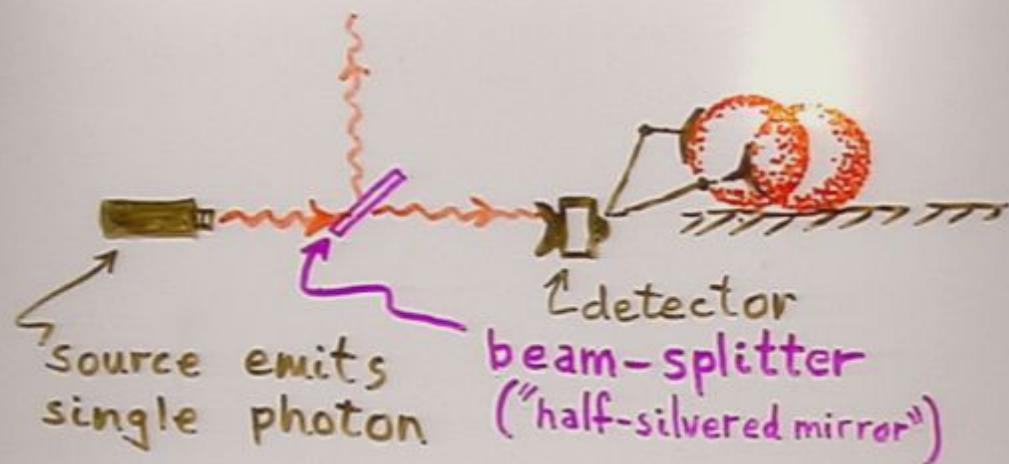
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But surely quantum-gravitational effects are far too tiny to have any relevance at the "ordinary" scales under consideration. E.g.

Planck length $\doteq 10^{-33}$ cm.

Planck time $\doteq 10^{-43}$ s.

~ 20 orders of magnitude below tiniest particle physics processes

These arise from multiplying together two quantities G and $\hbar$, each of which is tiny on ordinary scales.
 Newton's const. Planck's const.

However, the proposed decay time $\hbar/E_G$

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quantities by the other. $\therefore$ One must
examine the situation in detail to see
if this is significant in any particular situation.

relevance at the "ordinary" scales under consideration. E.g.

Planck length $\doteq 10^{-33}$ cm.

Planck time $\doteq 10^{-43}$ s.

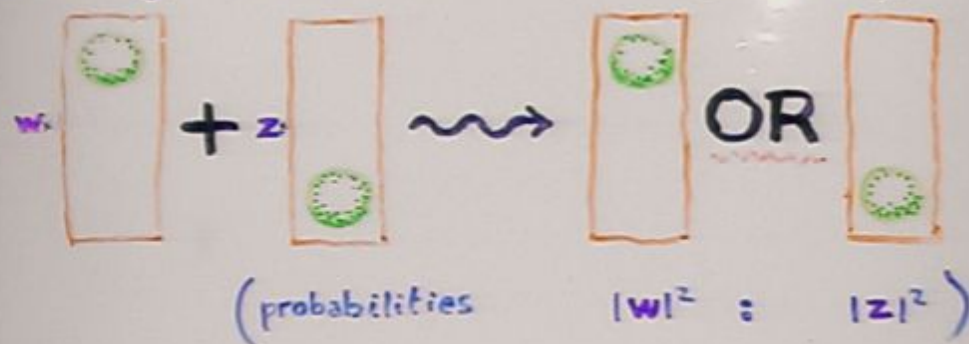
~ 20 orders of magnitude below
tiniest particle physics processes

These arise from multiplying
together two quantities G and $\hbar$
each of which is tiny on ordinary scales
However, the proposed decay time

$$\hbar/E_G$$

involves dividing one of these
quantities by the other. $\therefore$ One must
examine the situation in detail to see
if this is significant in any particular situation.

Decay times (isolated system)

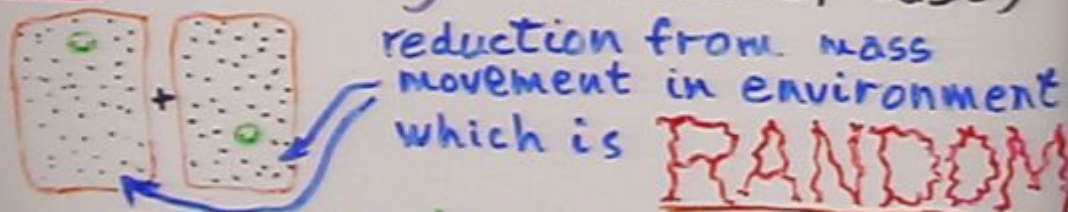


nucleon: a few million years
 (taking nucleon as uniform sphere — more correct:
 ~ far longer than age of universe)

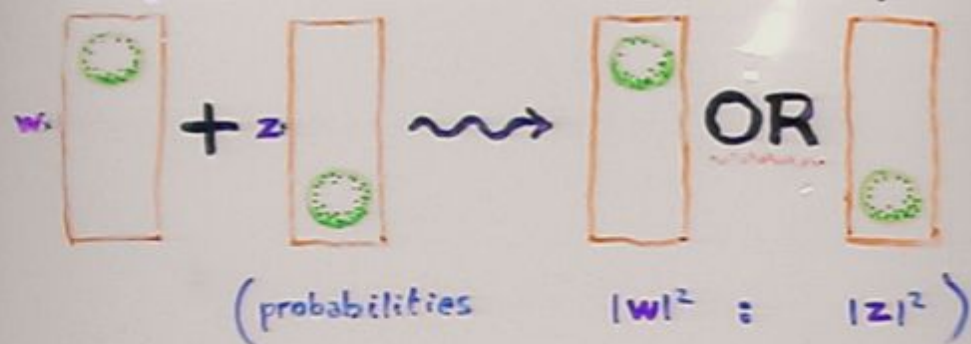
water speck:

| | | |
|--------|--------------|-------------------------|
| radius | 10^{-5} cm | ~ hours |
| | micron | ~ $\frac{1}{20}$ second |
| | 10^{-3} cm | ~ millionth of a second |

Non-isolated system (usual case)



Decay times (isolated system)

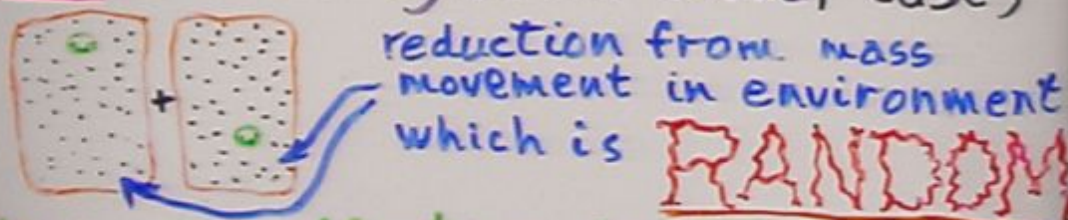


nucleon: a few million years
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water speck:

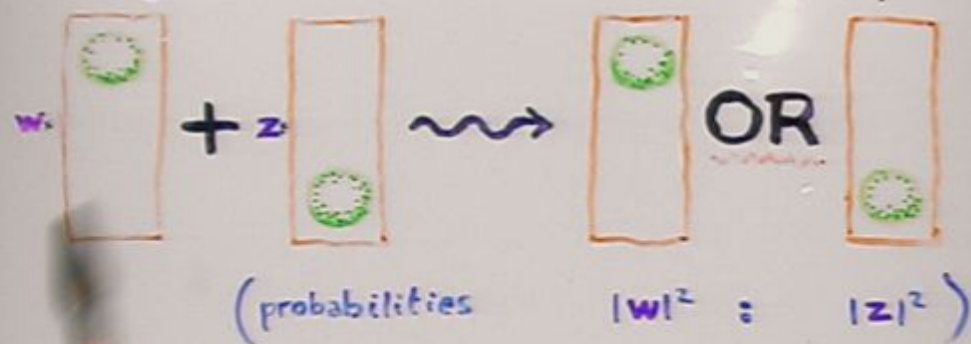
| | | |
|--------|---|--|
| radius | $\begin{cases} 10^{-5} \text{ cm} \\ \text{micron} \\ 10^{-3} \text{ cm} \end{cases}$ | $\begin{matrix} \sim \text{hours} \\ \sim \frac{1}{20} \text{ second} \\ \sim \text{millionth of a second} \end{matrix}$ |
|--------|---|--|

Non-isolated system (usual case)



Need very effective isolation to see

Decay times (isolated system)

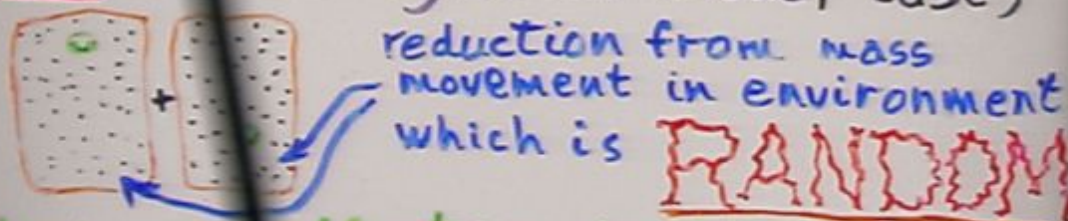


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water speck:

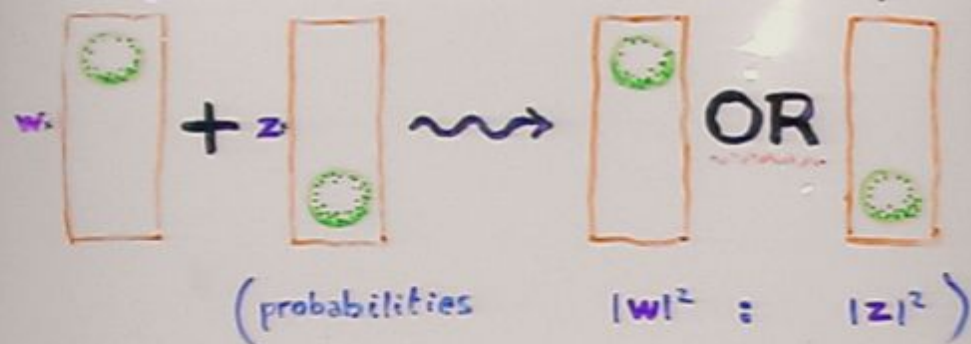
| | | |
|--------|---|-------------------------------------|
| radius | $\begin{cases} 10^{-5} \text{ cm} \\ \text{micron} \\ 10^{-3} \text{ cm} \end{cases}$ | $\sim \text{hours}$ |
| | | $\sim \frac{1}{20} \text{ second}$ |
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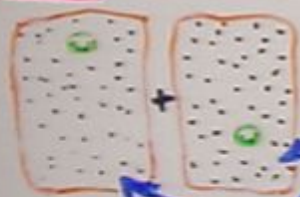
radius $\begin{cases} 10^{-5} \text{ cm} \\ \text{micron} \\ 10^{-3} \text{ cm} \end{cases}$

~ hours

~ $\frac{1}{20}$ second

~ millionth of a second

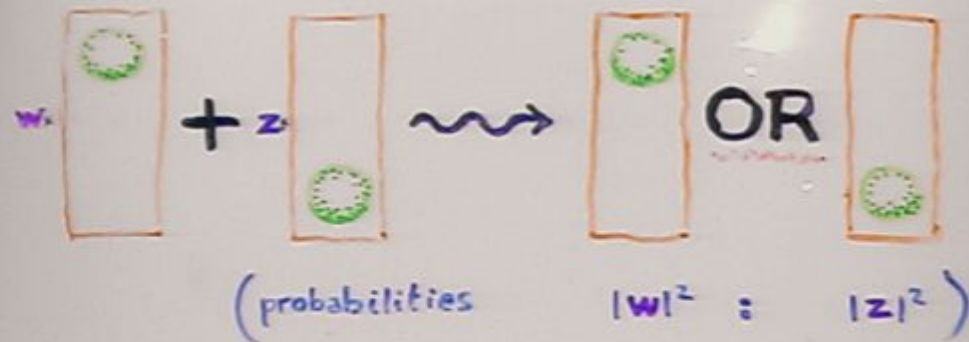
Non-isolated system (usual case)



reduction from mass
 movement in environment
 which is **RANDOM**

Need very effective isolation to see

Decay times (isolated system)

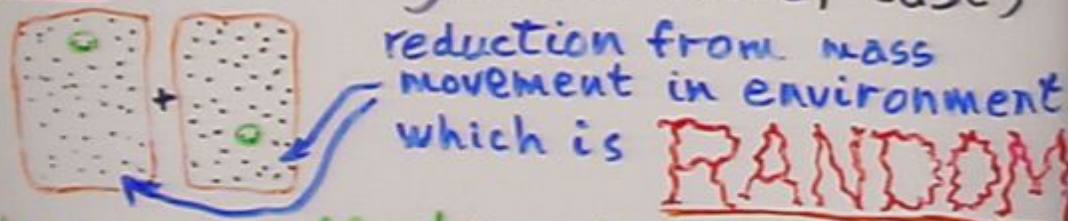


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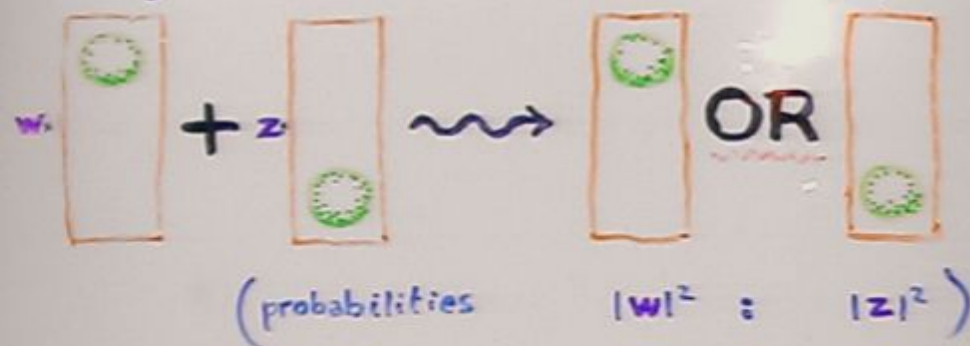
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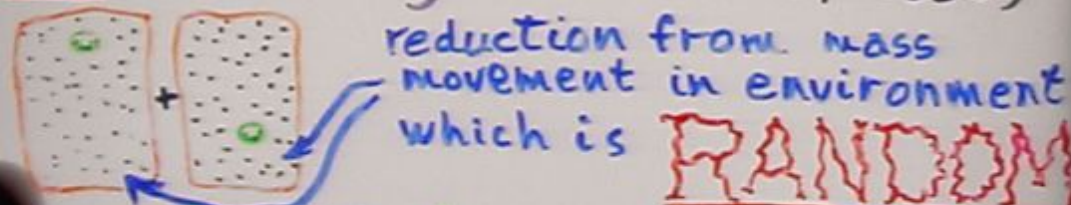


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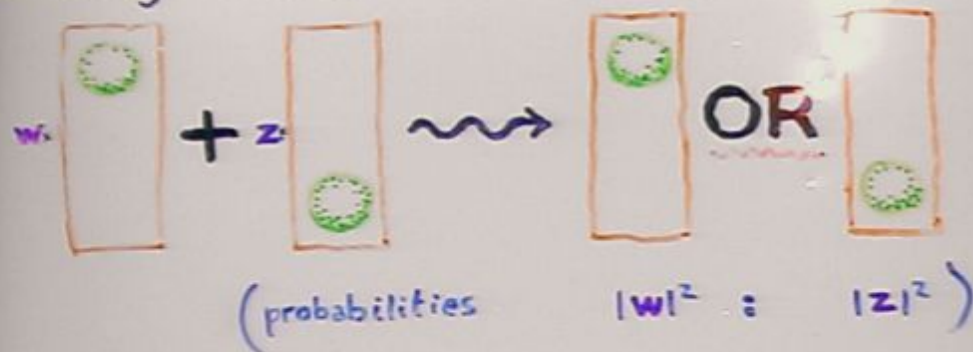
| | | |
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Decay times (isolated system)

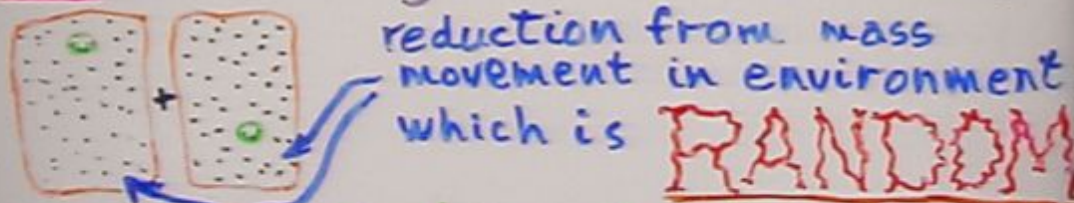


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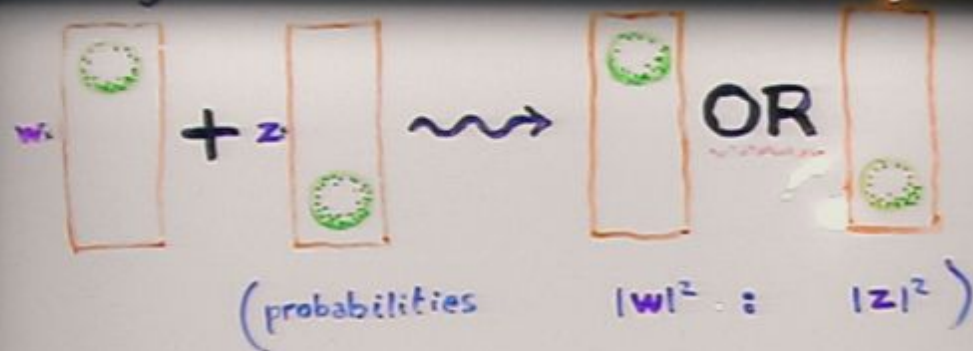
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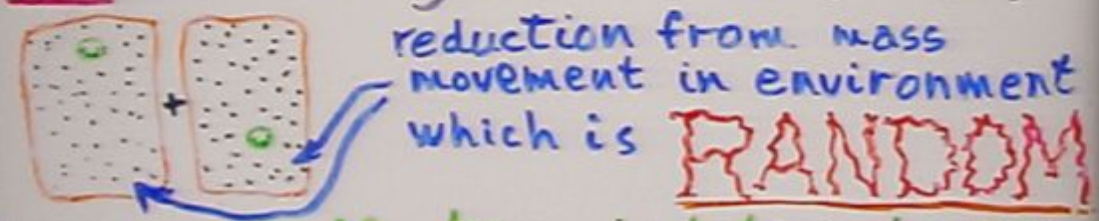
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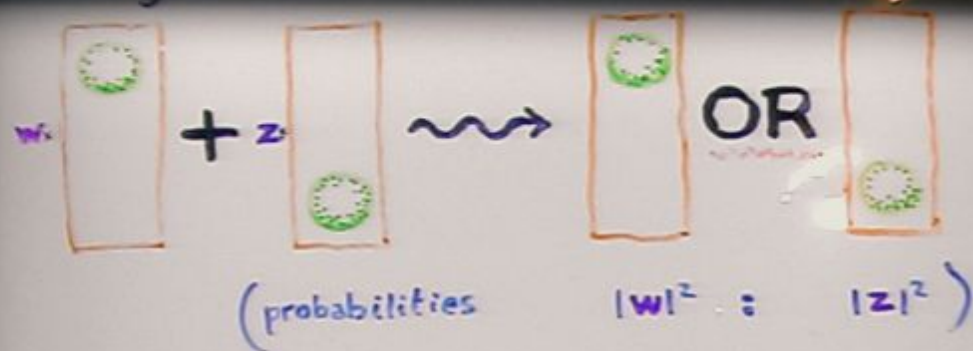
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Non-isolated system (usual case)



Need very effective isolation to see the non-random effects of **OR**

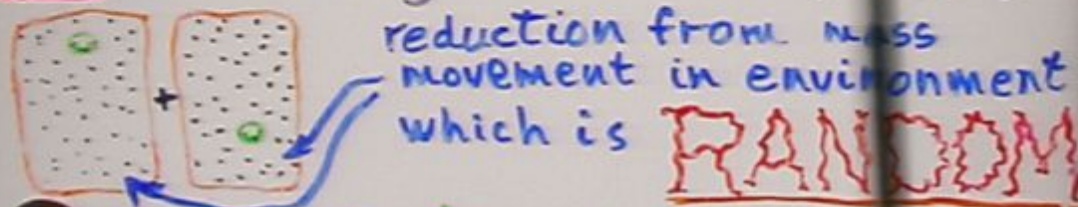


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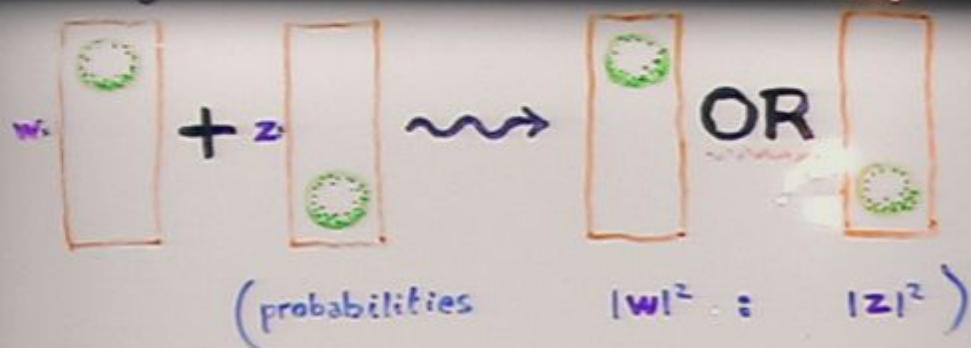
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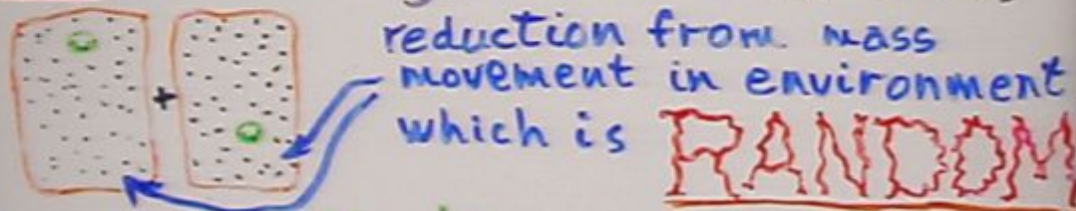


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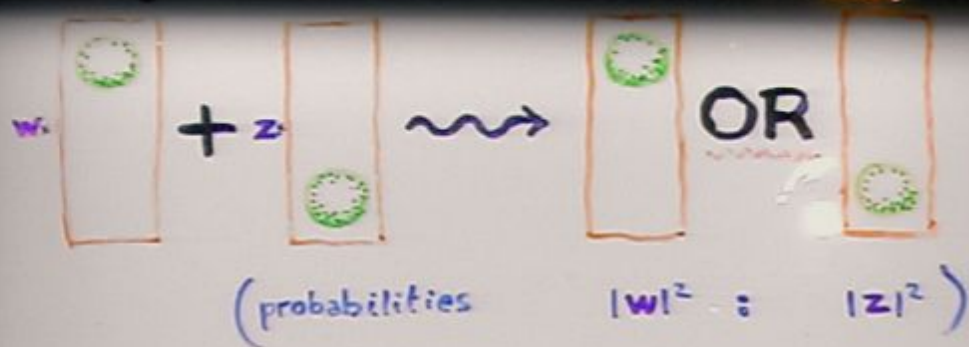
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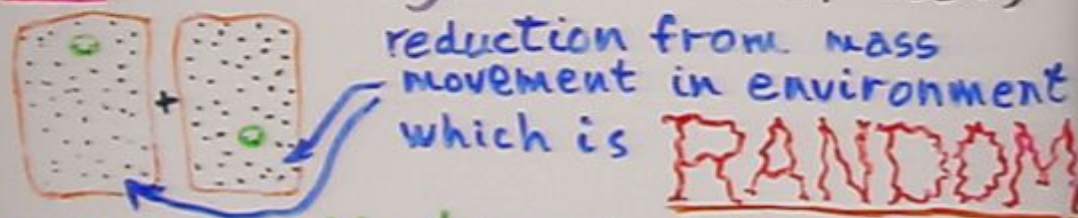


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Non-isolated system (usual case)



Need very effective isolation to see the non-random effects of **OR**

(probabilities

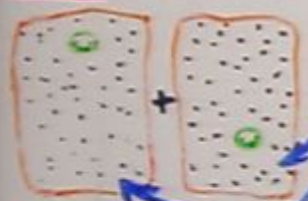
$$|w|^2 : |z|^2)$$

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Non-isolated system (usual case)



reduction from mass
movement in environment
which is

RANDOM

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$|w|^2$:

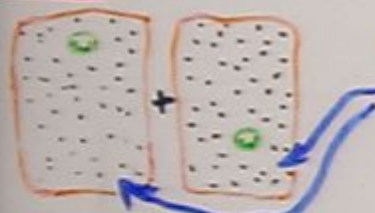
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↑
Mass
distribution



Individual
particles



"delta
functions"

Would give INFINITE effect ----
↪ but not stationary

Correct procedure: nuclei
spread, in stationary state



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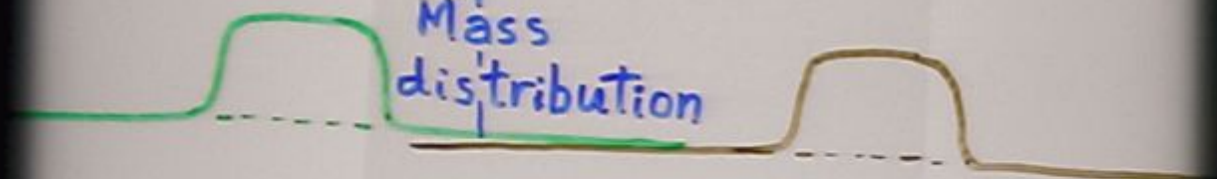
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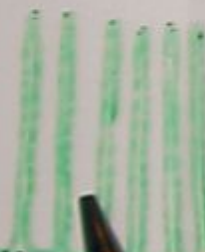
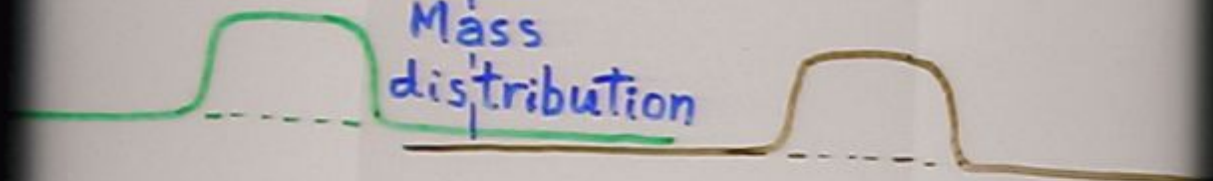
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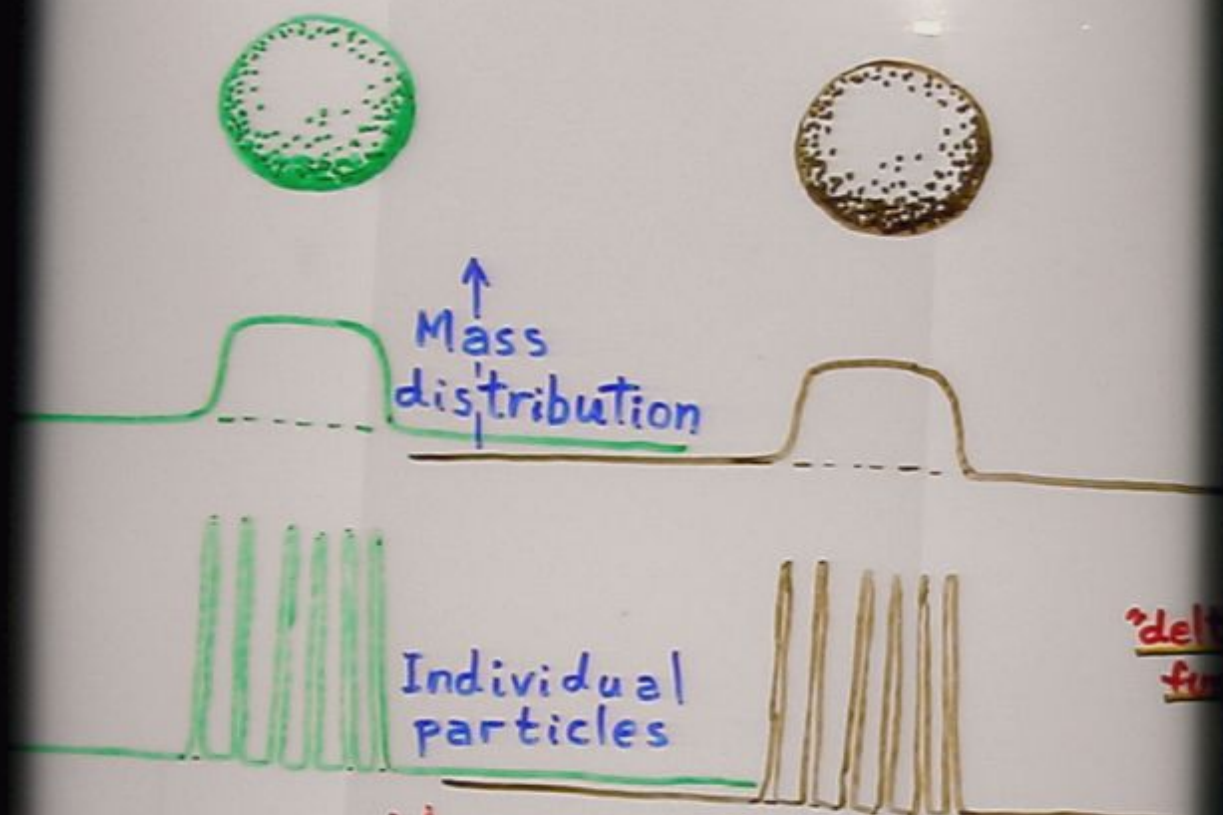
Individual
particles



delta
fun

Would give INFINITE effect
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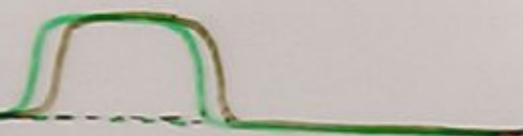
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Mass
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Individual
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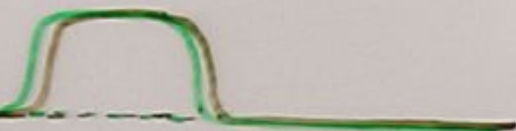
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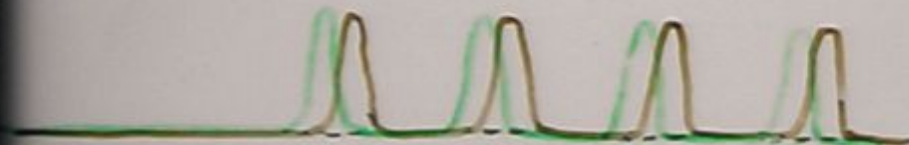
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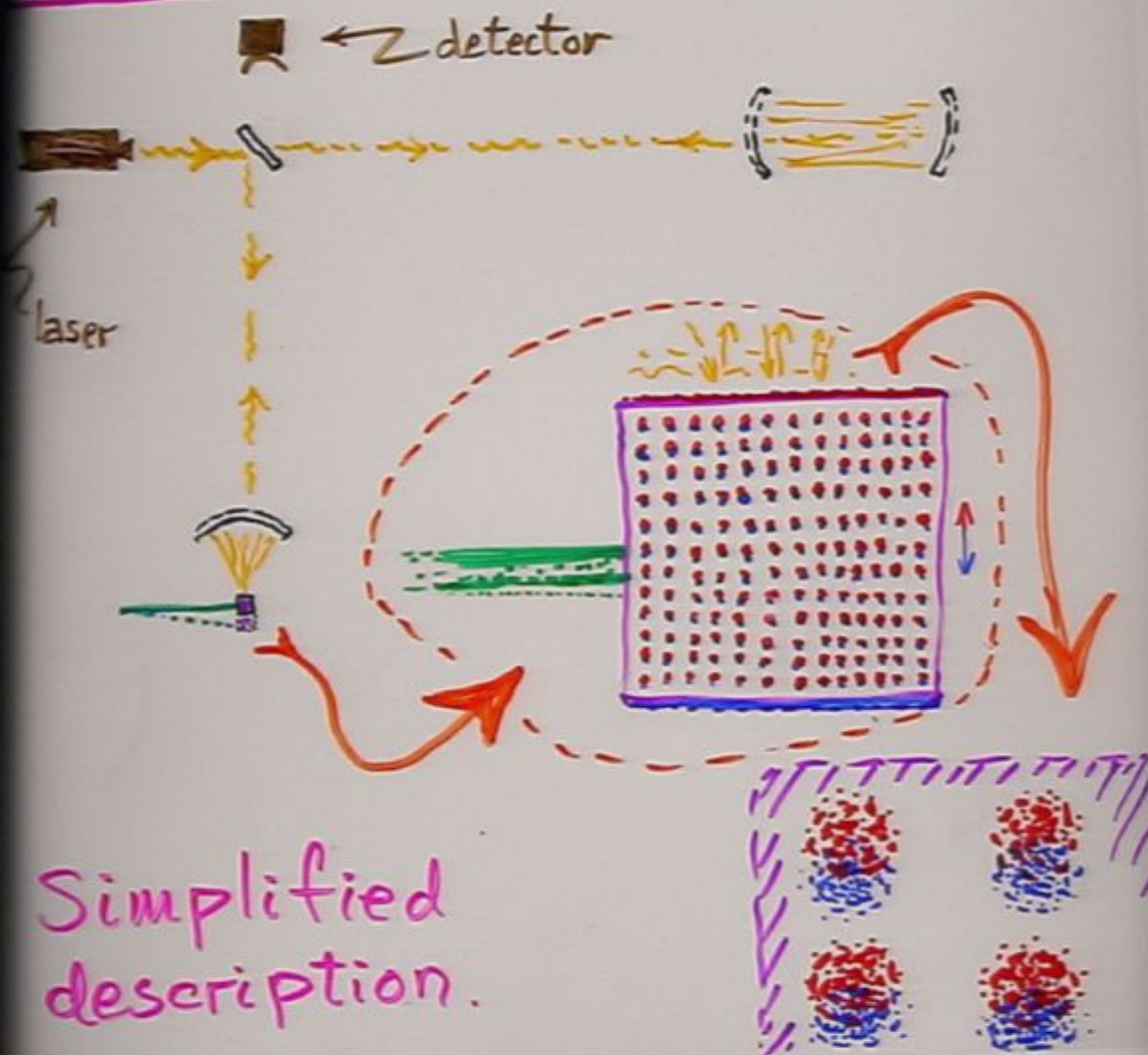
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A Proposed Experiment

aimed at eventually testing Gravitational OR

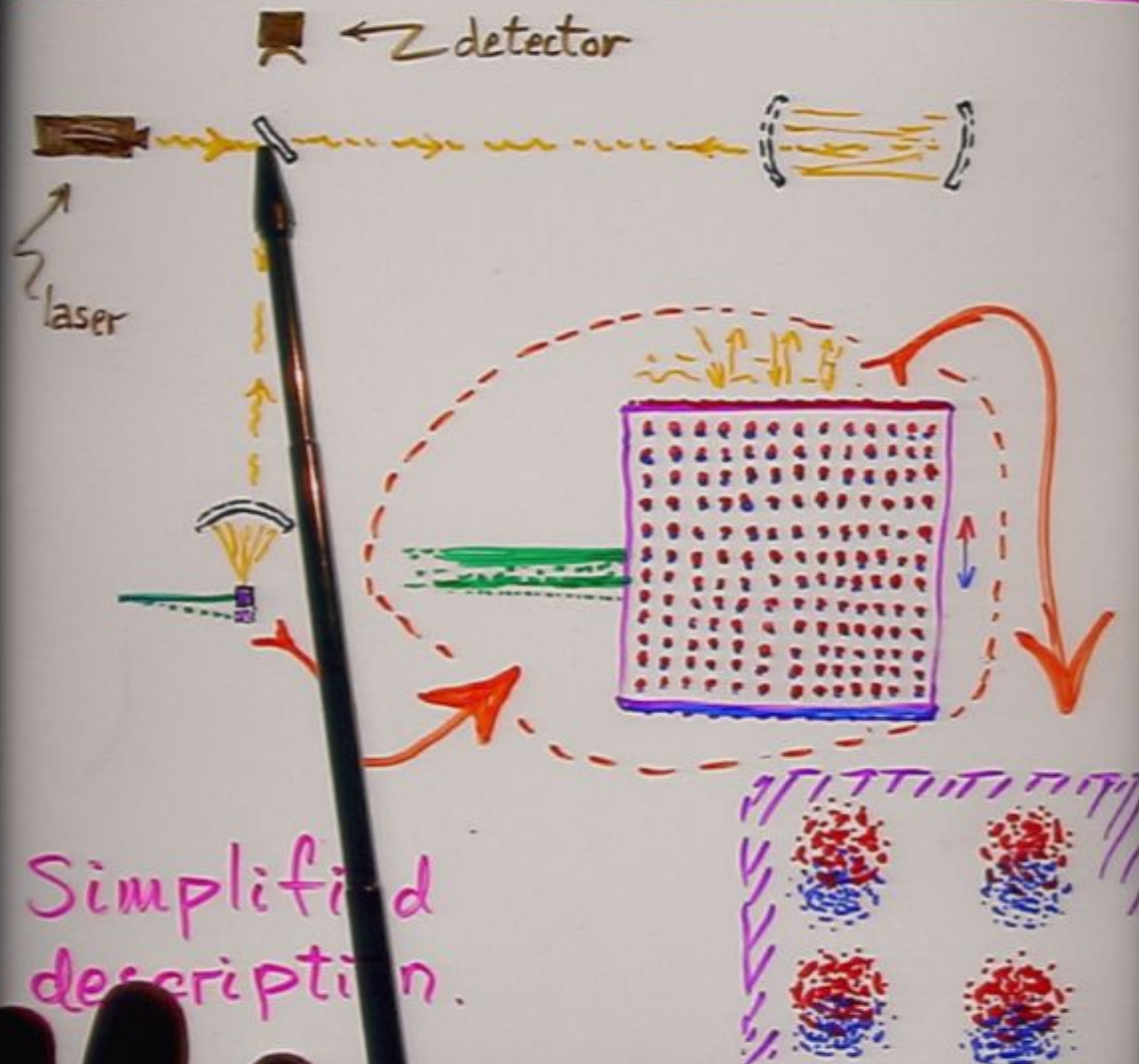
ask Bouwmeester, Will Marshall, Christoph Simon, ... & RP
(& early input from Johannes Dapprich, Anton Zeilinger, ...)



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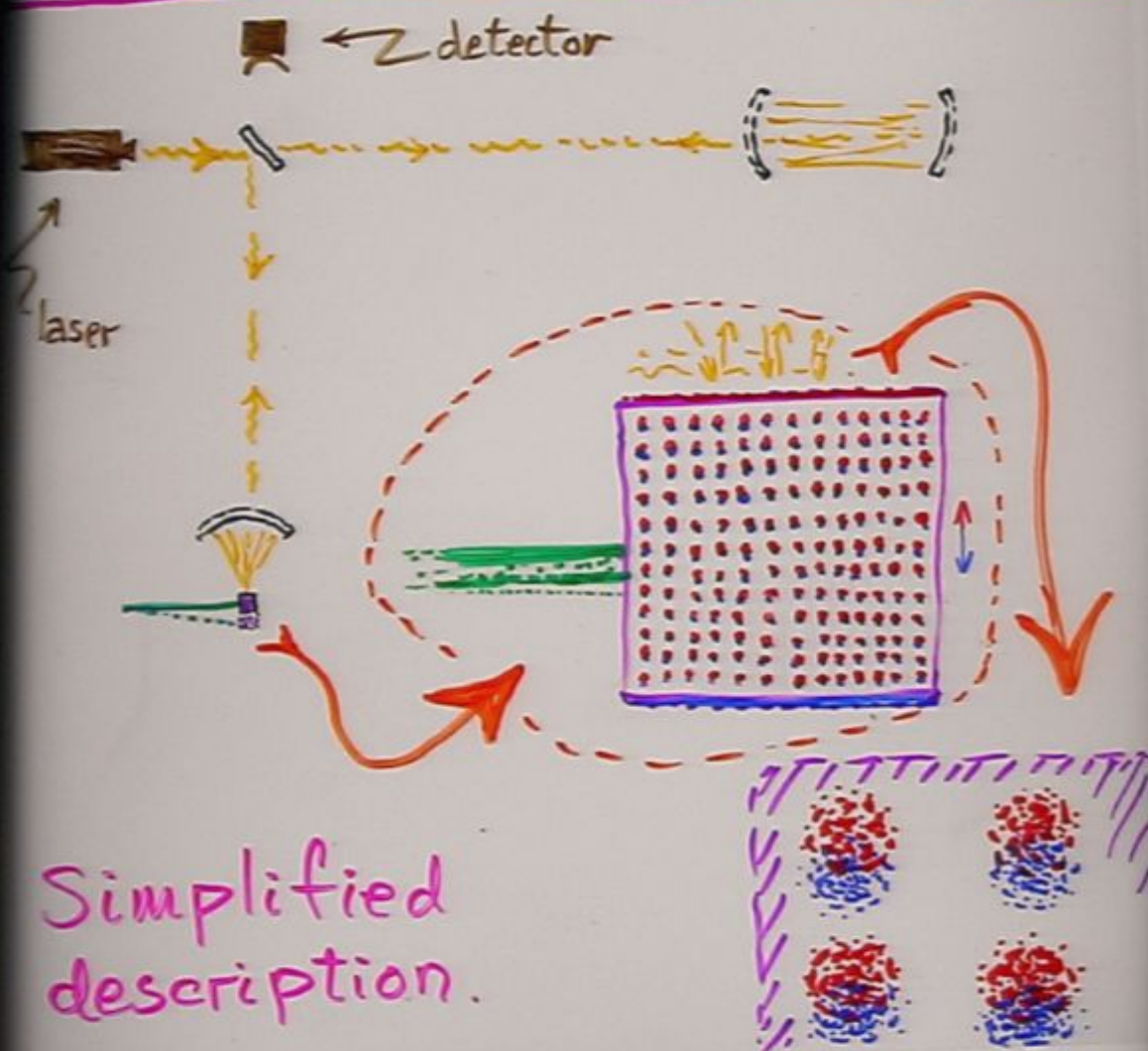
Dik Bouwmeester, Will Marshall, Christoph Simon, ... & RP
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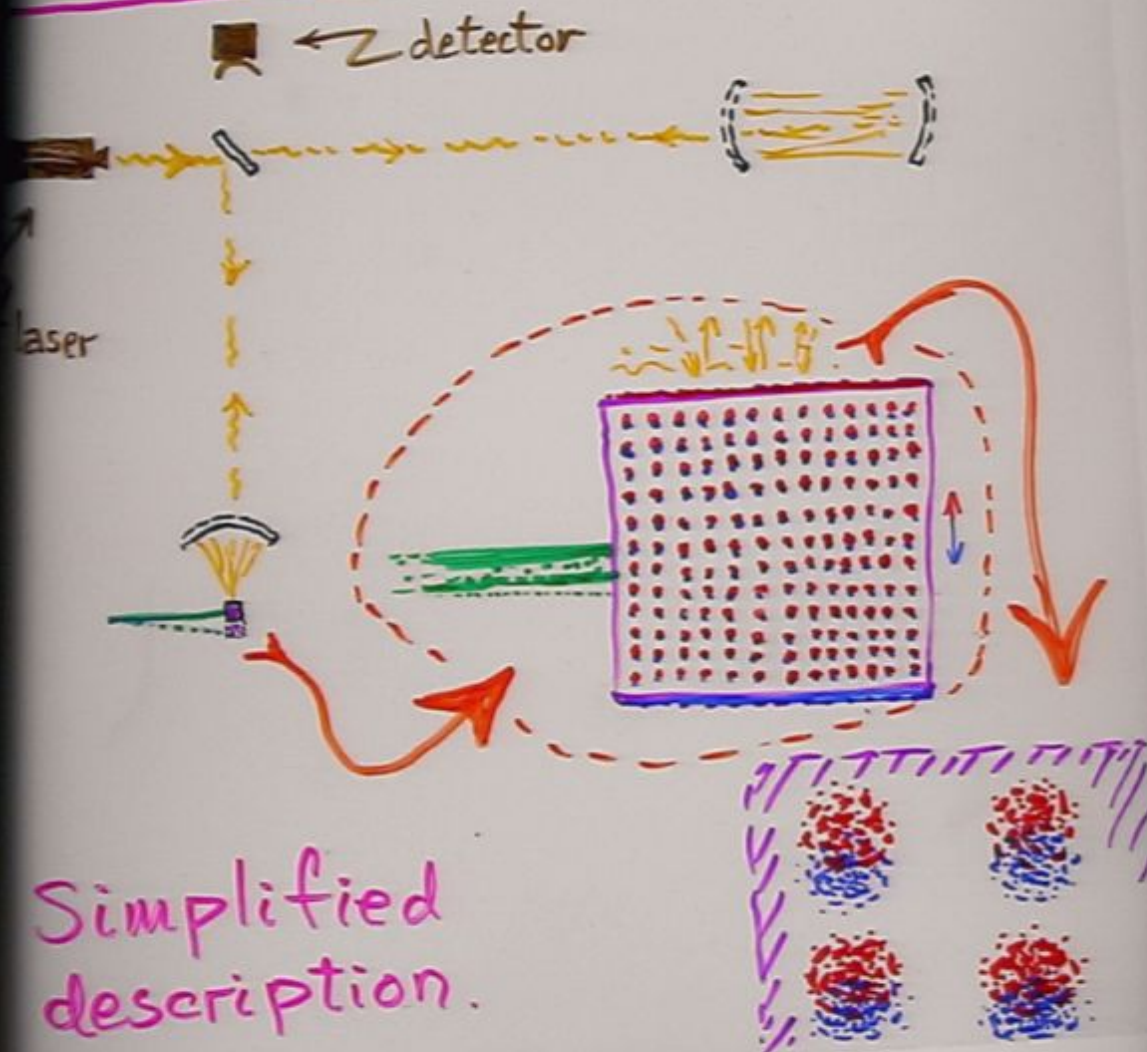
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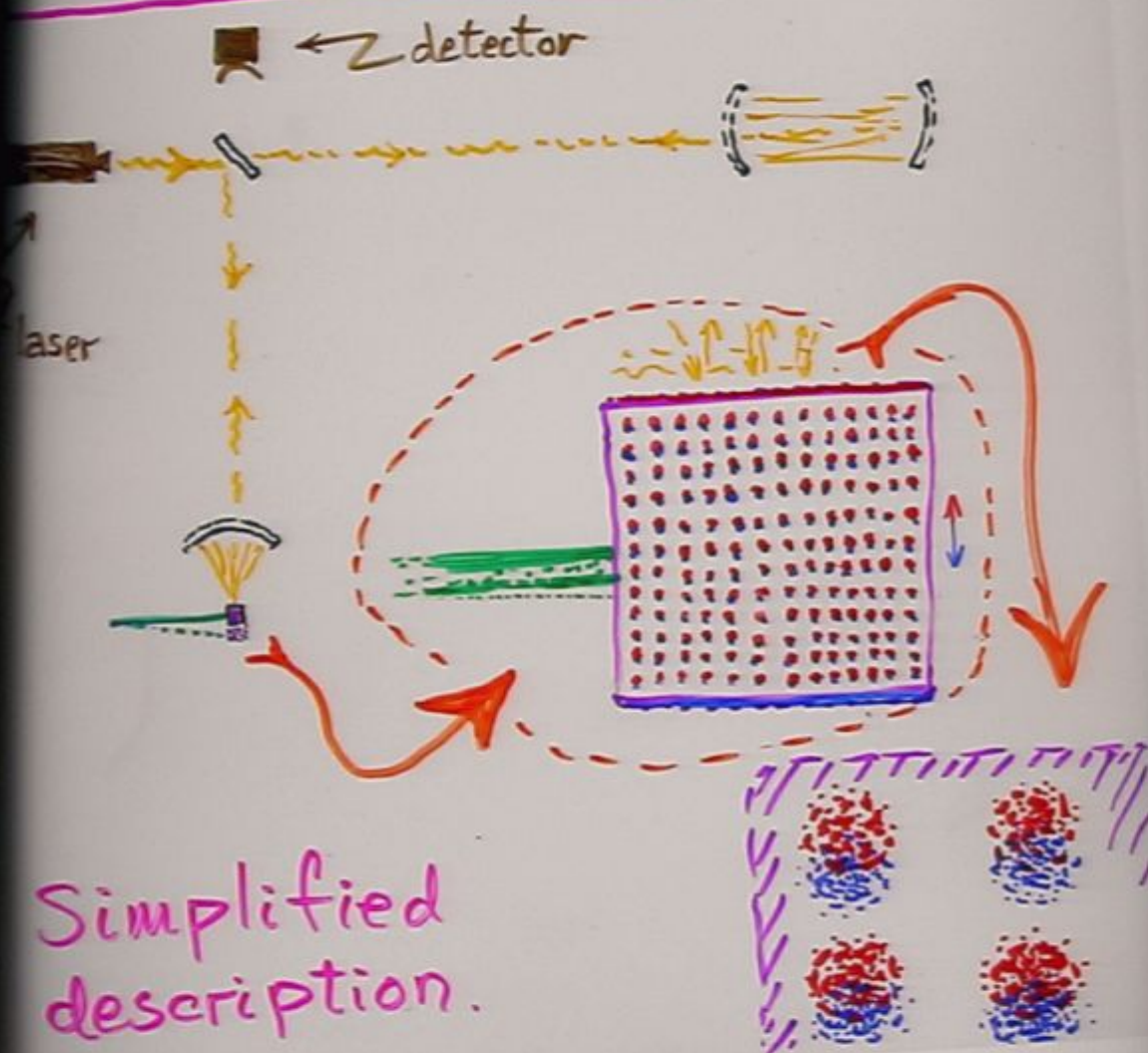
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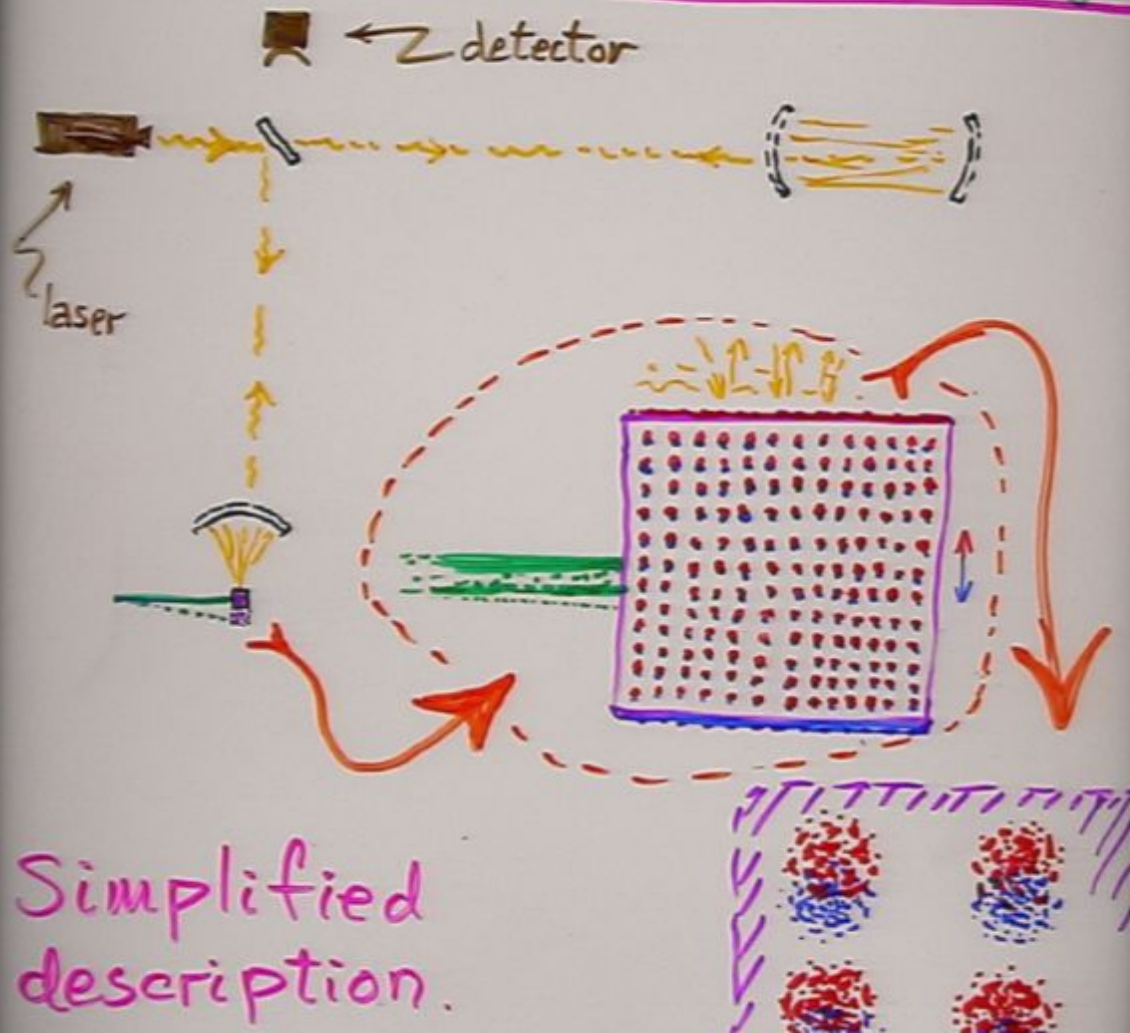
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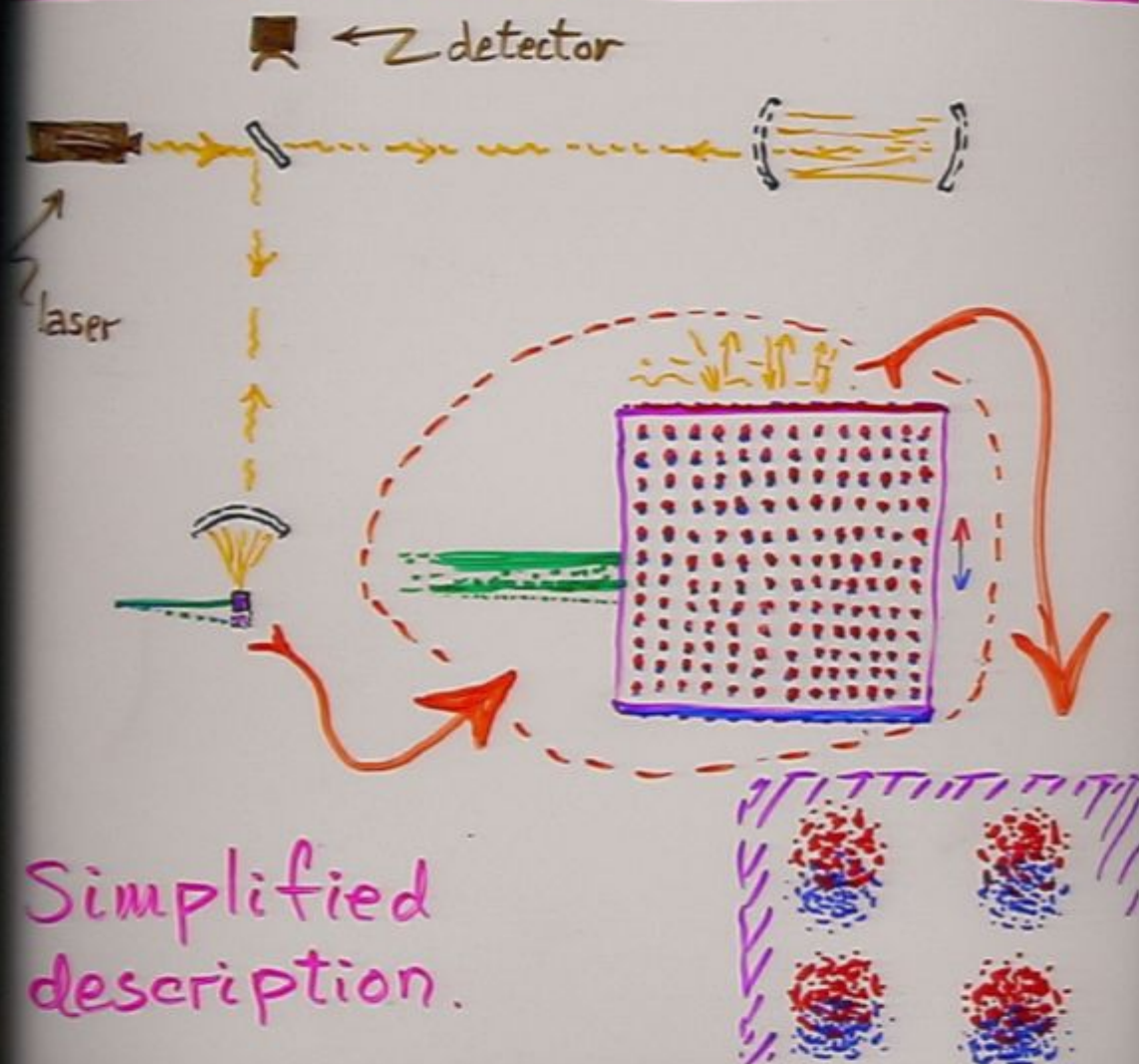
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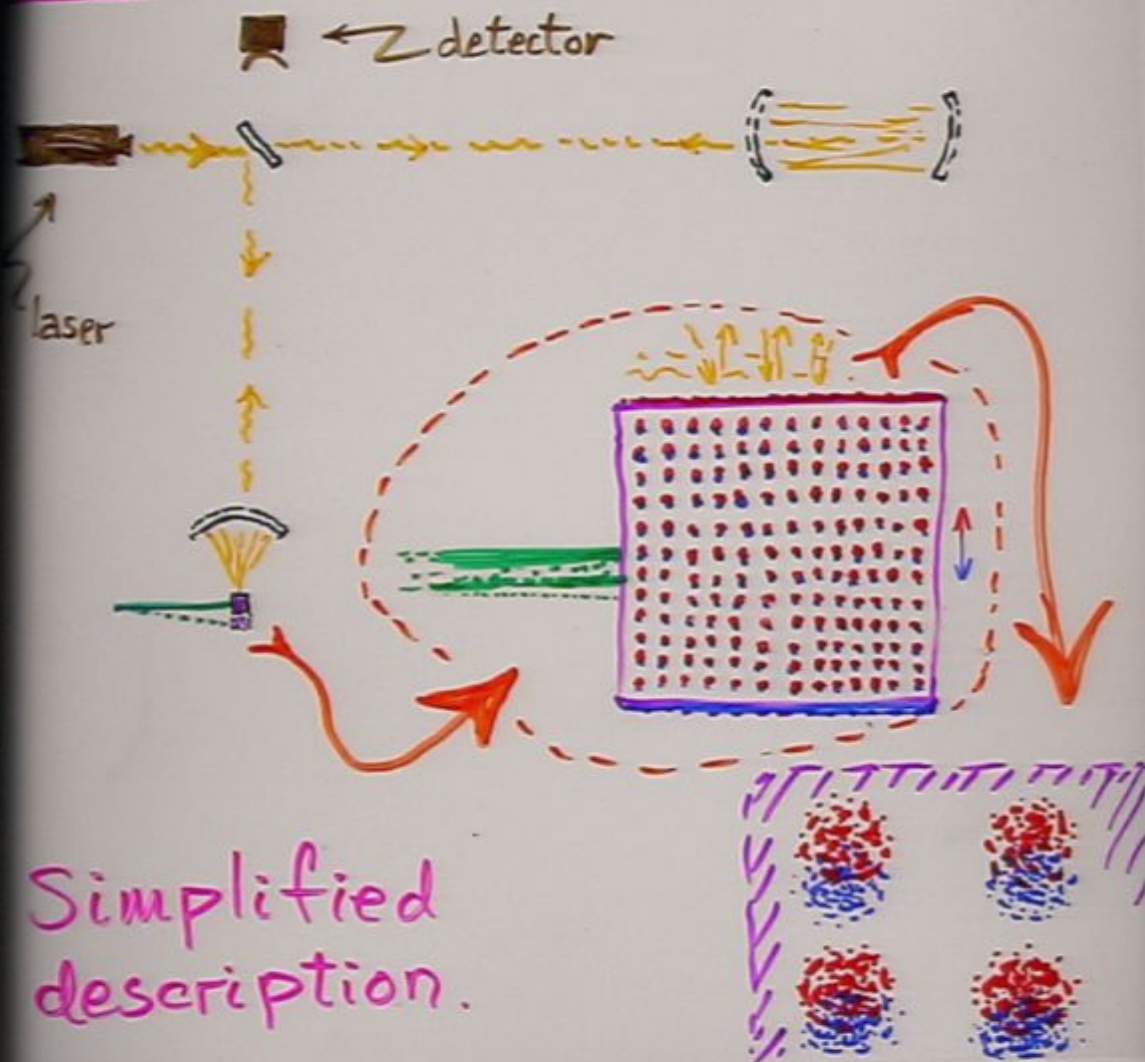
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A Proposed Experiment

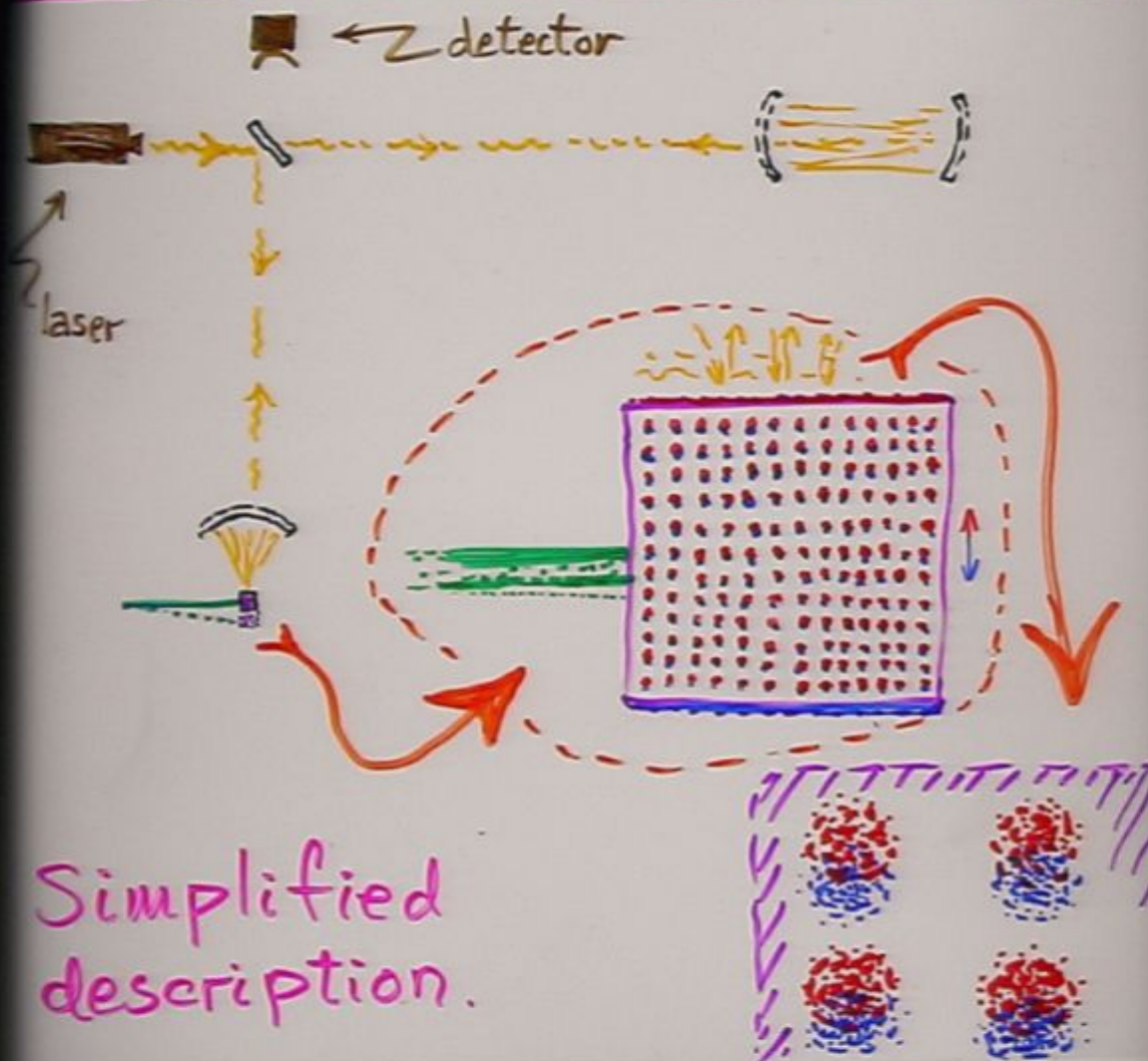
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Dik Bouwmeester, Will Marshall, Christoph Monz, & RP
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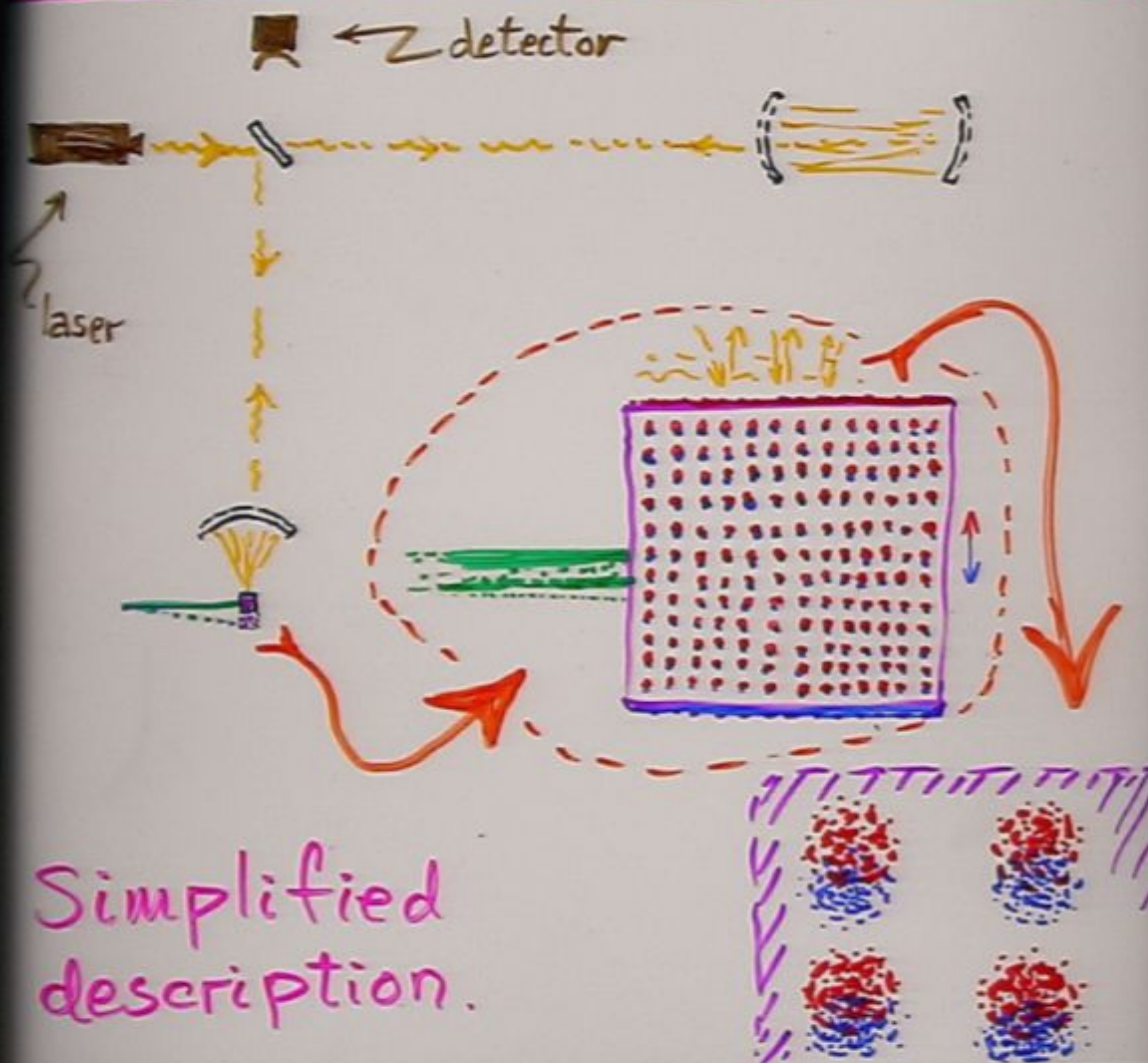
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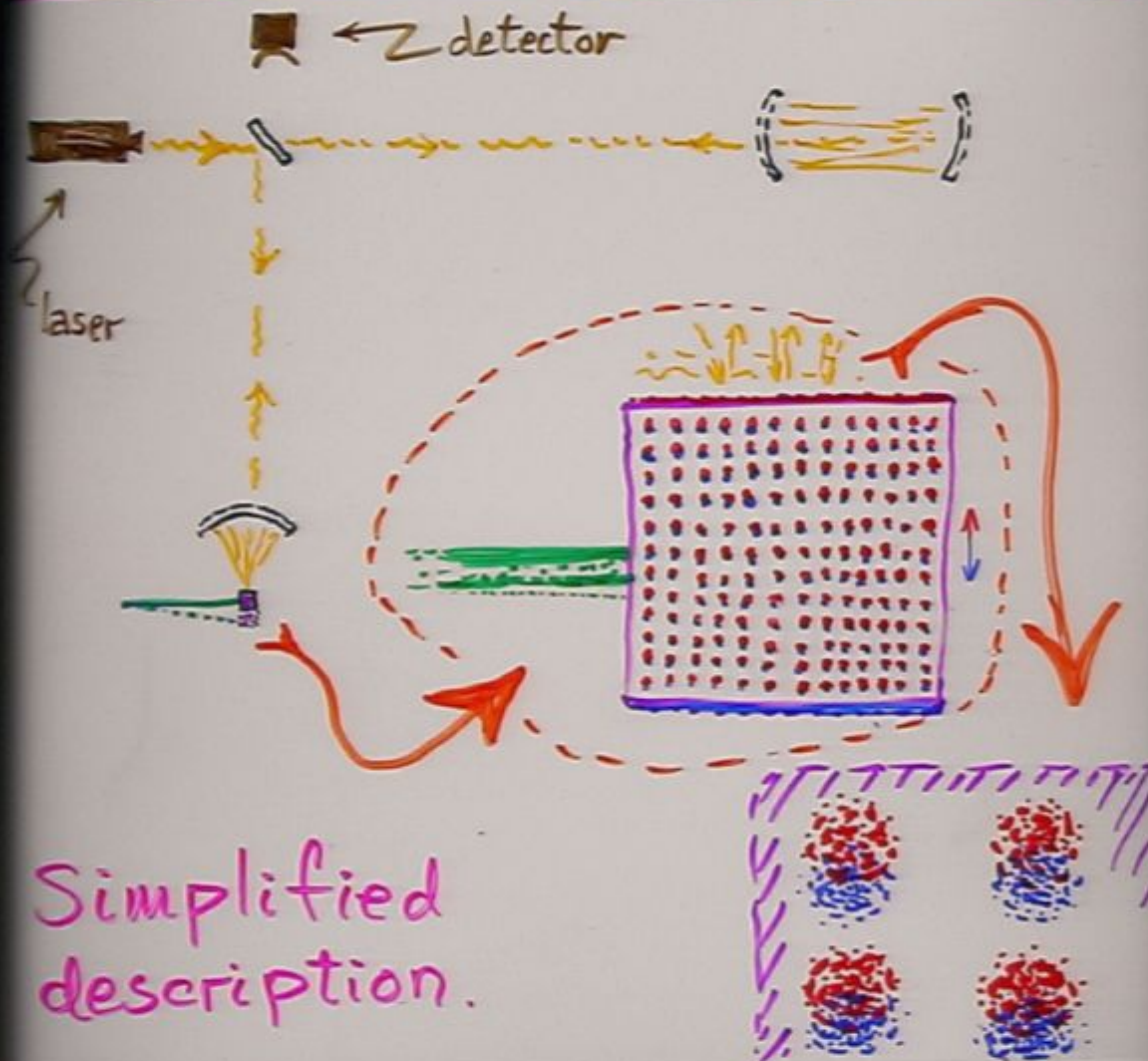
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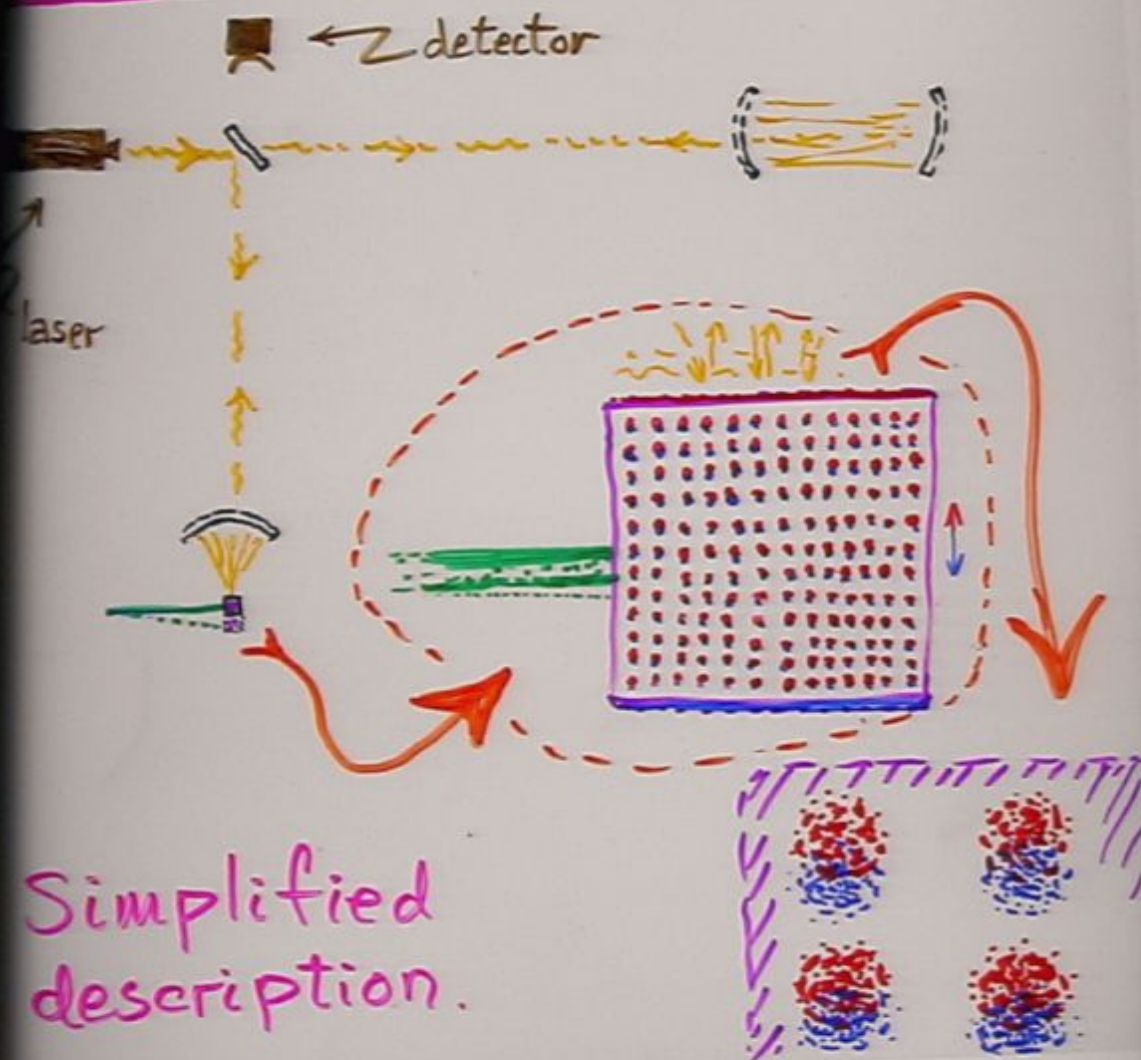
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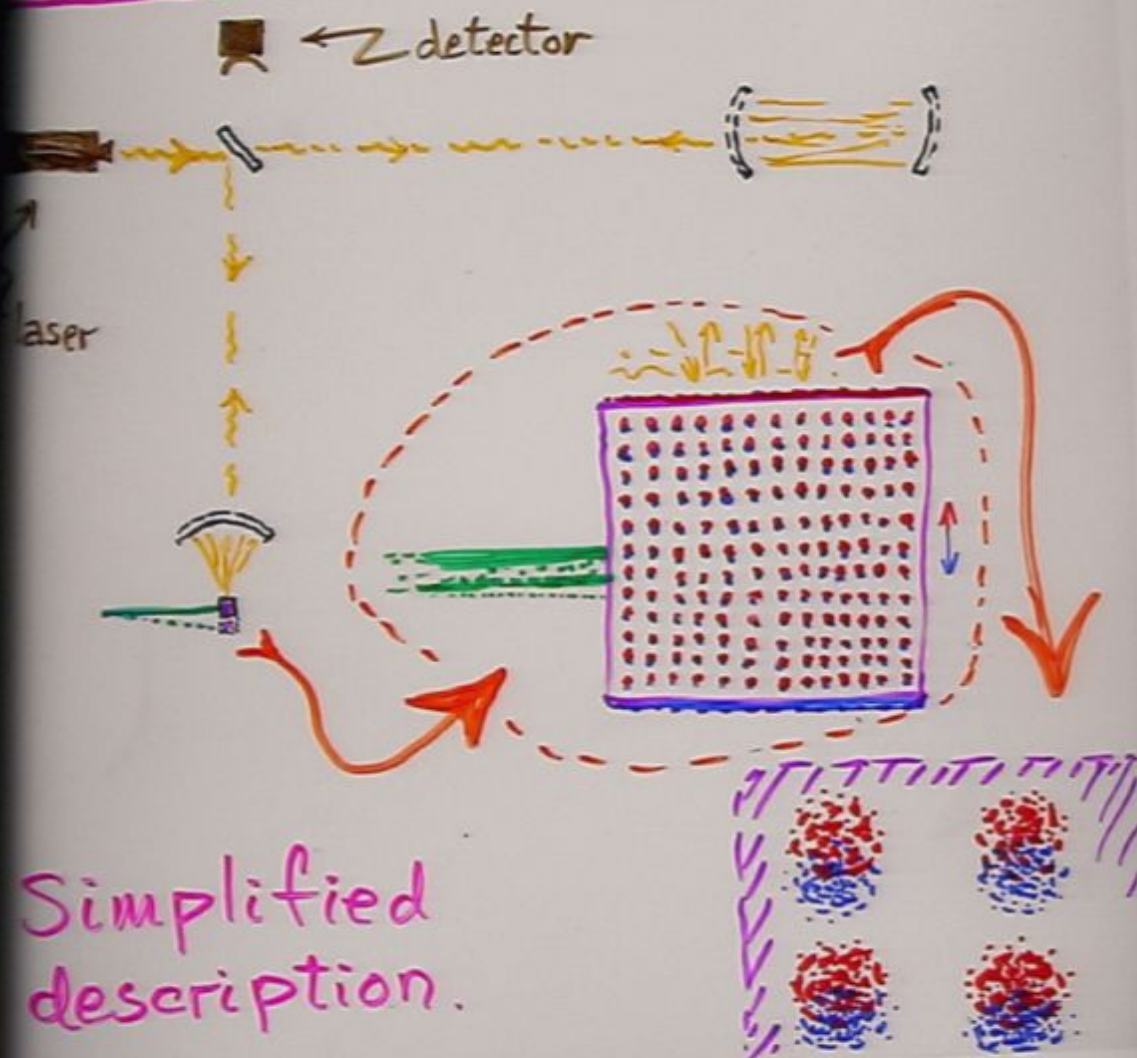
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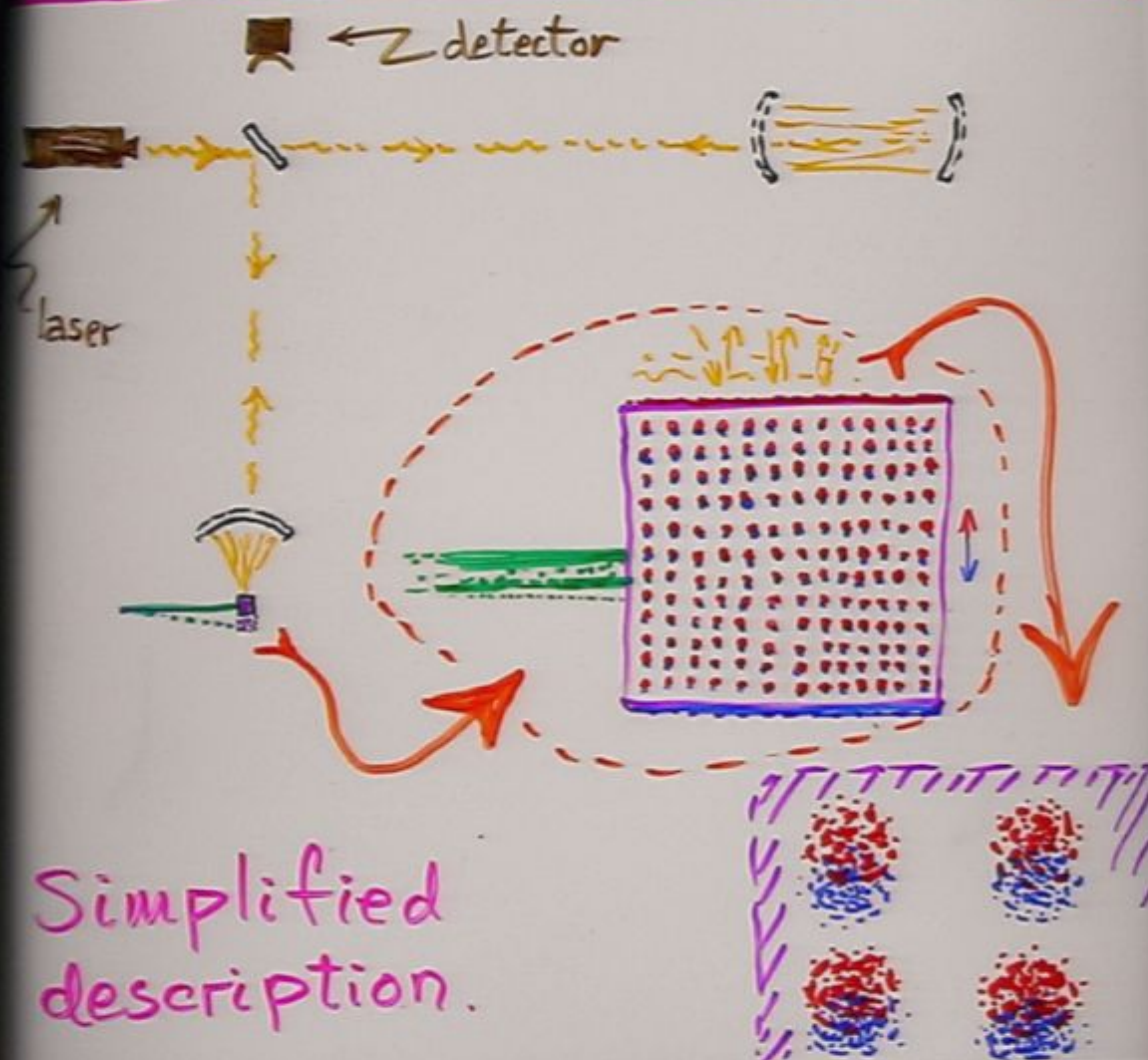


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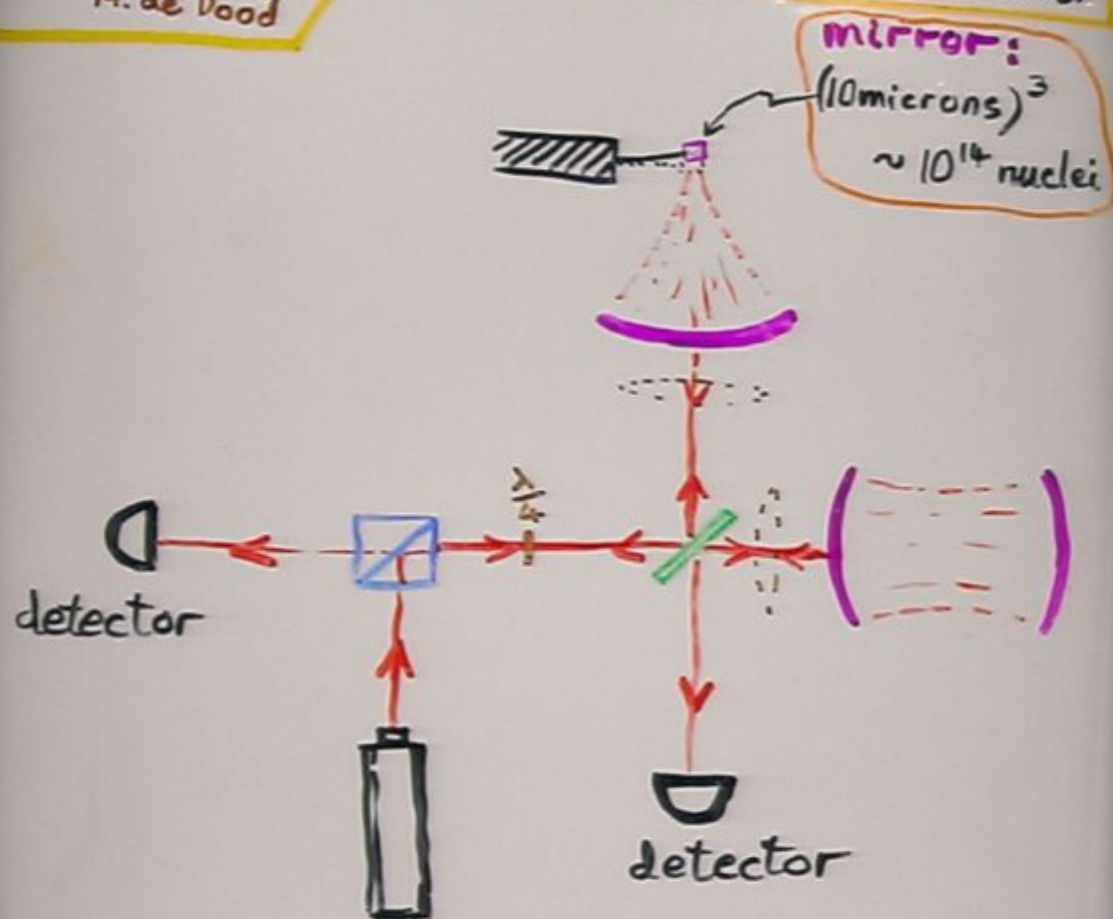
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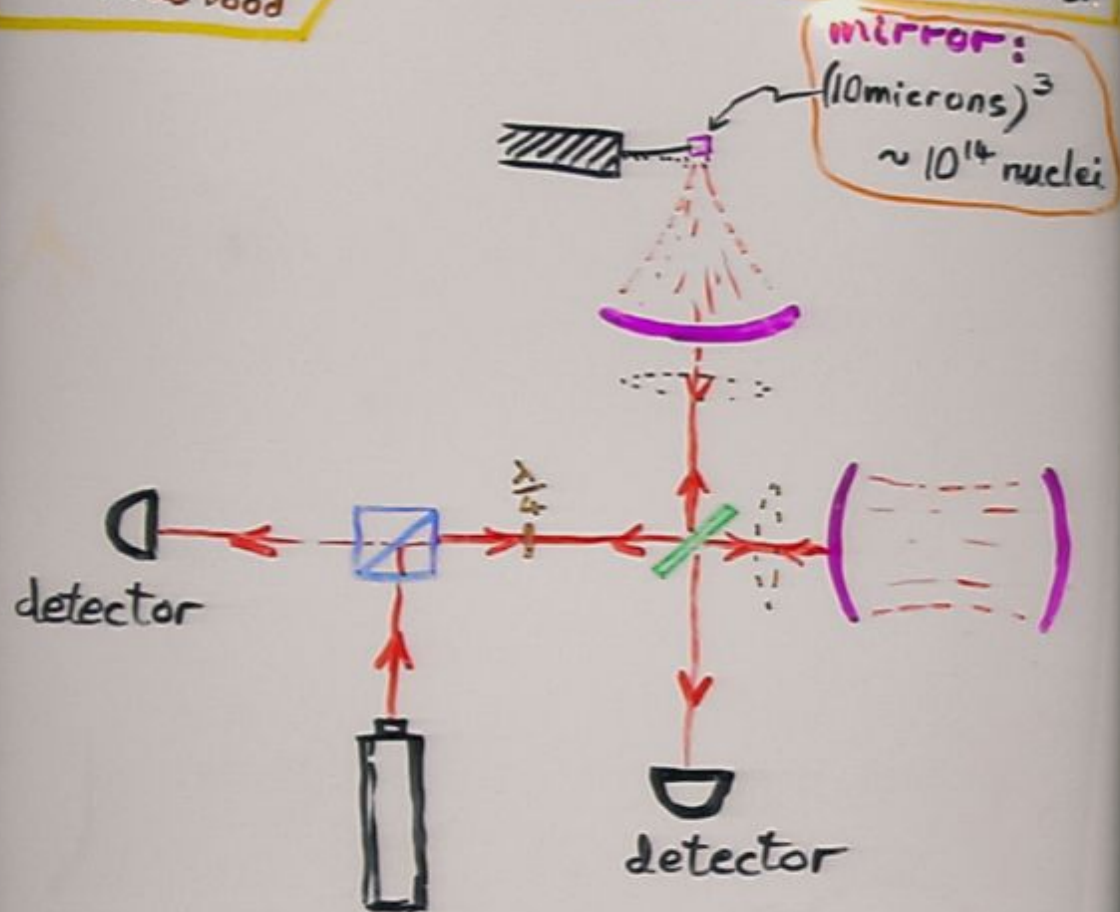
W. Marshall, C. Simon, R.P., & D. Bouwmeester
 "Towards quantum superpositions of a mirror"
 also S. Hastings
 M. de Dood



quant-ph/0210001

Phys. Rev. Letters 91 130401 (2003) pp. 13-16

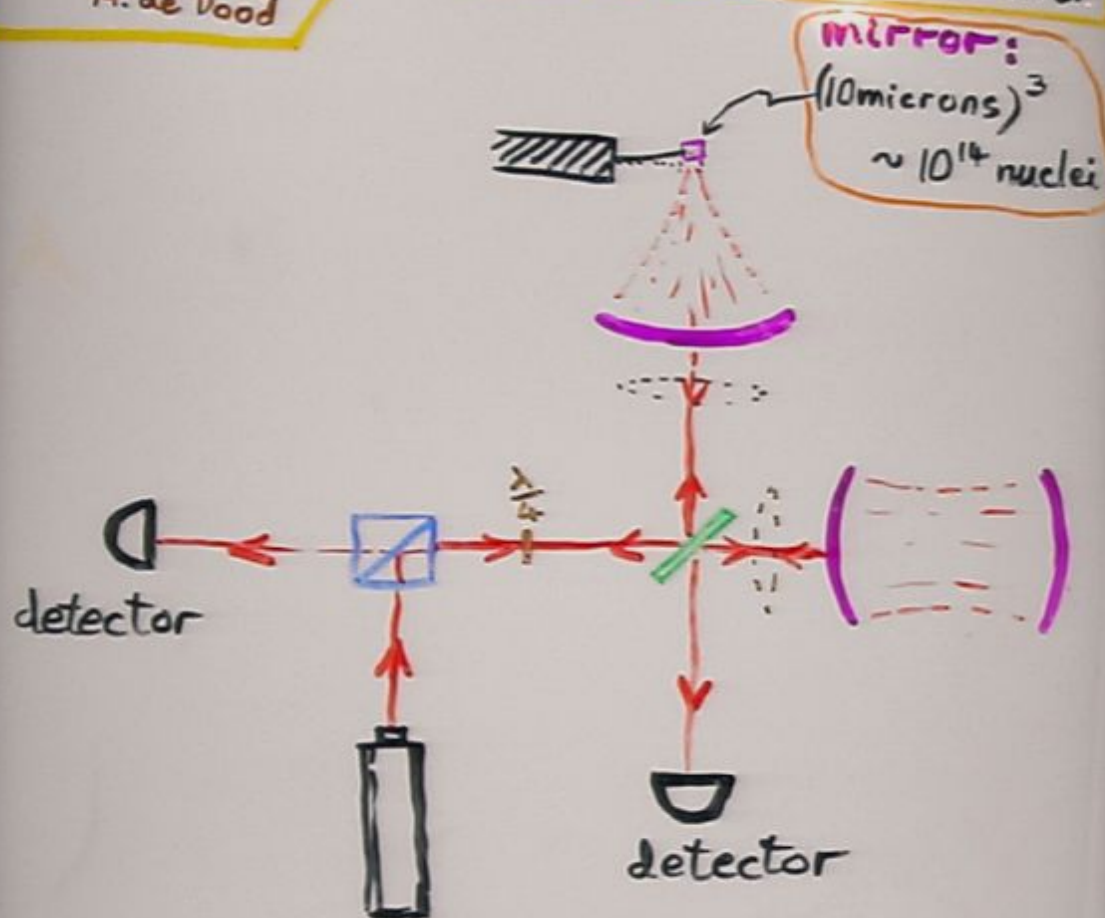
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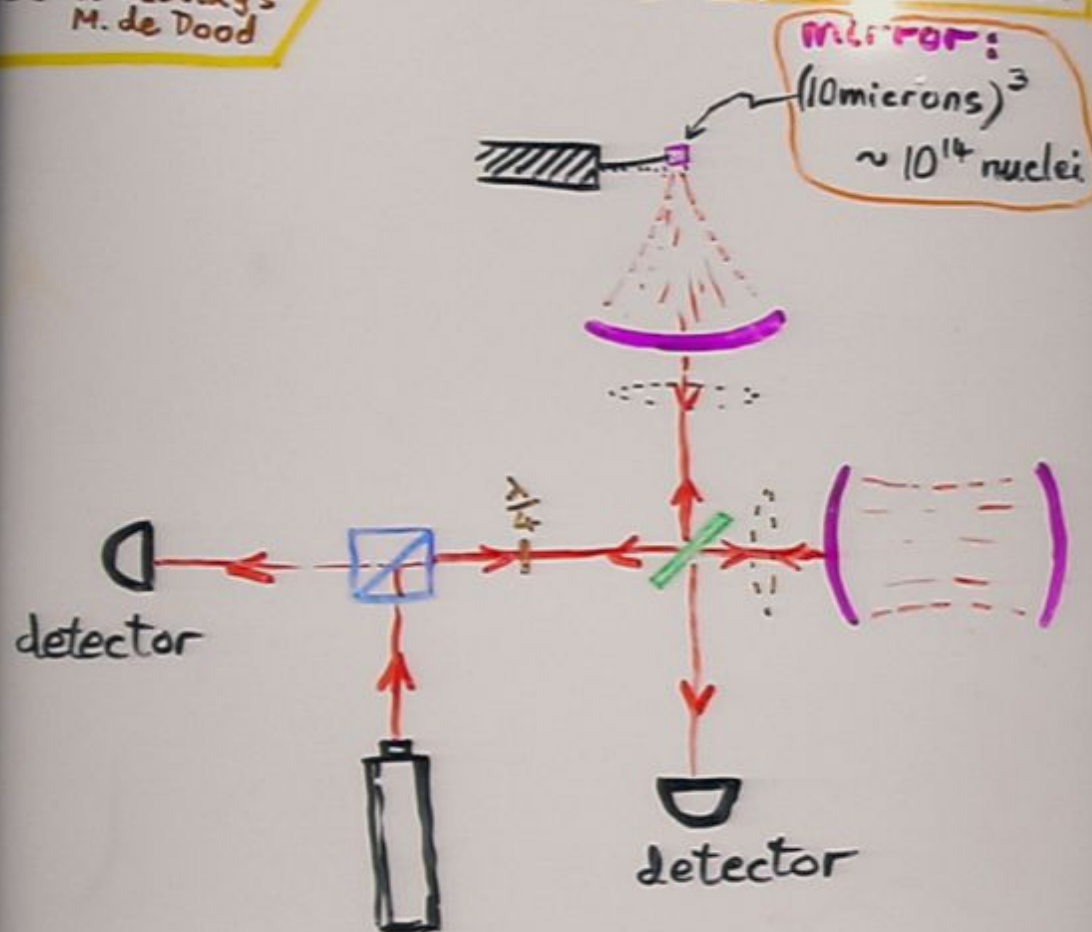


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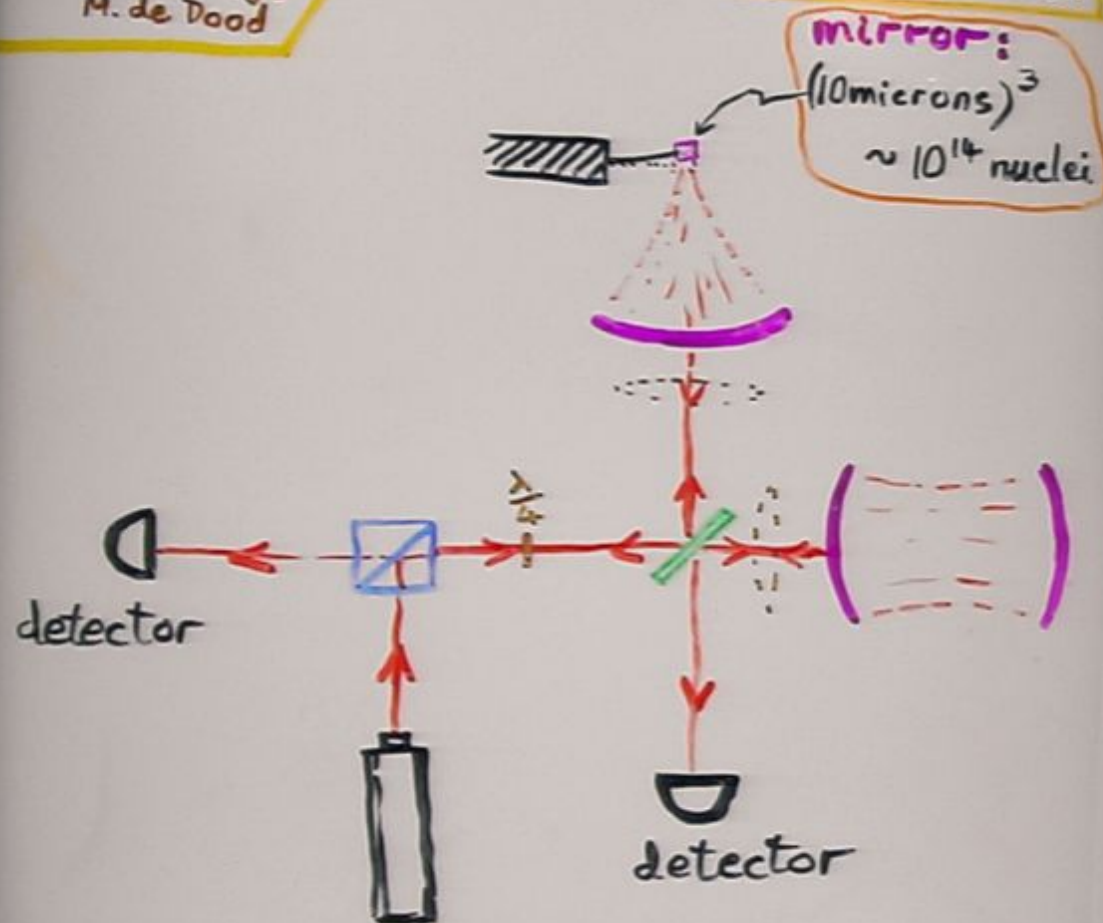
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quant-ph/0210001

Phys. Rev. Letters 91 130401 (2003) pp. 13-16.

Time-asymmetry in space-time
singularity structure
& the 2nd Law of Thermodynamics

↖ entropy (= "disorder")
increases in time

∴ the initial state of the
universe (= **BIG BANG**)
must have been extraordinarily
special — in fact, extremely
uniform —

Odds against
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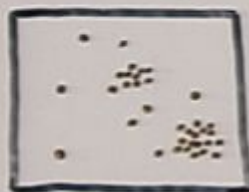
Entropy increases with time.
↳ "disorder" (roughly speaking)

Gas in a box



time increases →
entropy increases →

Gravitating bodies

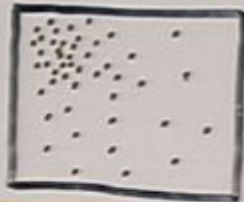


Maximum entropy:
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2nd Law of Thermodynamics

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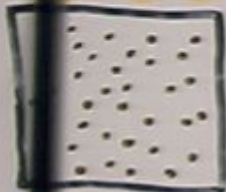
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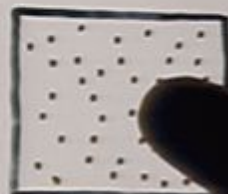
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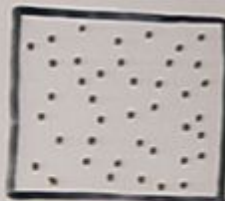
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Entropy can keep it down.
by emitting few high-energy photons
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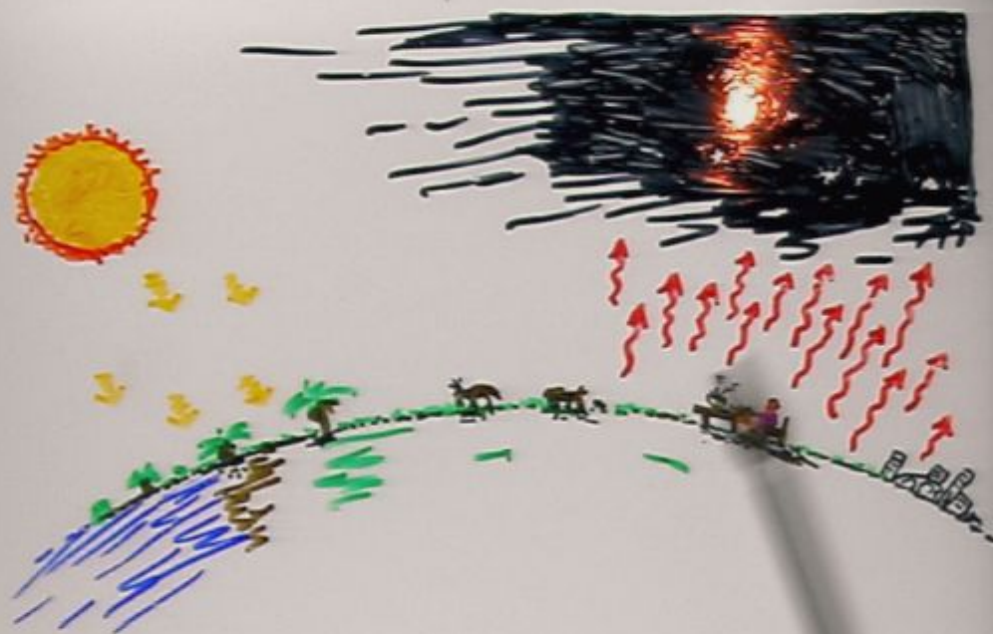


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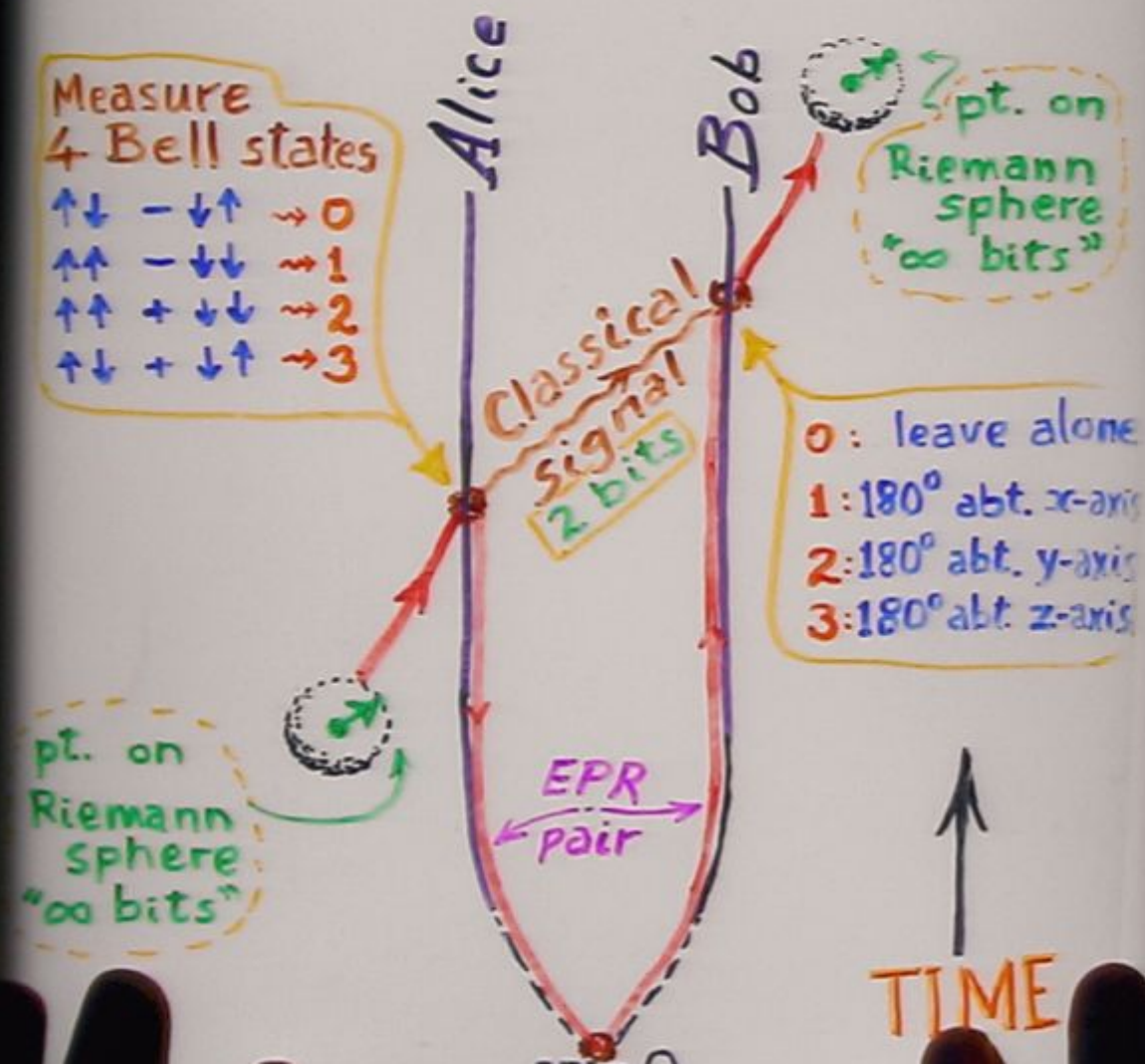
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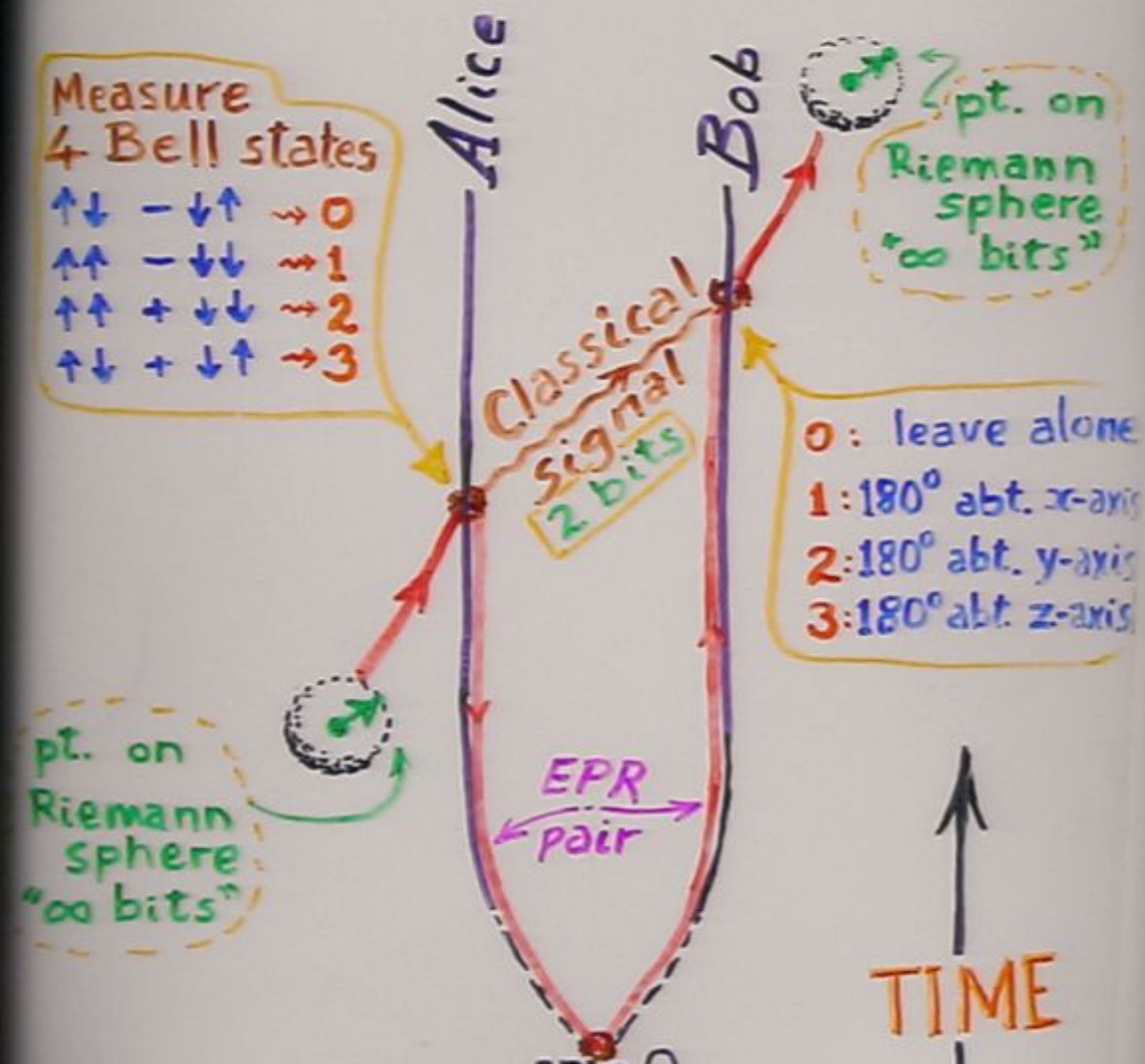
Quantum "teleportation"



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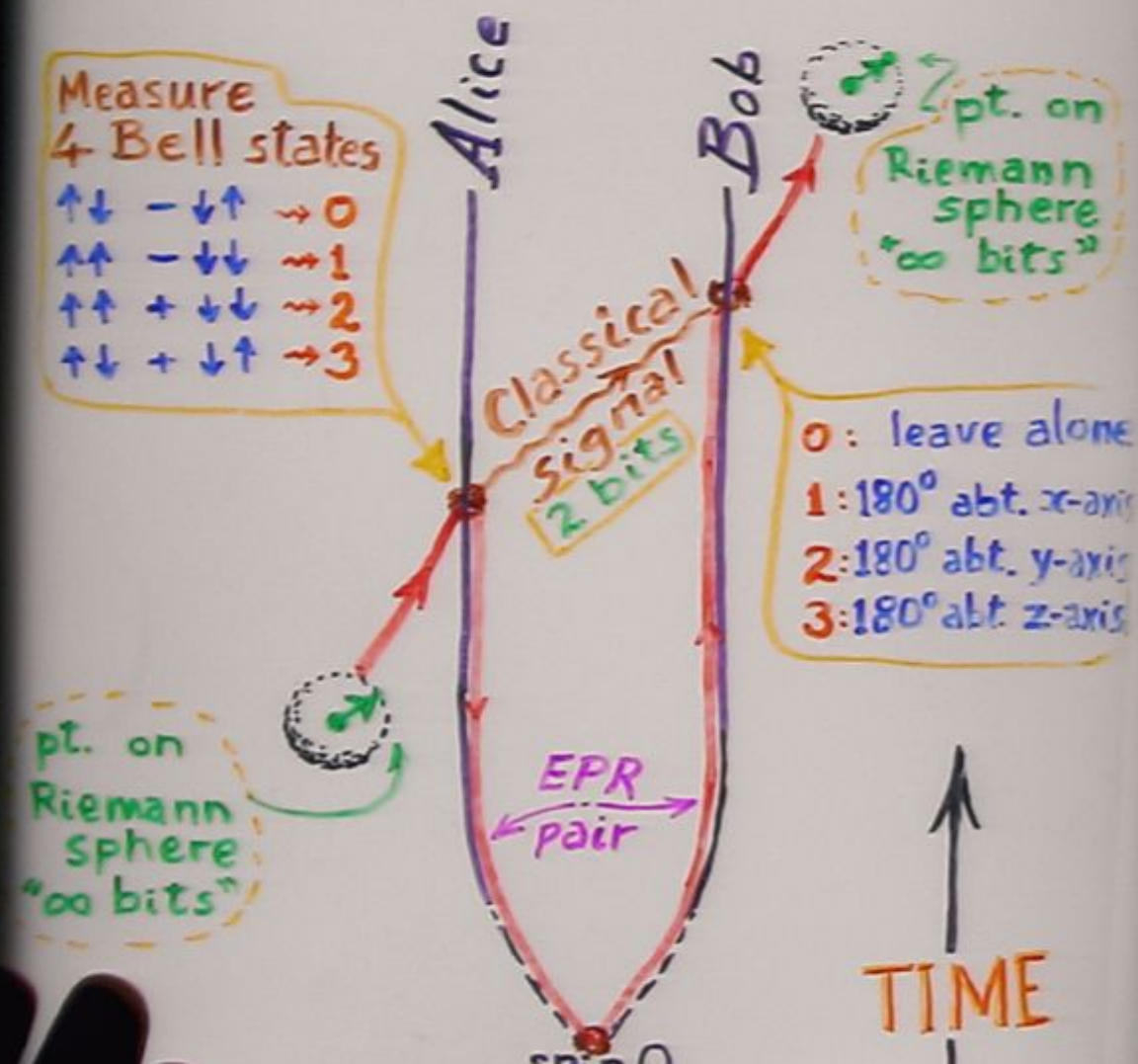
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Schrödinger's Little Mermaid
Hans Christian Andersen Lecture

a New Angle on the Basic Paradox of Quantum Mechanics



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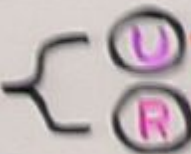
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C: Classical physics - Deterministic

Quantum physics



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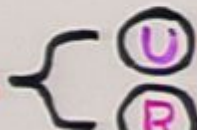
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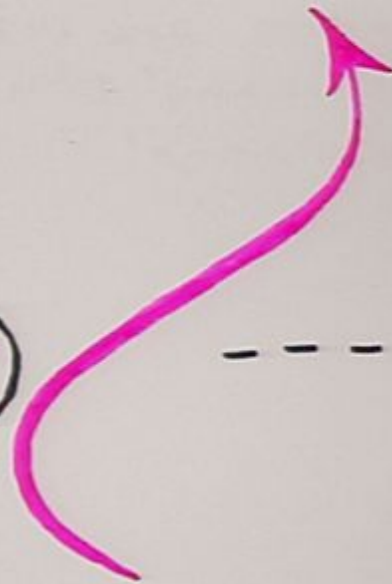
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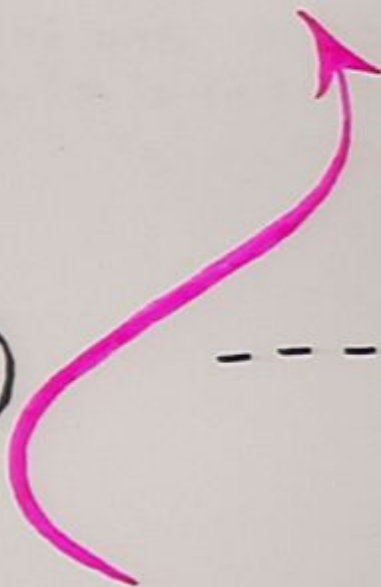
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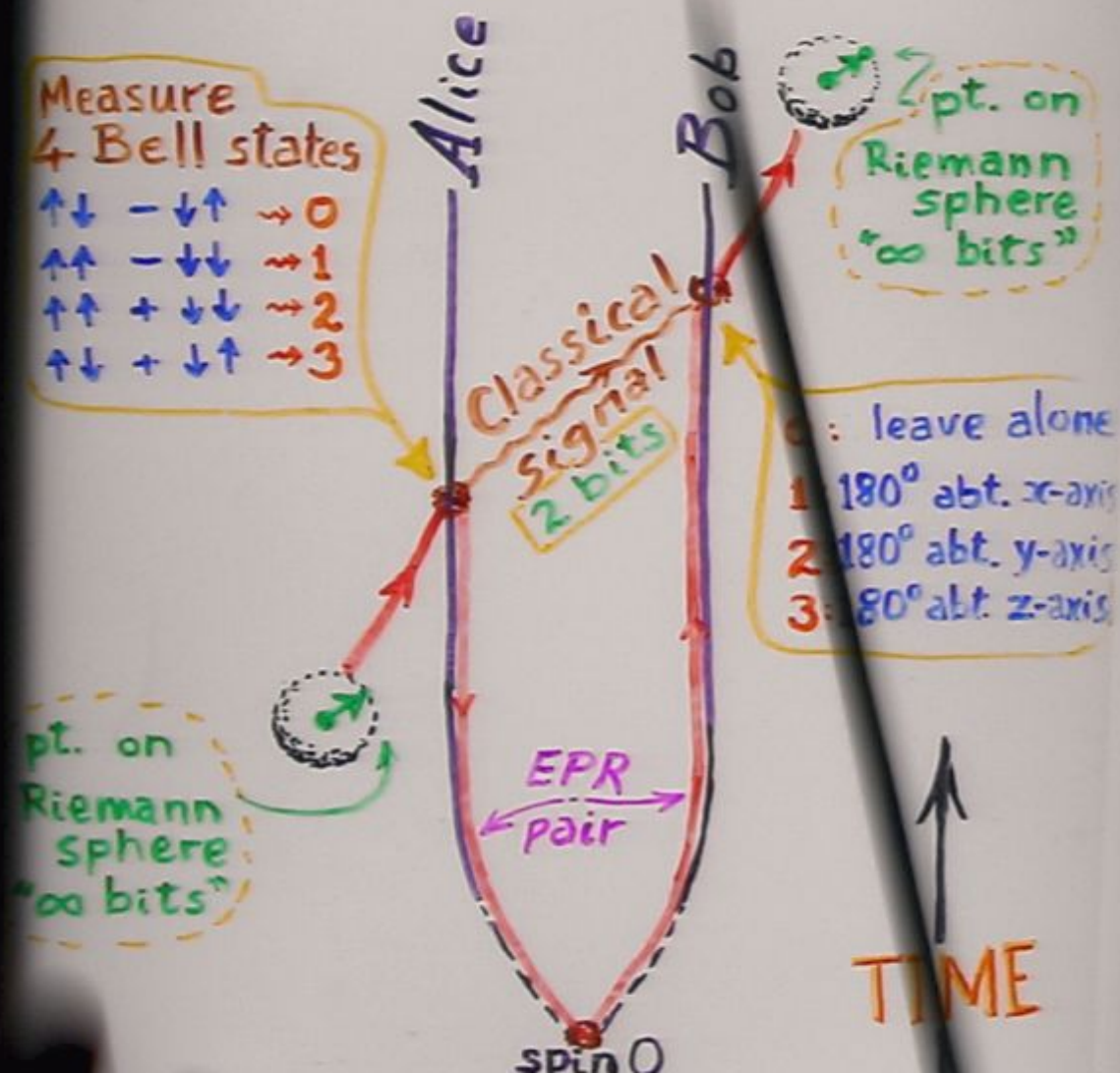
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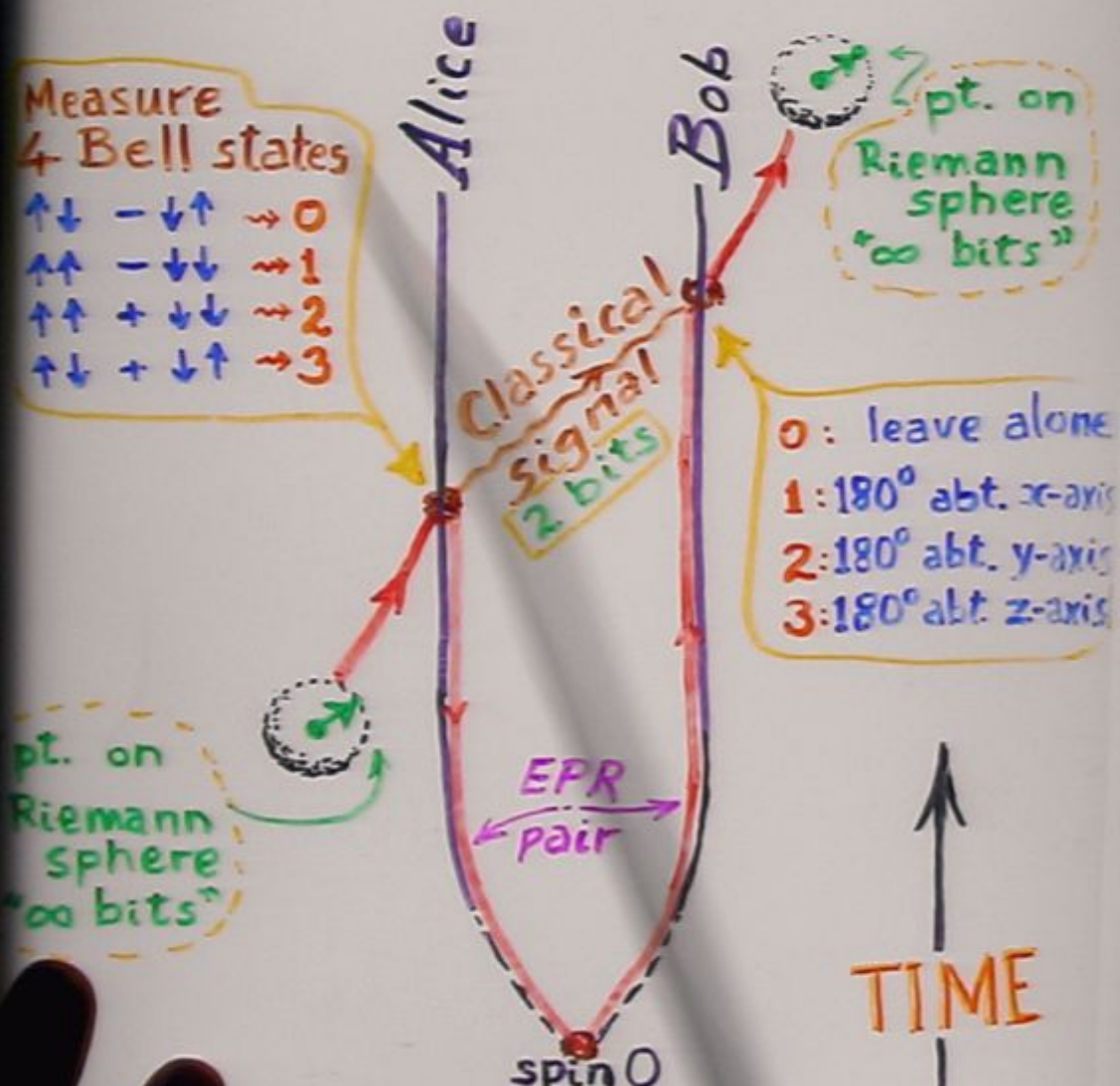
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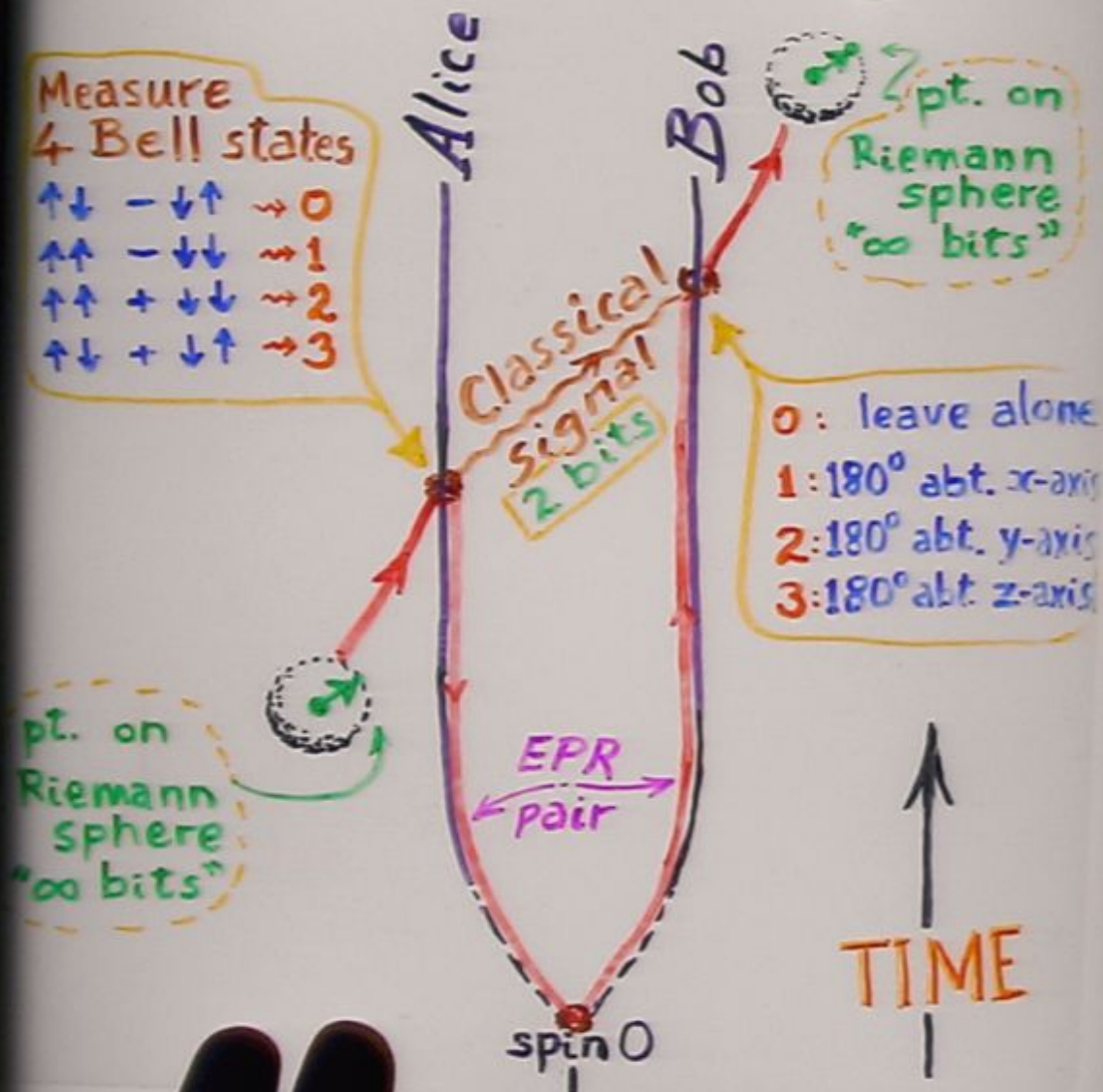
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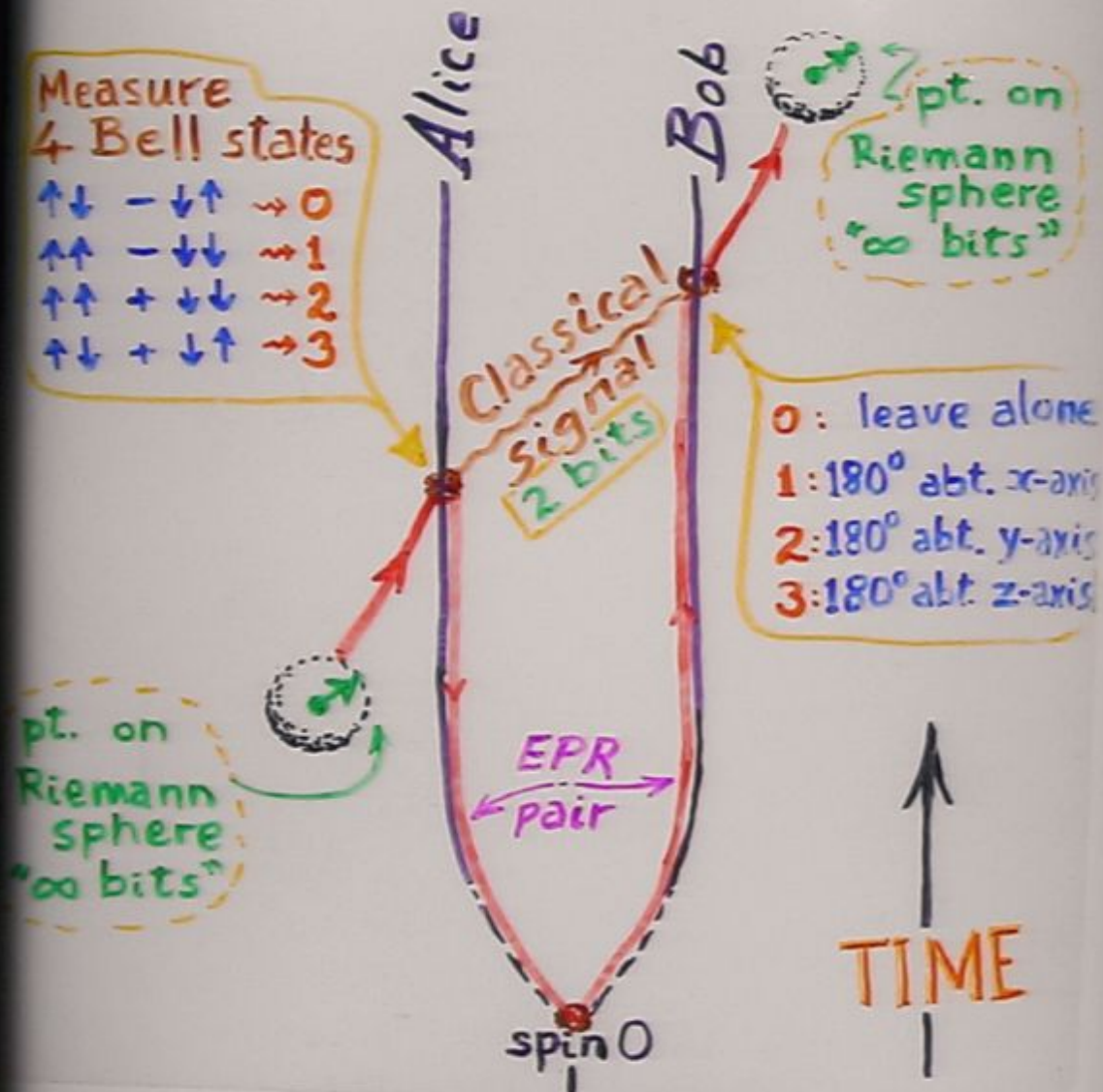
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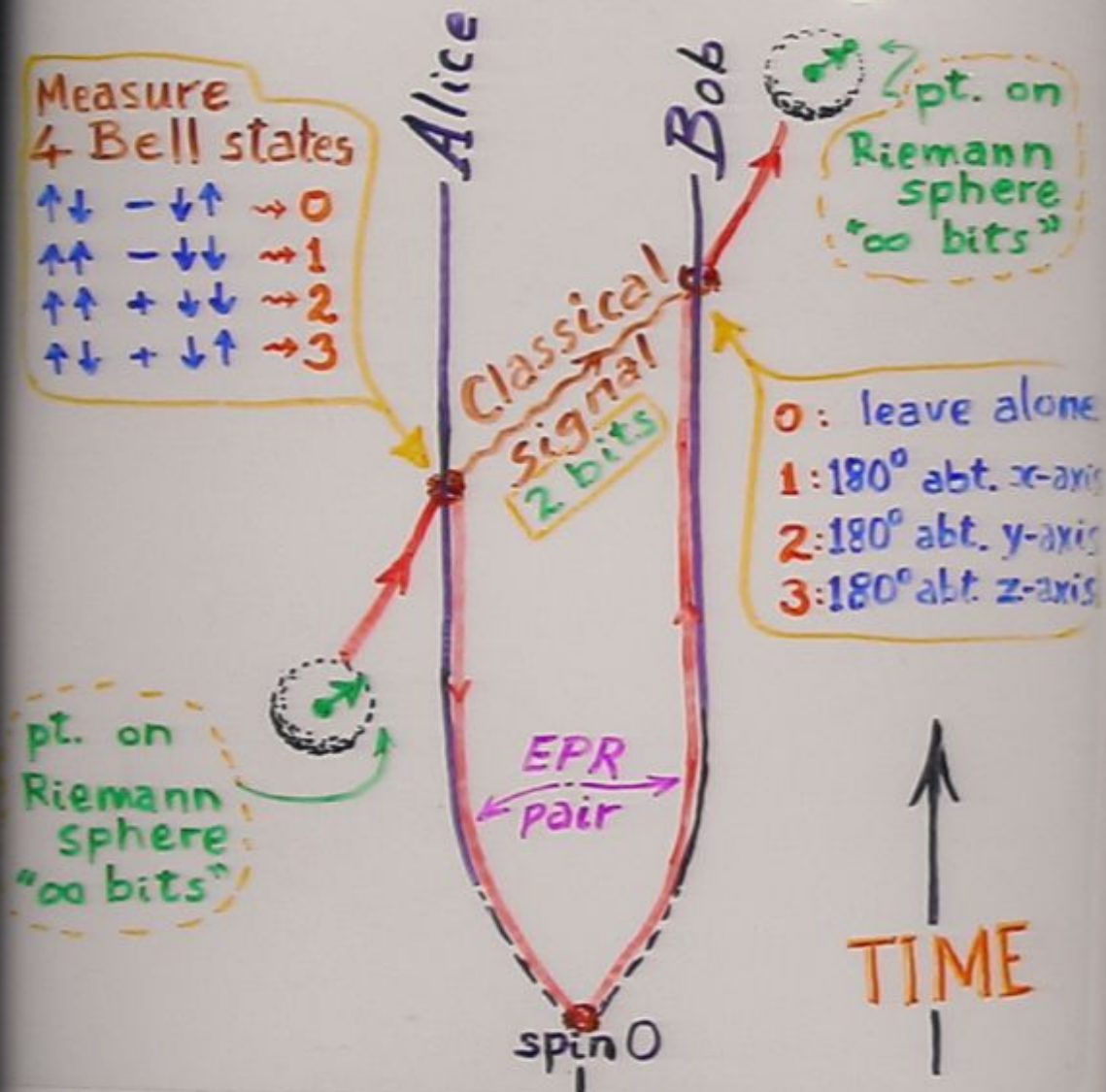
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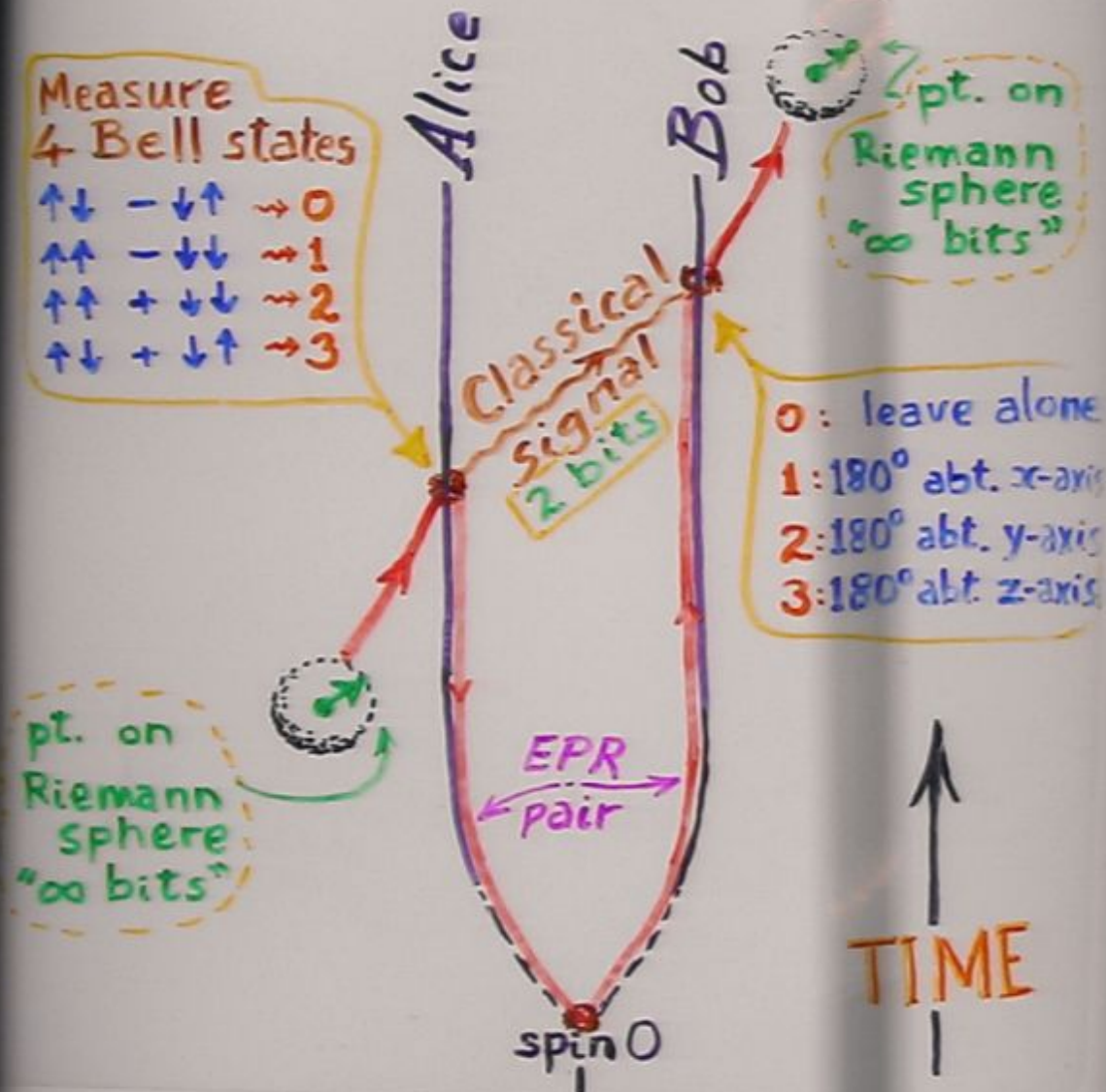
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Quantum "teleportation"

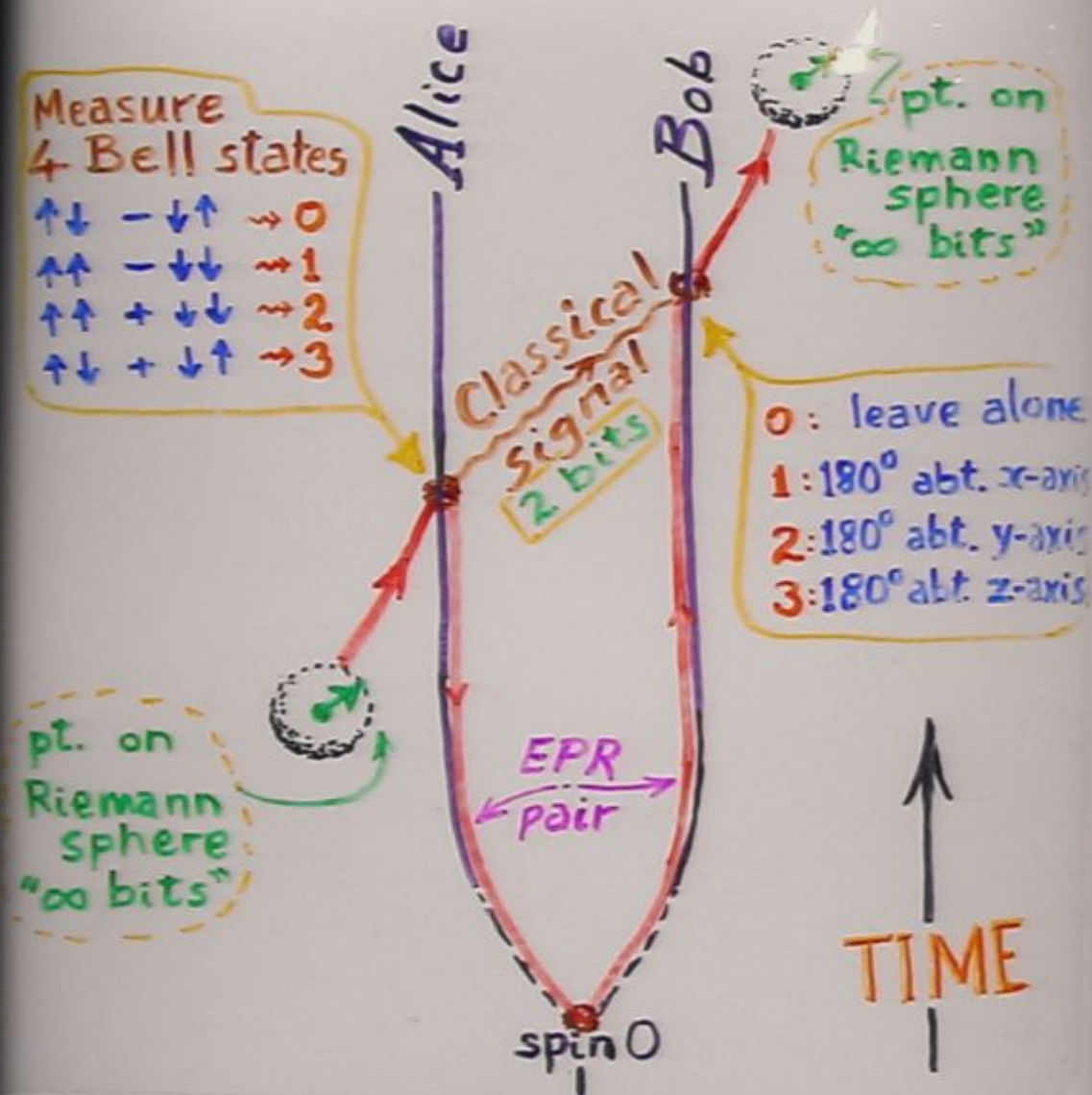


(= "quantum information")

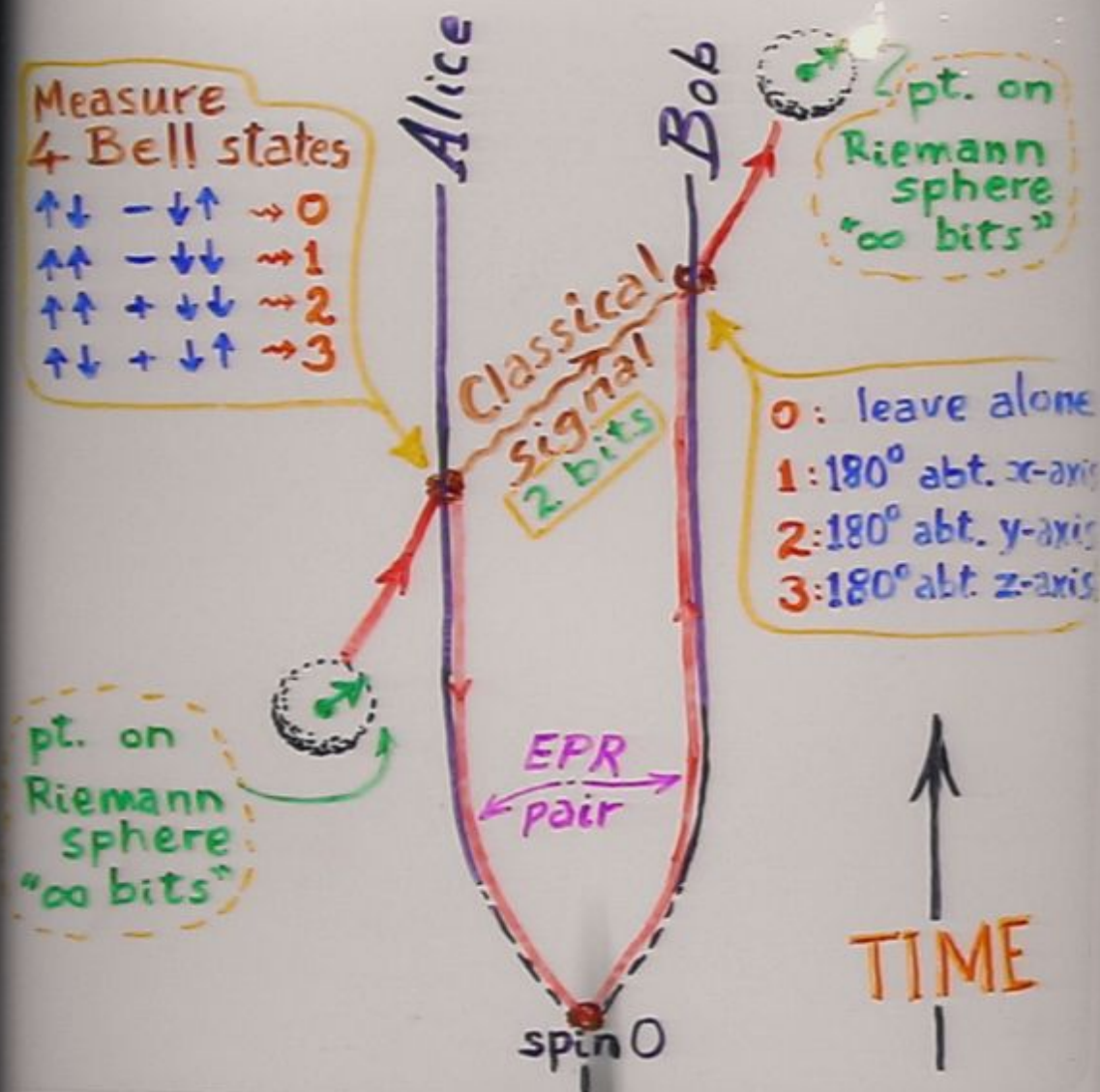
Quantum "teleportation"



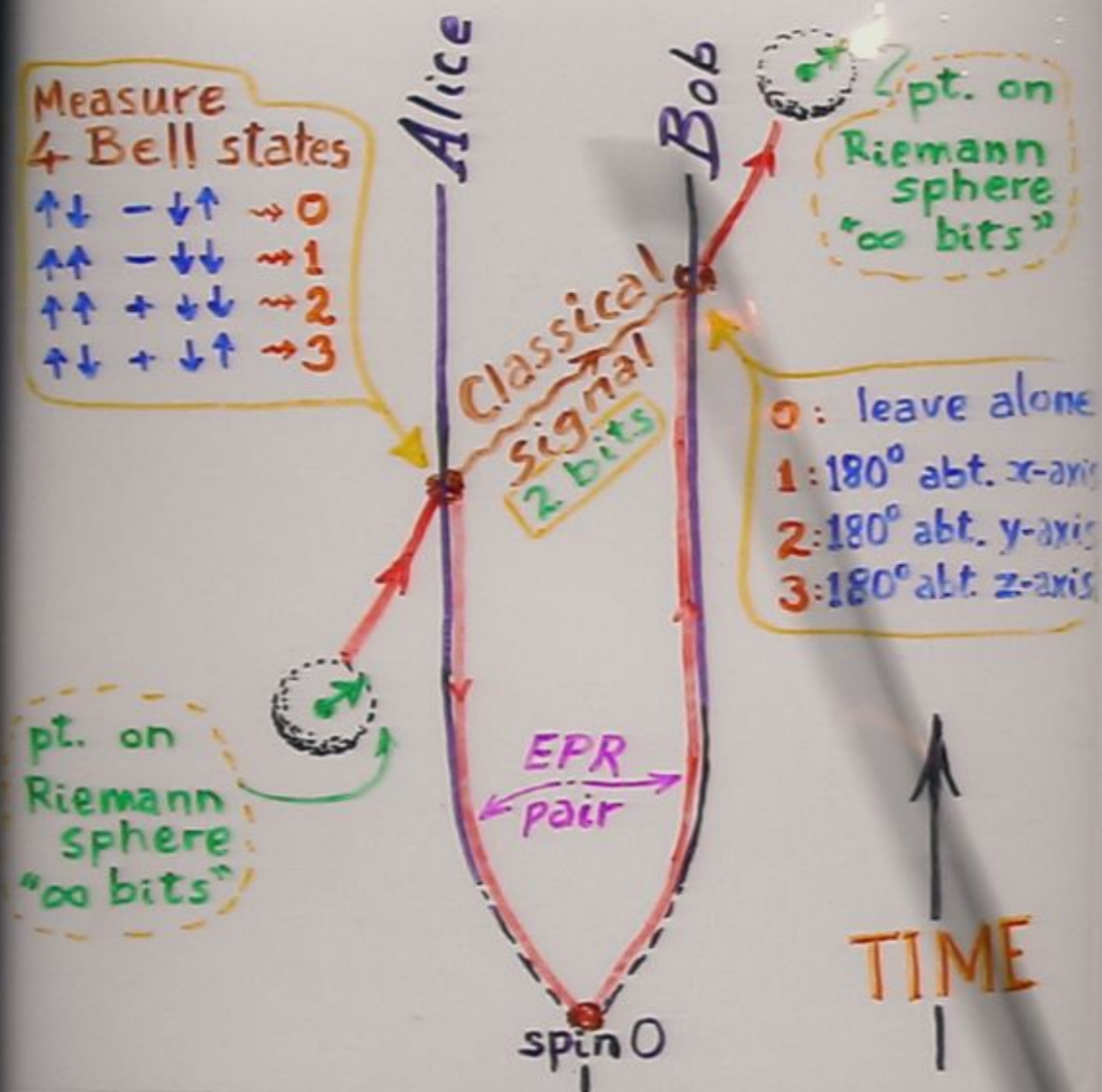
Quantum "teleportation"



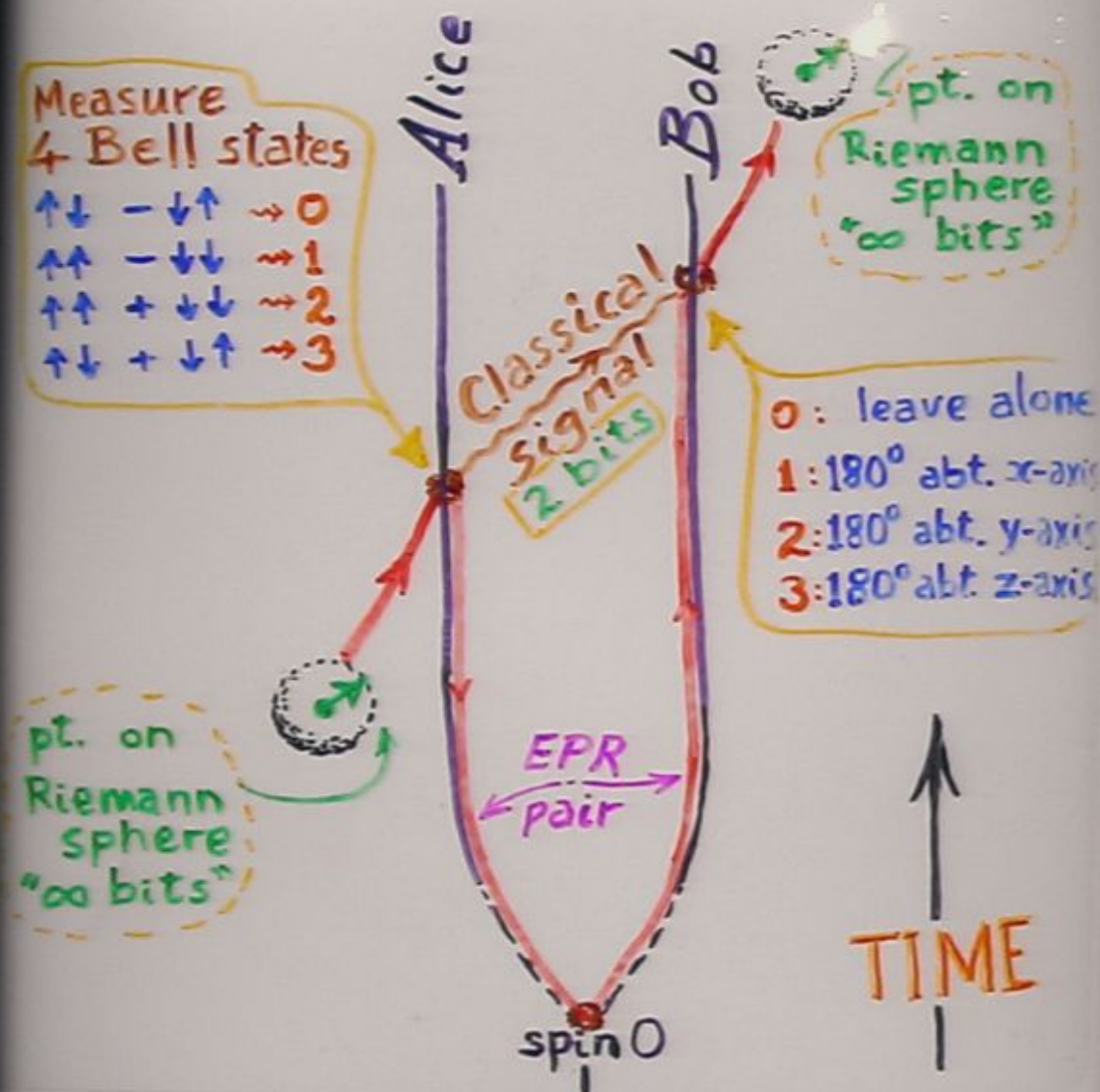
Quantum "teleportation"



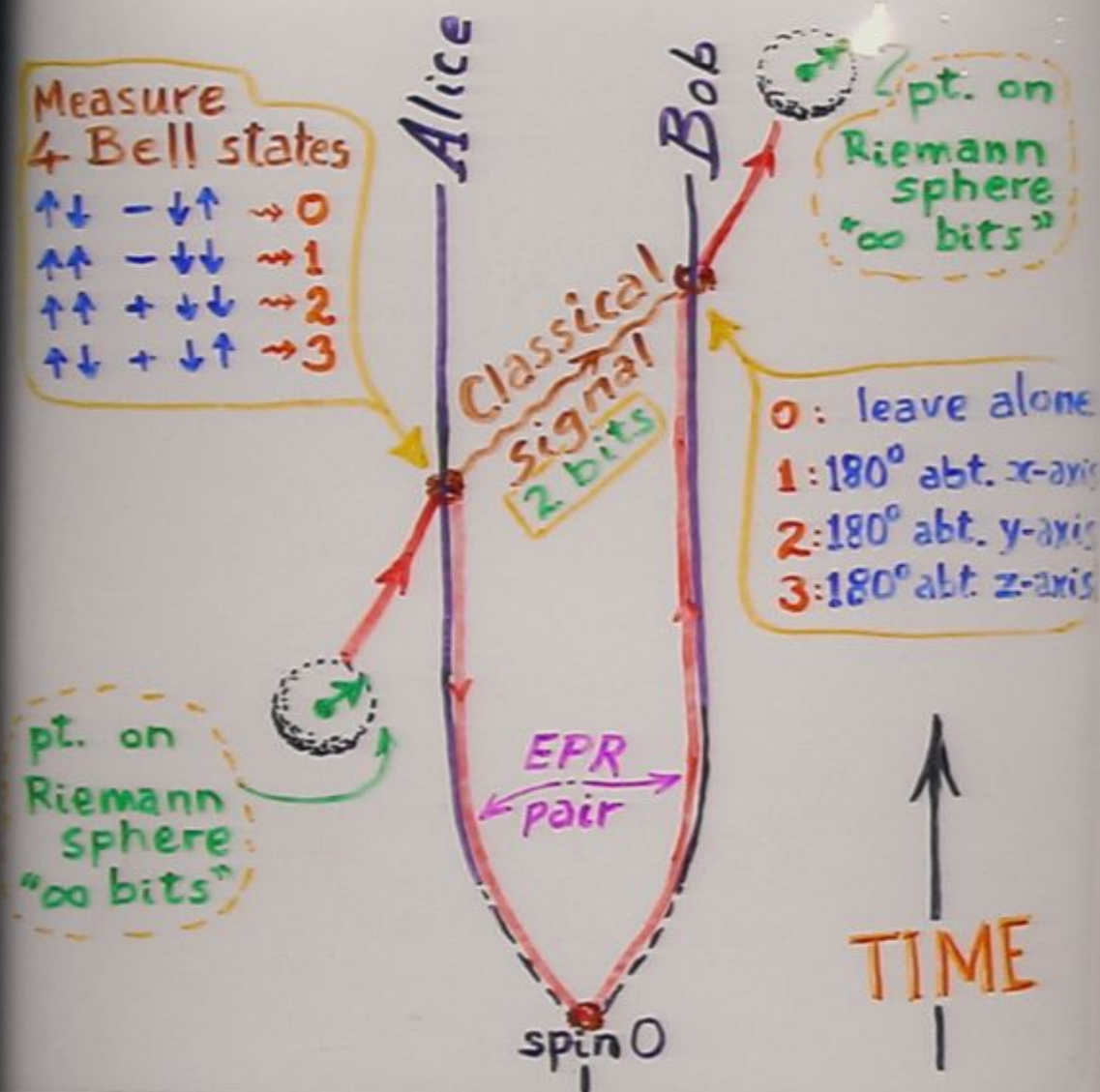
Quantum "teleportation"



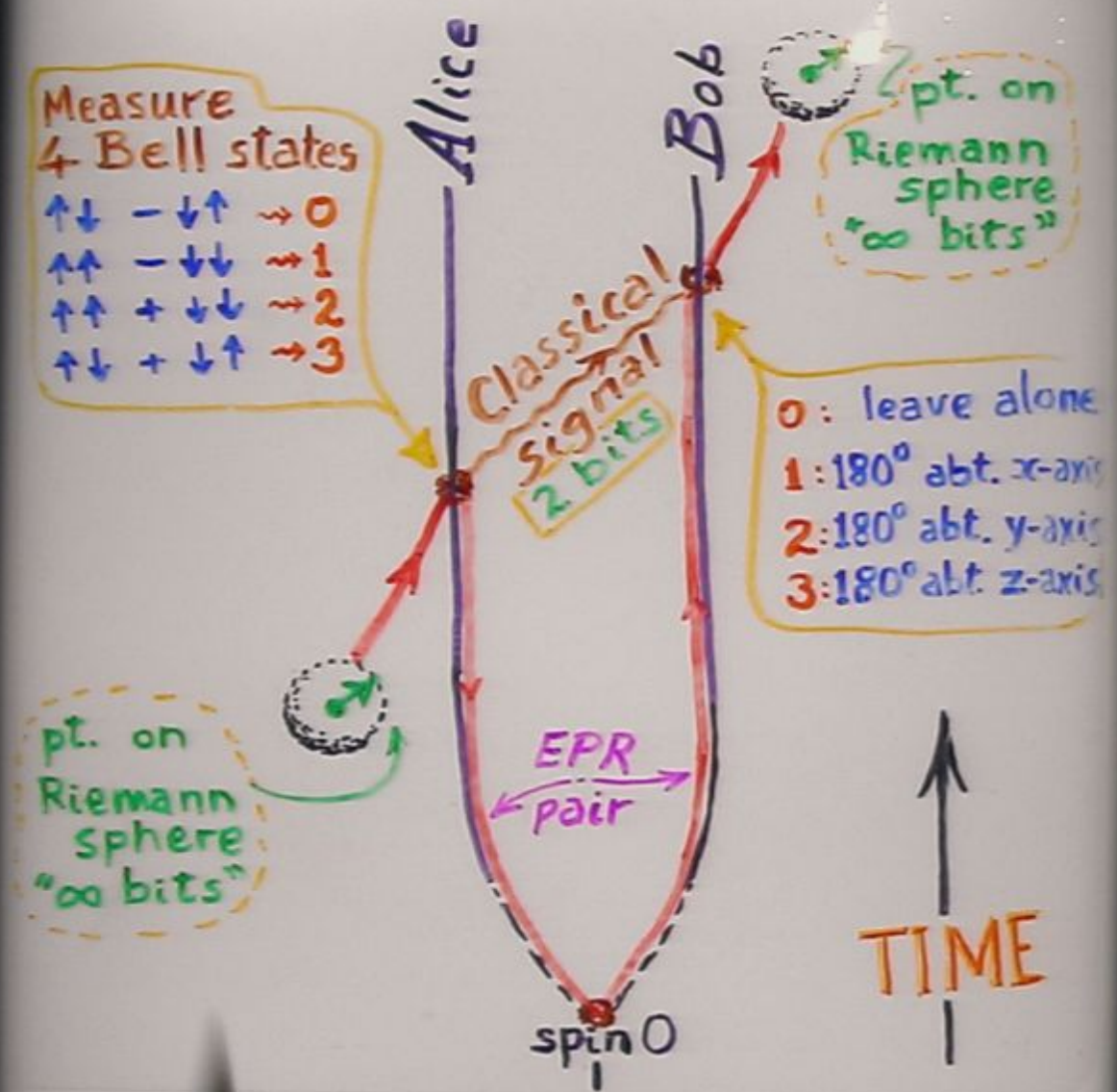
Quantum "teleportation"



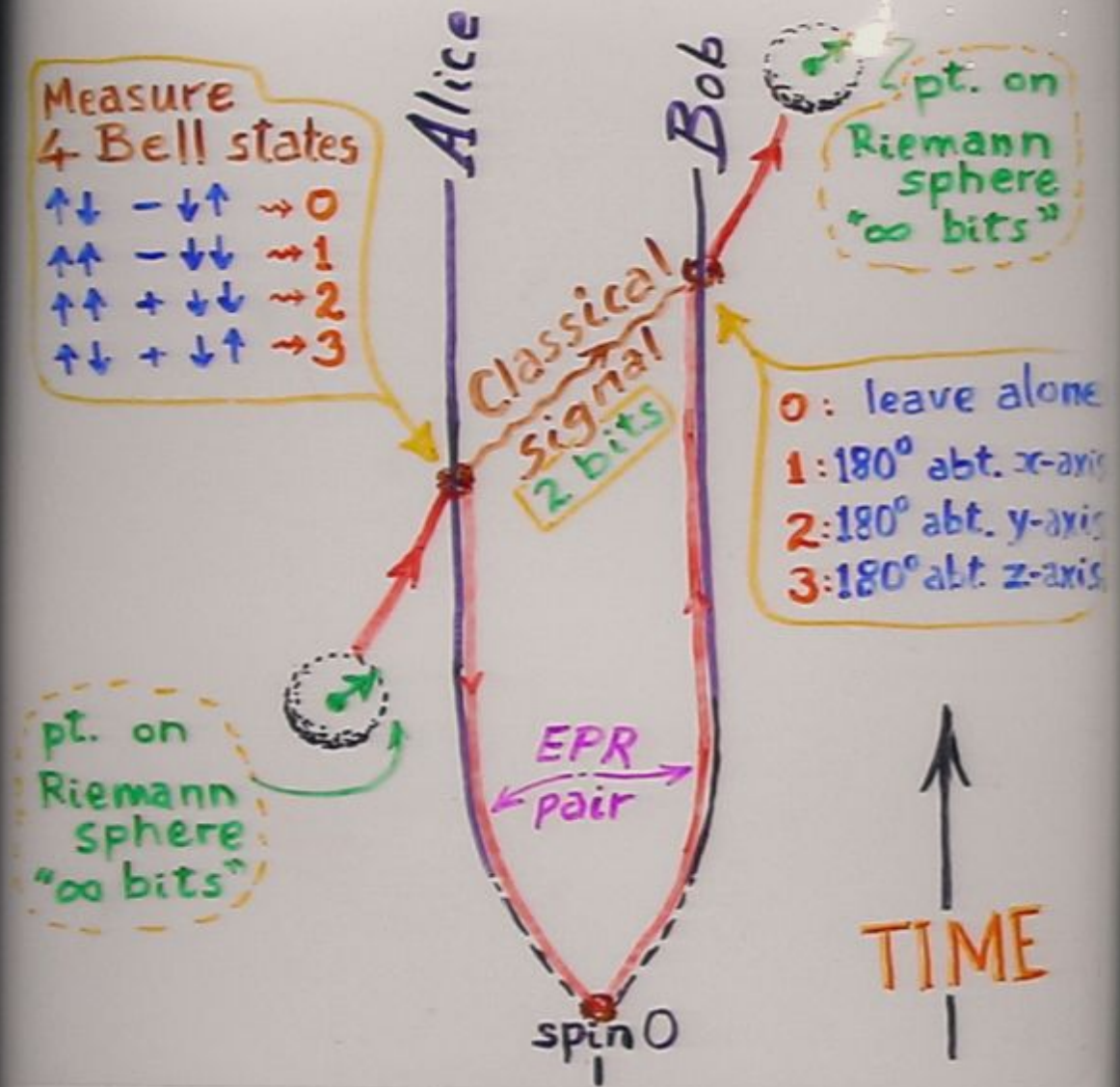
Quantum "teleportation"



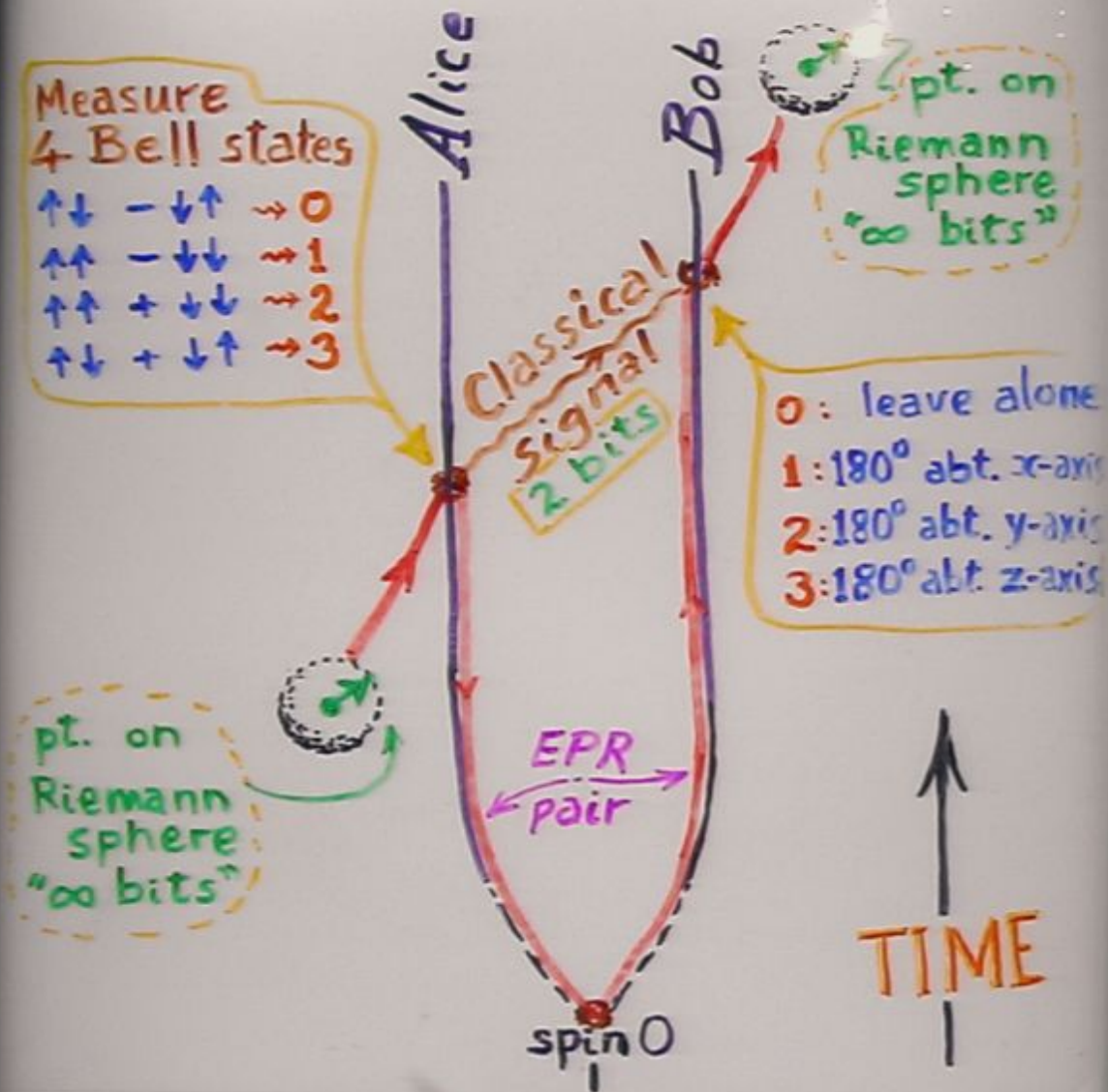
Quantum "teleportation"



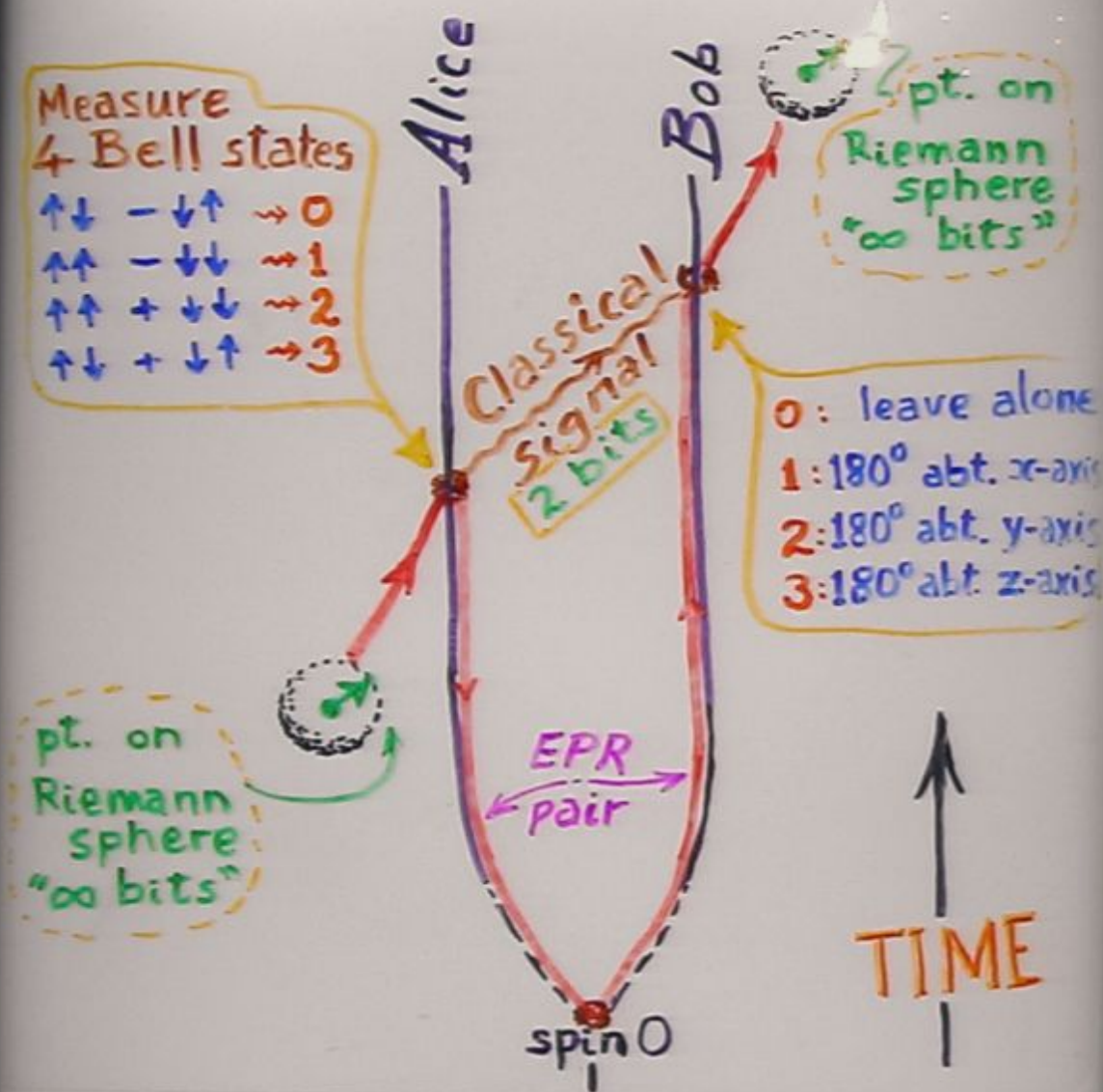
Quantum "teleportation"



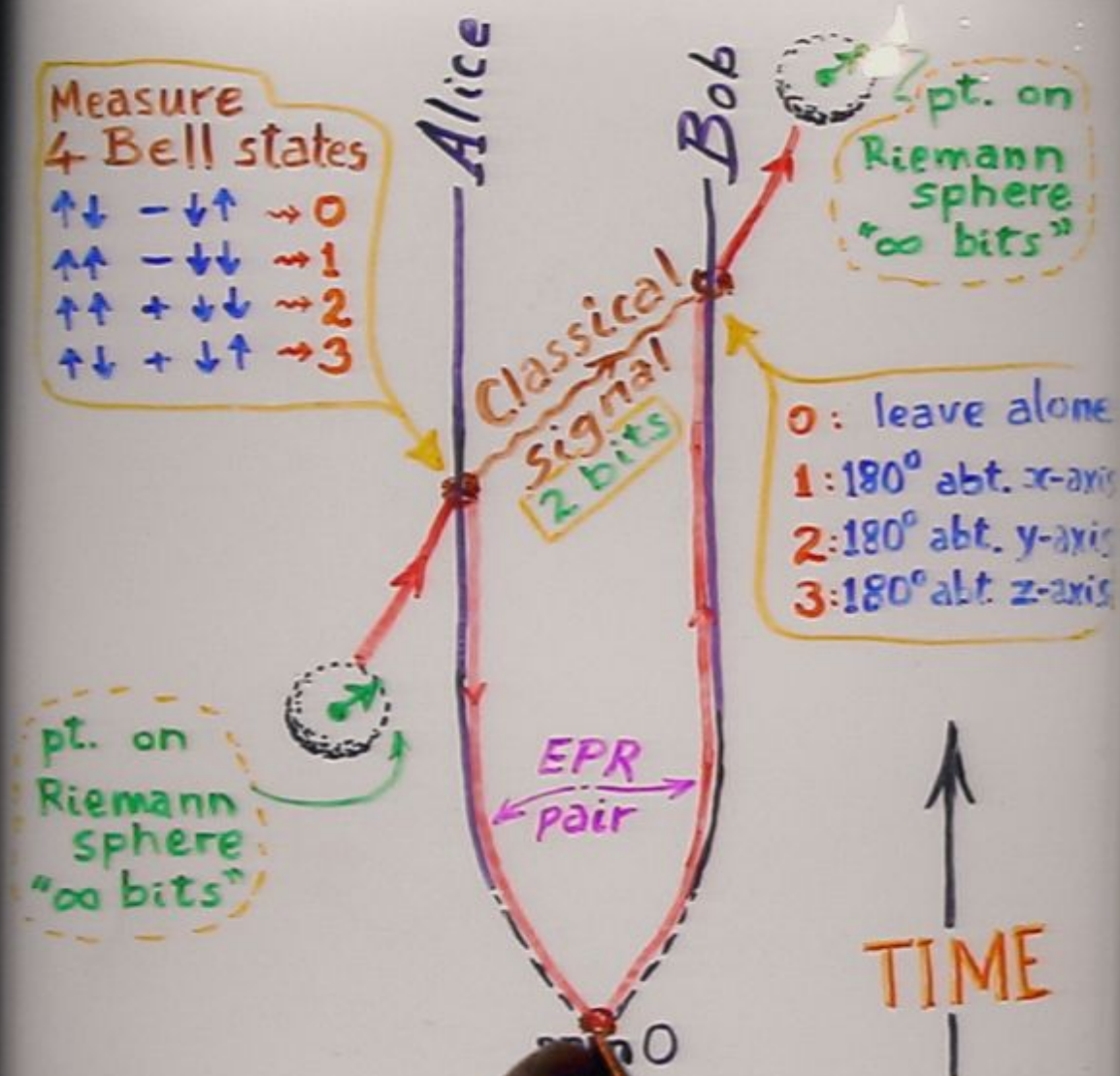
Quantum "teleportation"



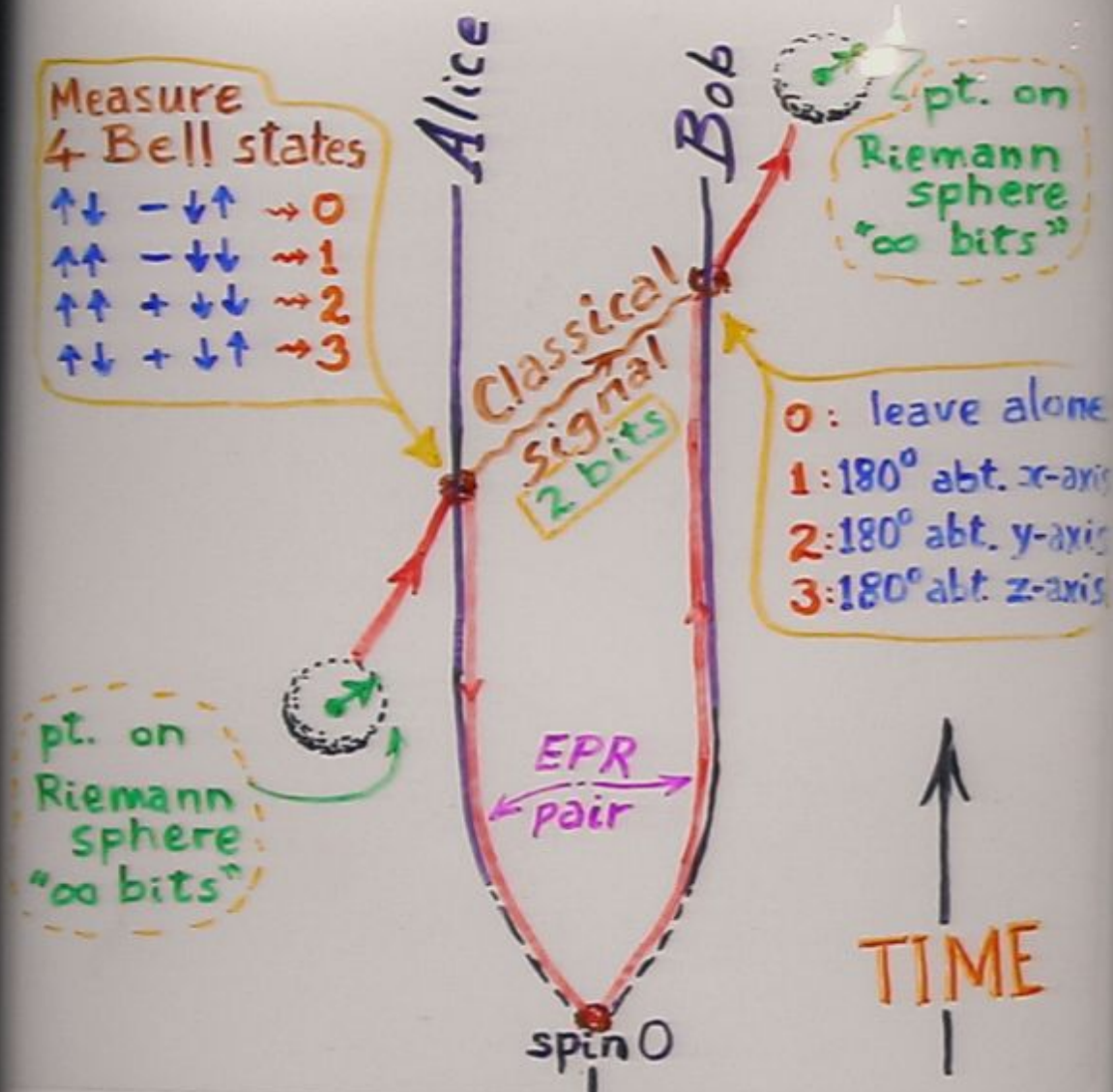
Quantum "teleportation"



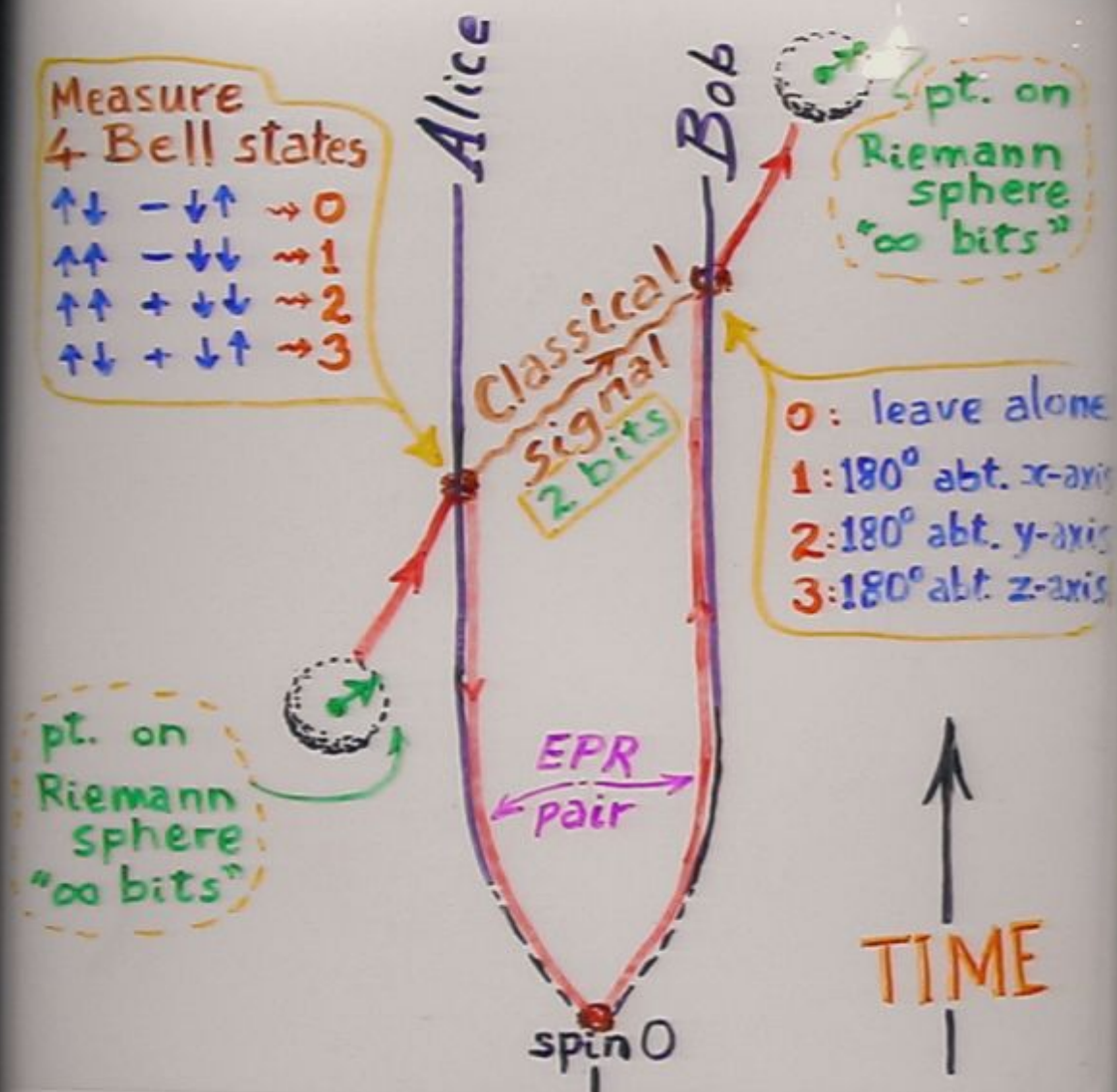
Quantum teleportation



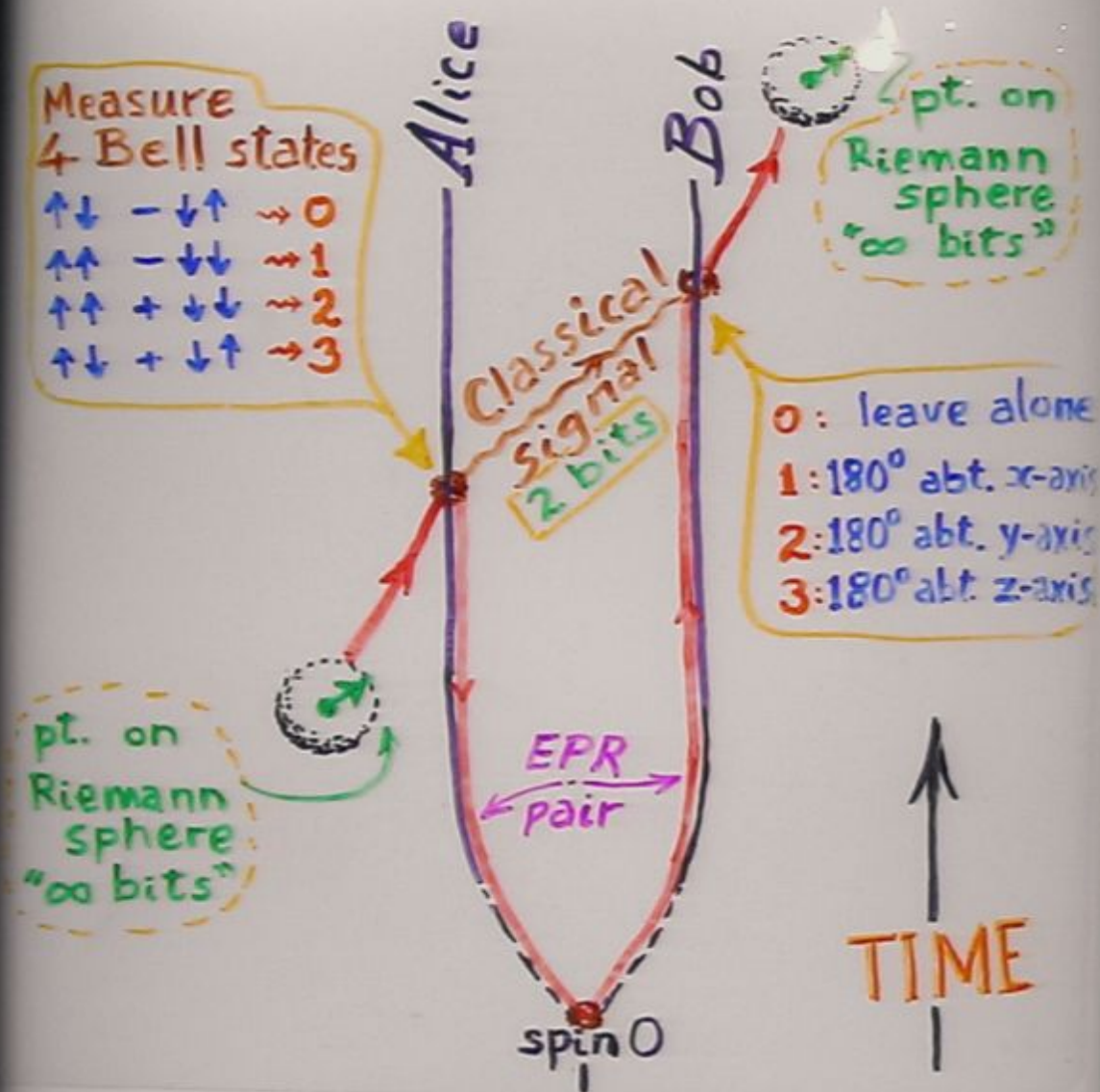
Quantum "teleportation"



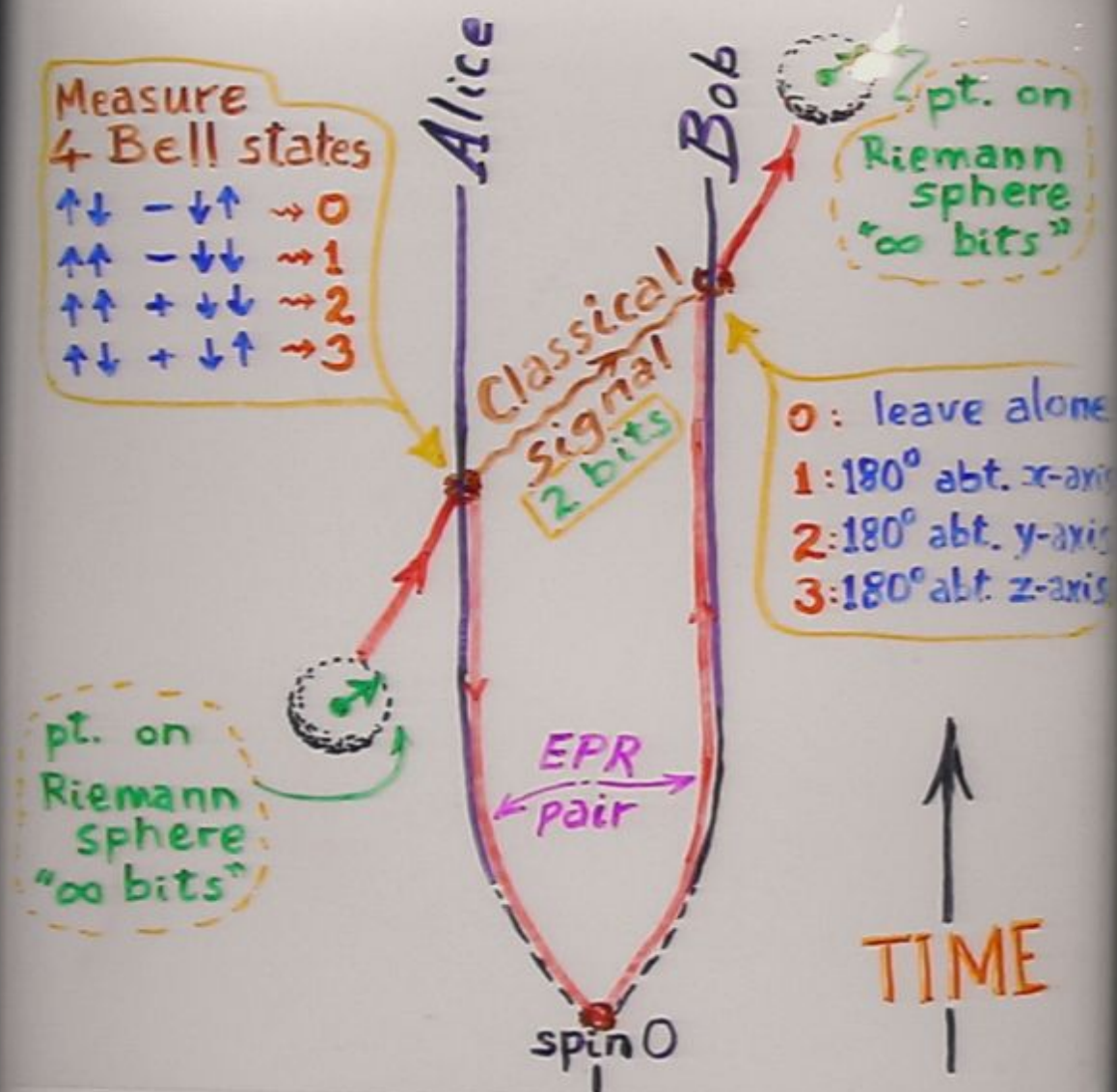
Quantum teleportation



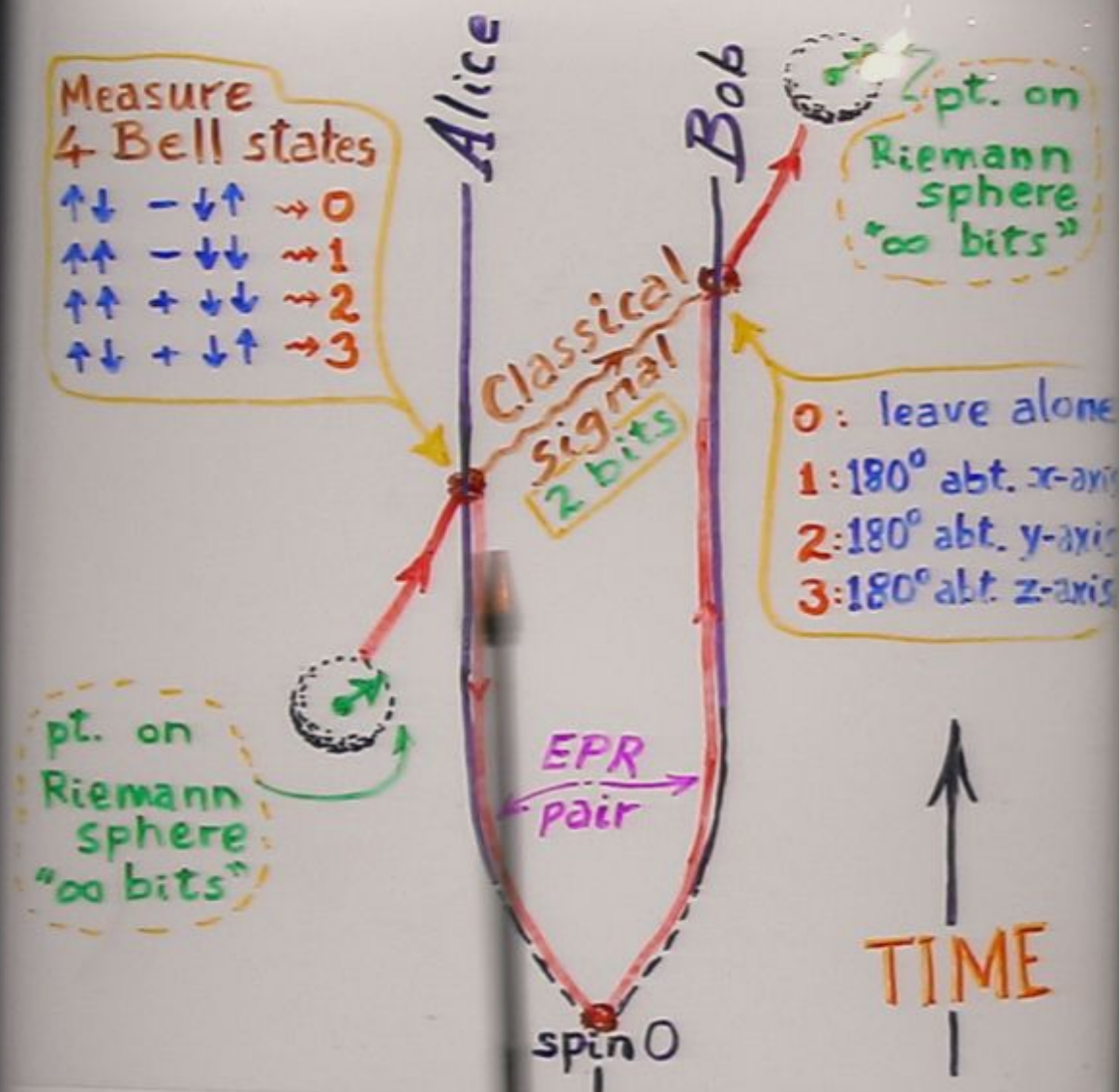
Quantum "teleportation"



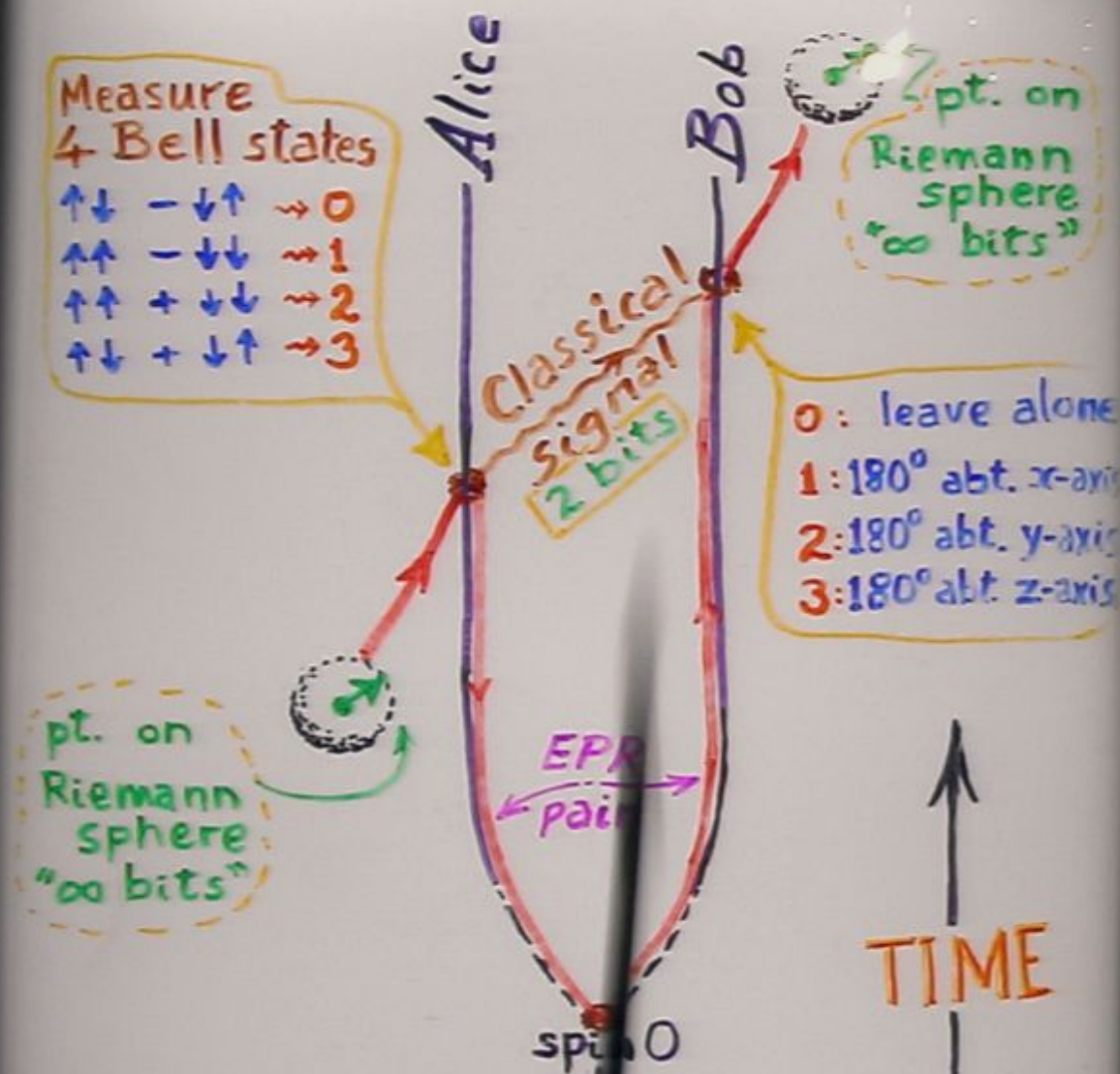
Quantum teleportation



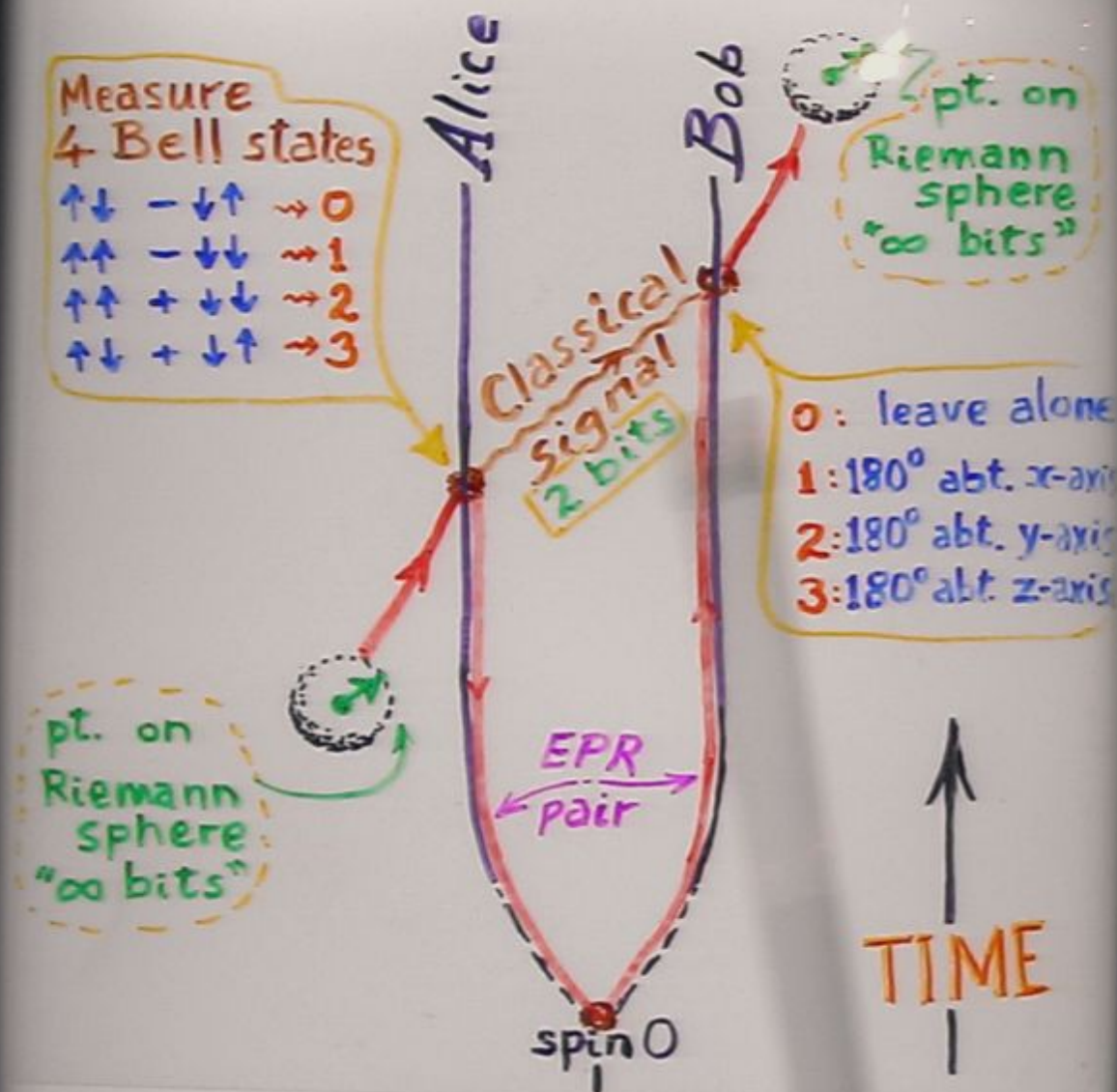
Quantum Teleportation



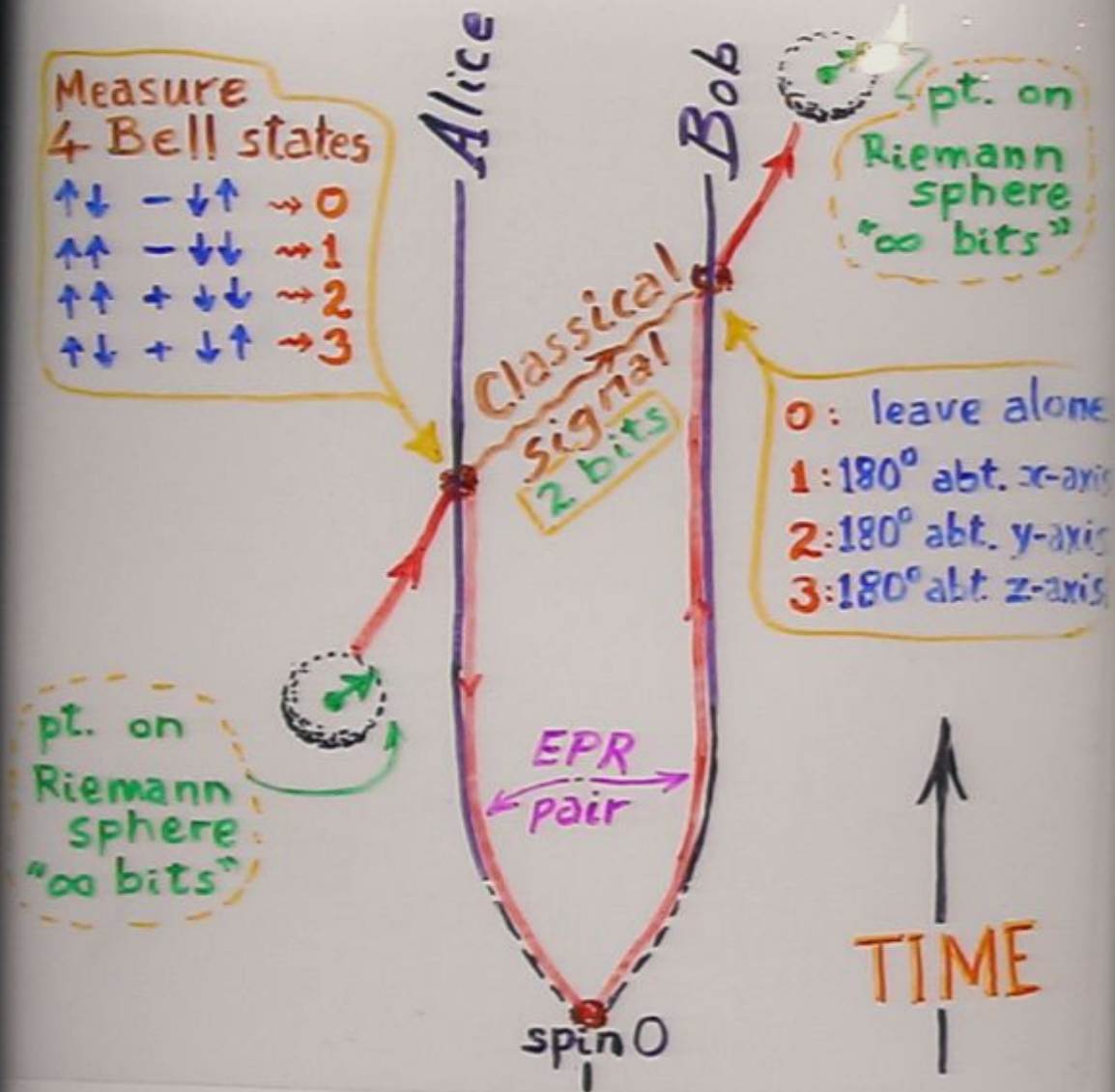
Quantum teleportation



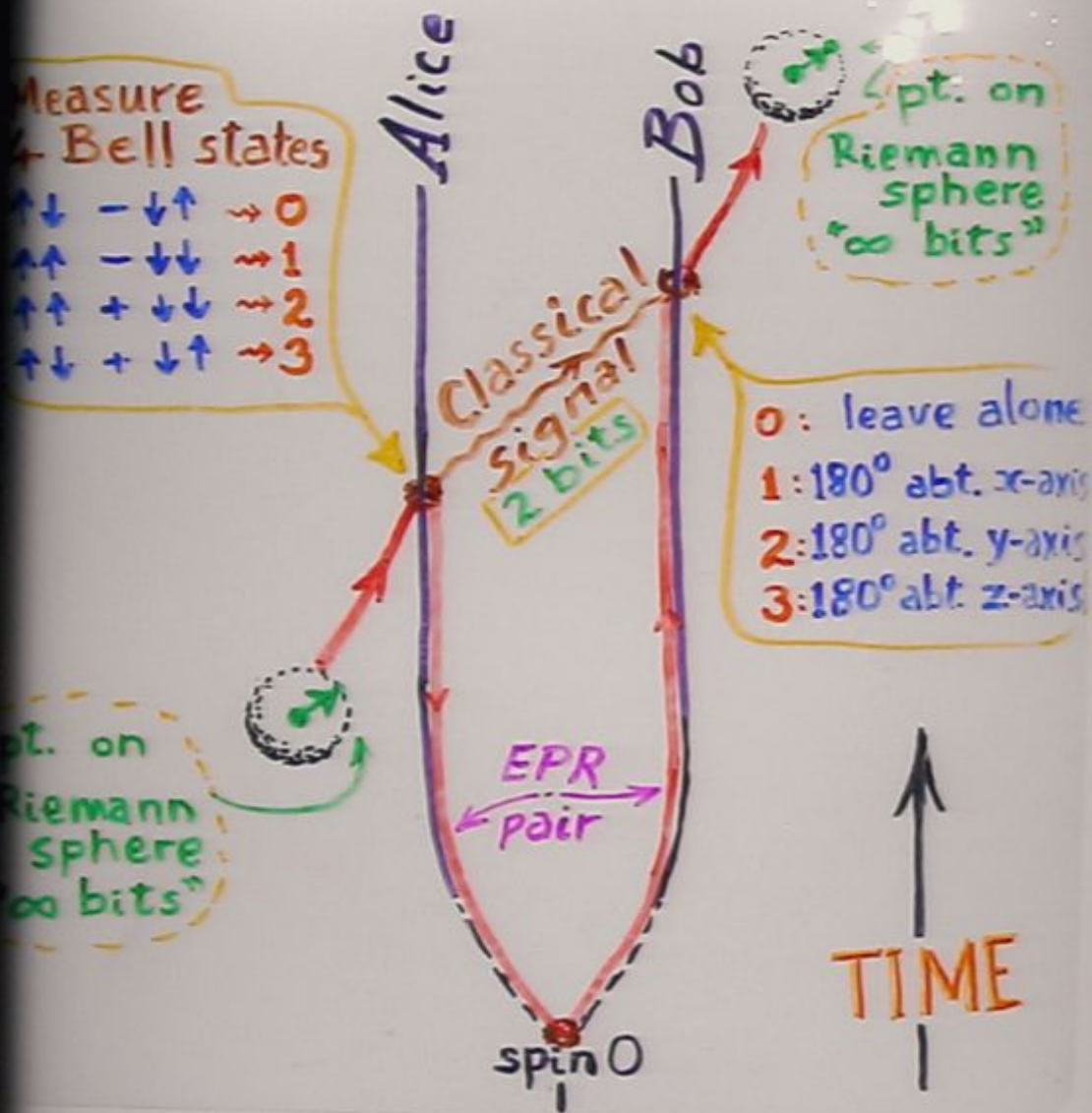
Quantum teleportation



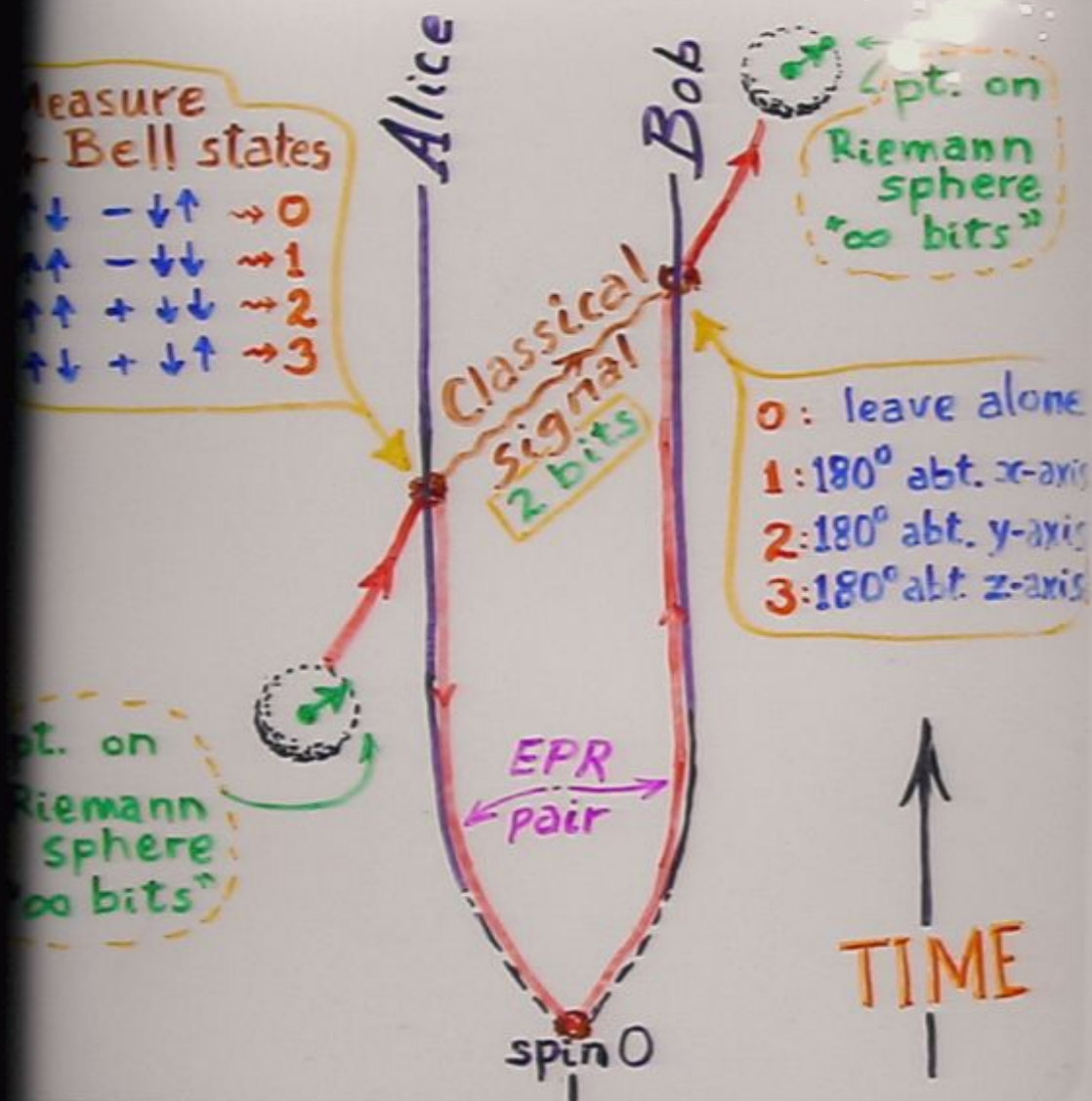
Quantum "teleportation"



Quantum "teleportation"



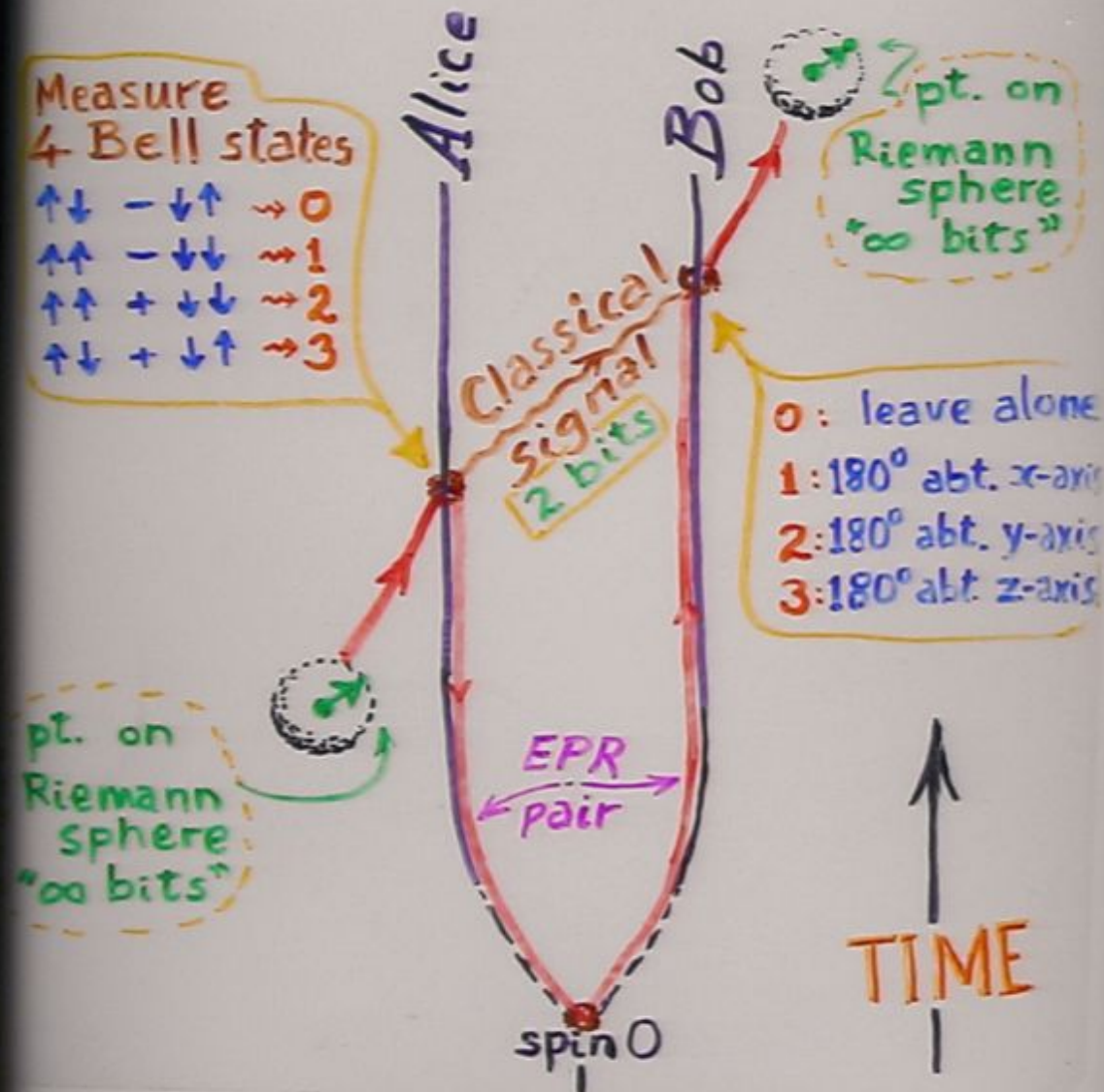
Quantum "teleportation"



Quantum information

(= "quantum information")

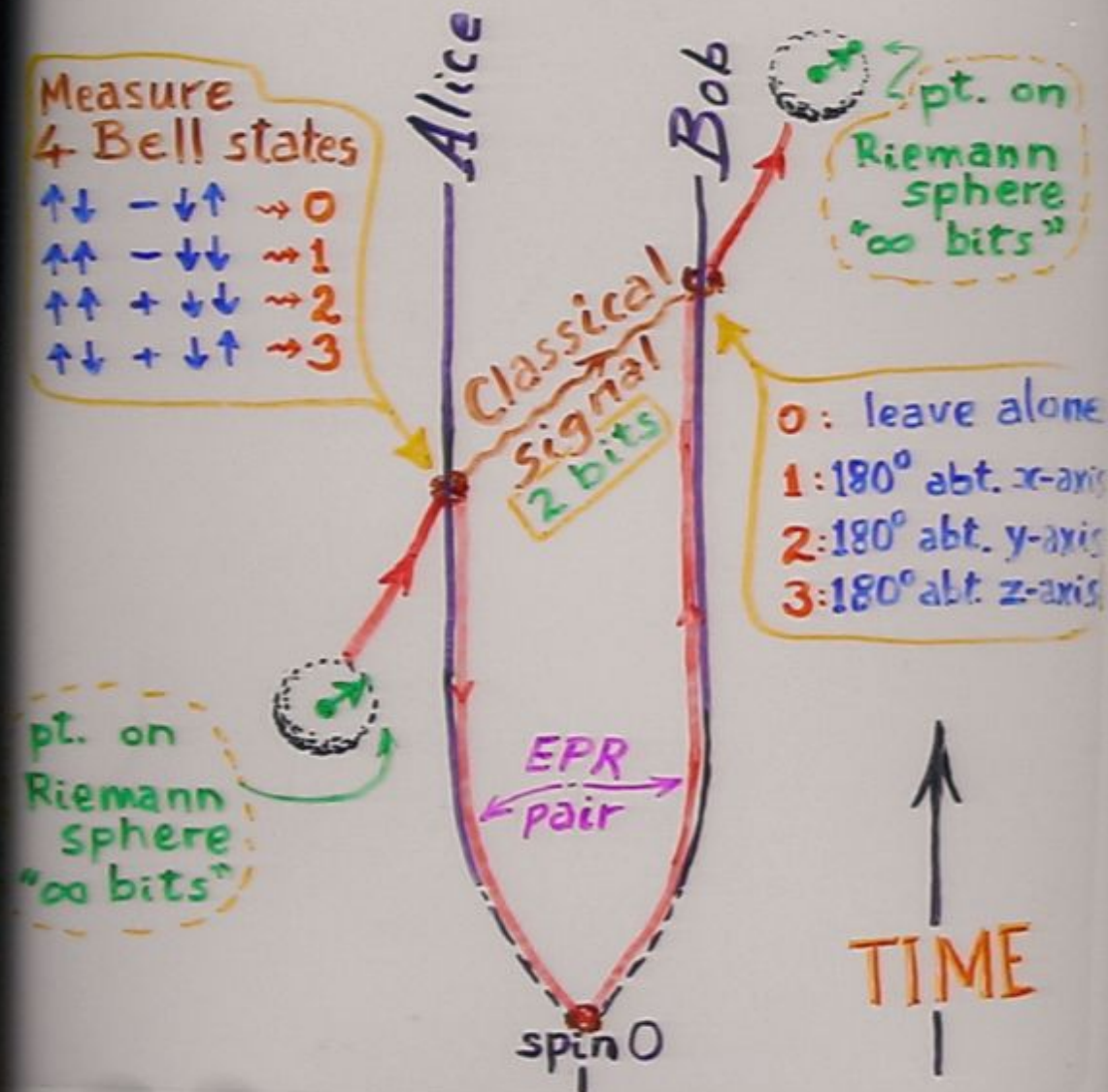
Quantum "teleportation"



Quantum information

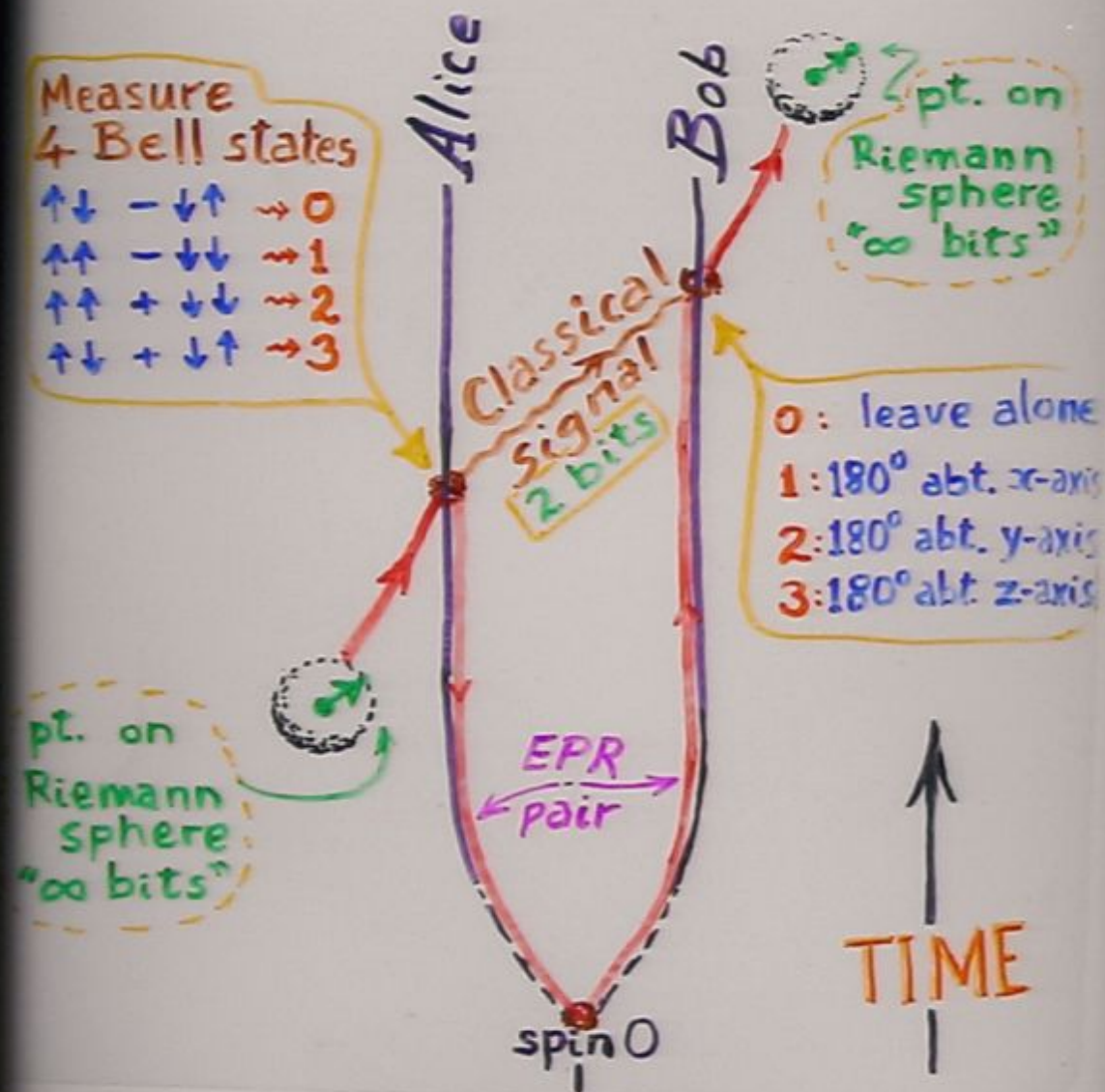
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Quantum "teleportation"



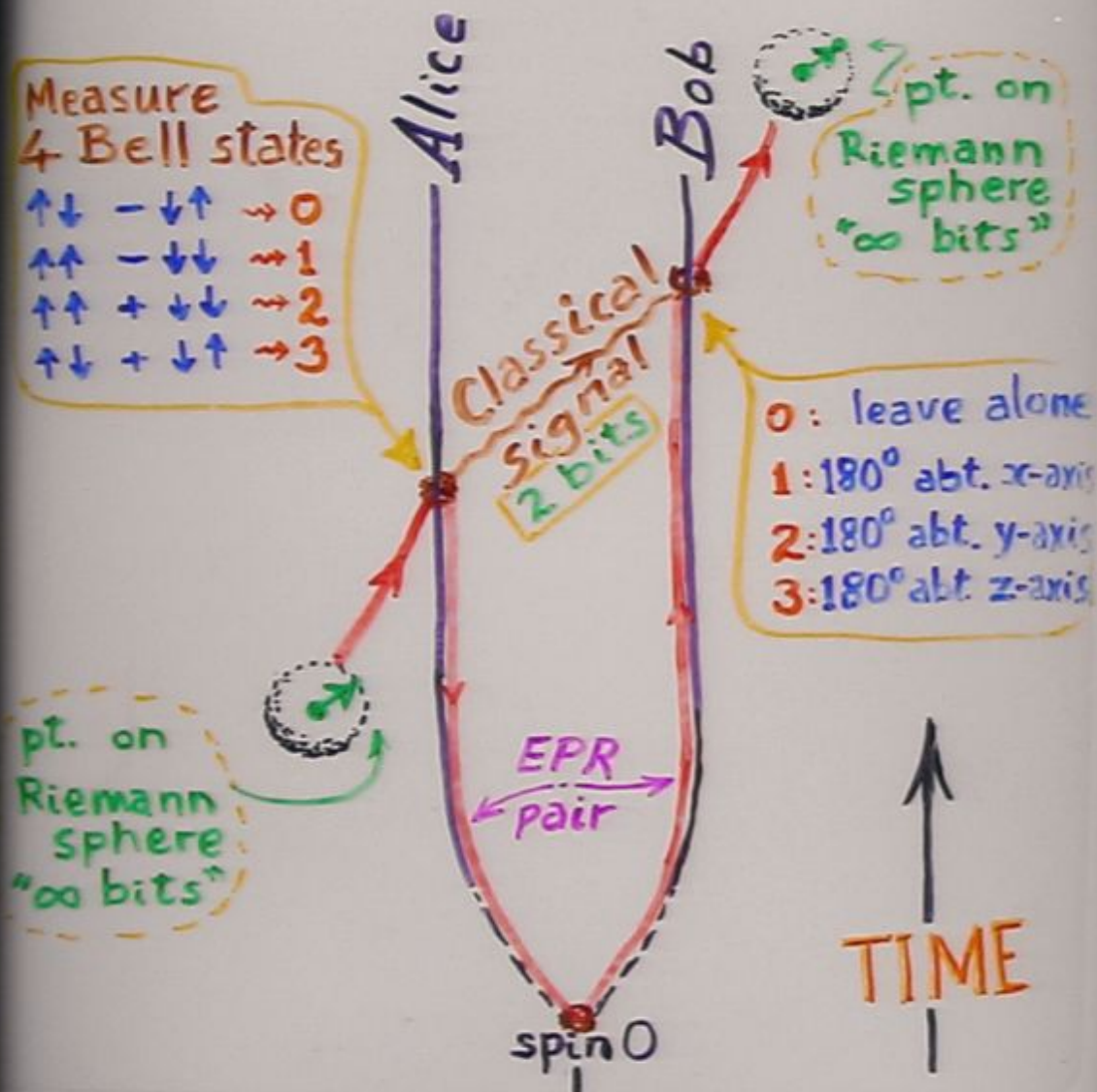
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Quantum "teleportation"



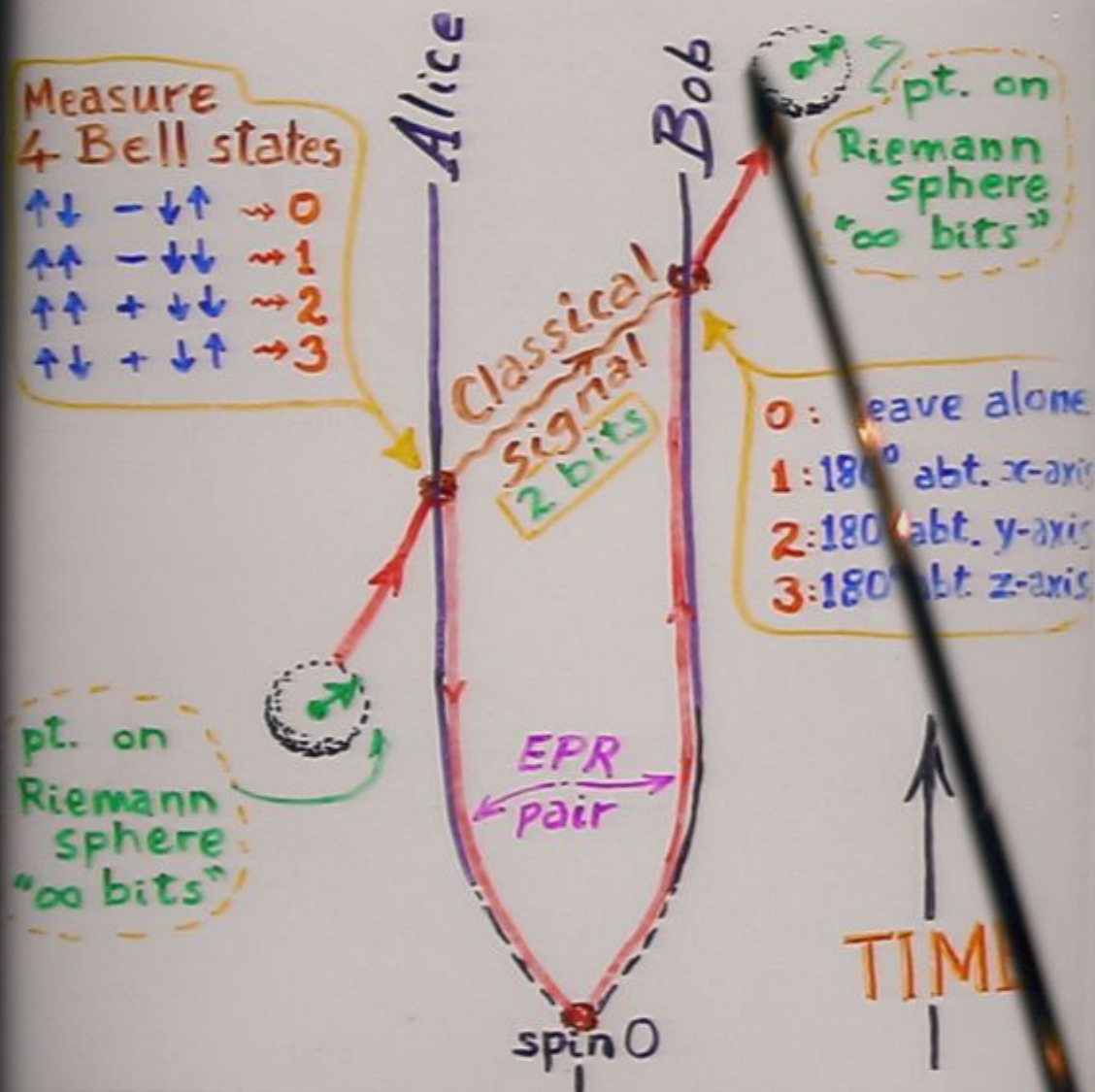
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Quantum "teleportation"



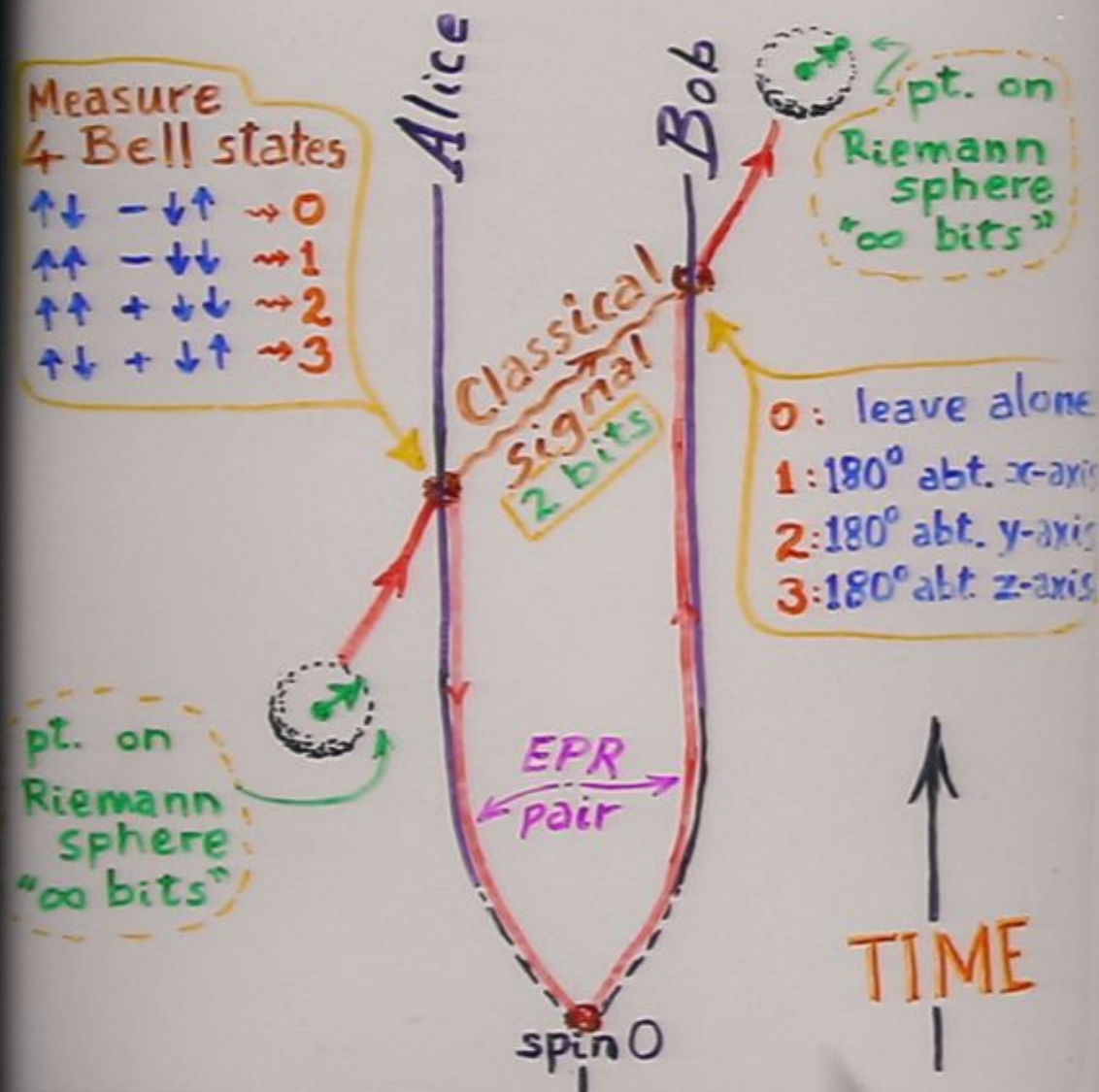
(= "quantum information")

Quantum "teleportation"



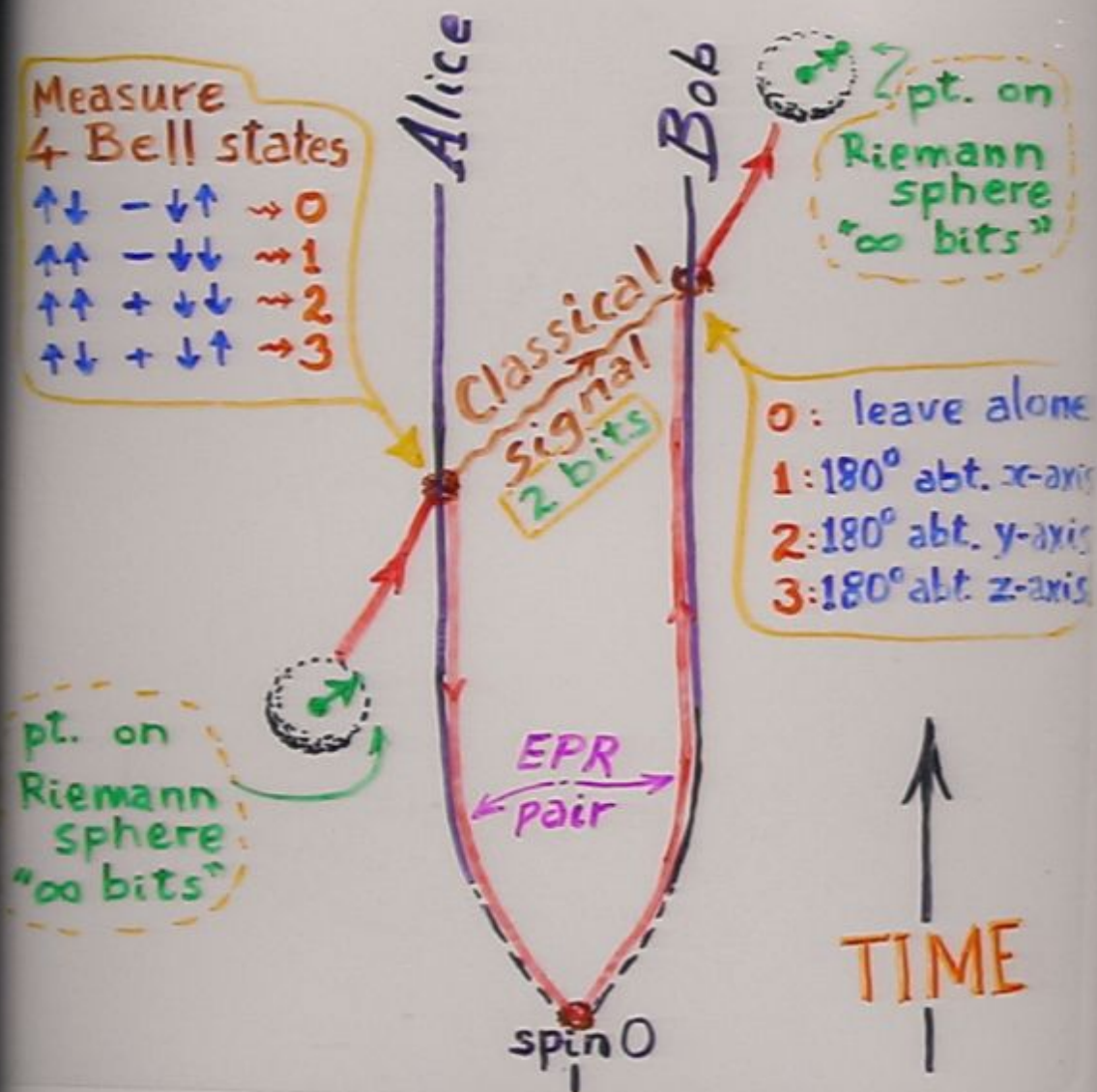
(= "quantum information")

Quantum "teleportation"



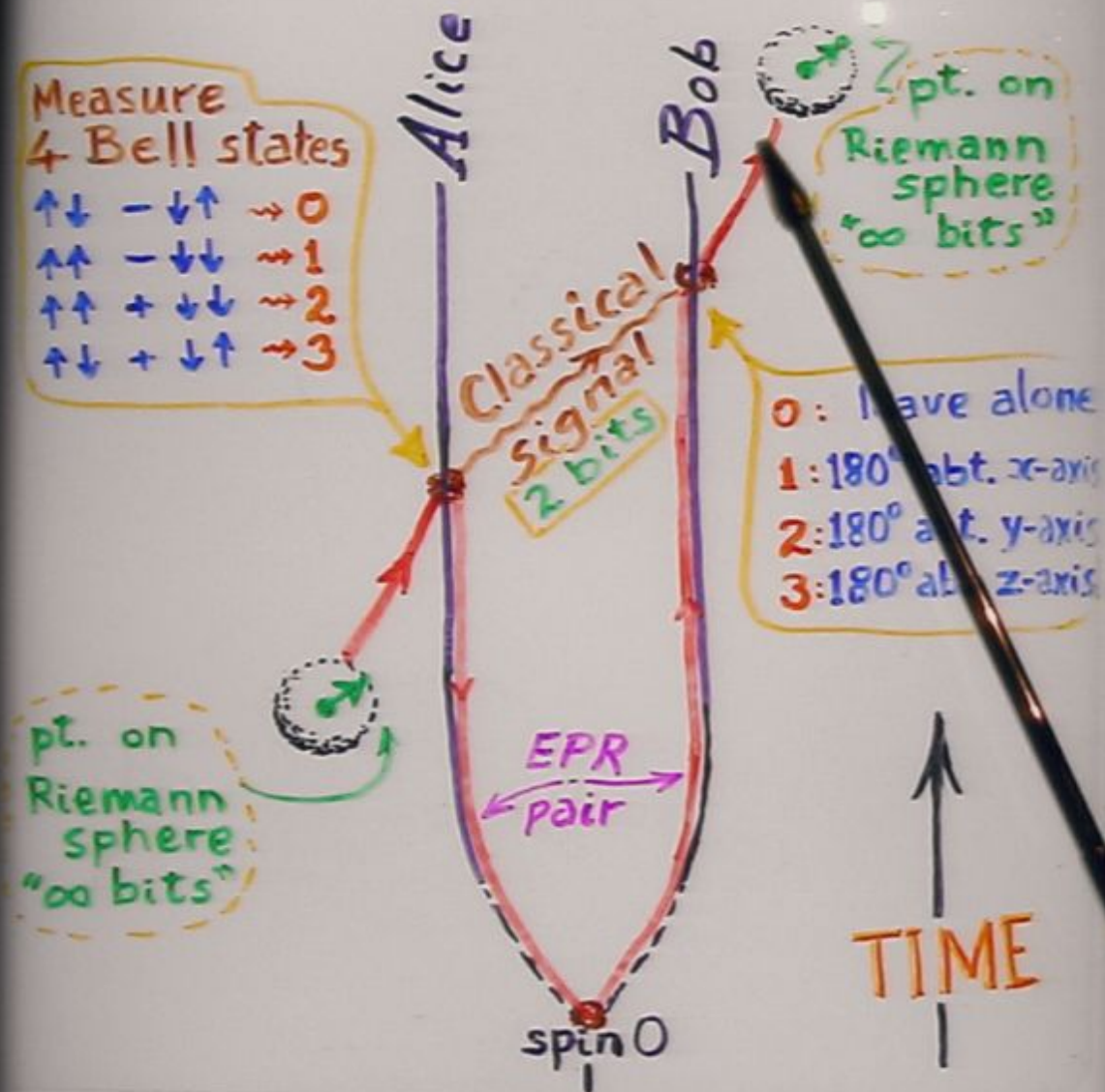
(= "quantum information")

Quantum "teleportation"



(= quantum information)

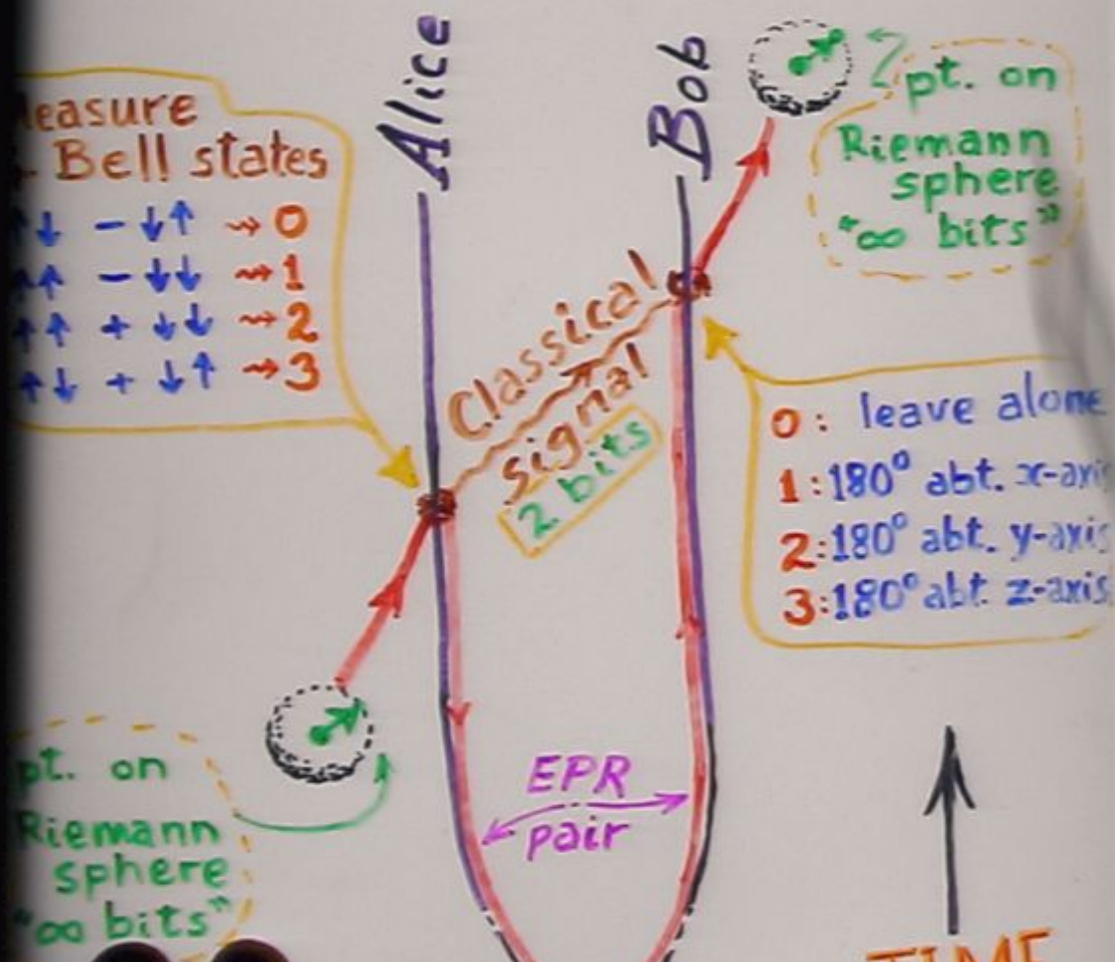
Quantum "teleportation"



Quanglement

(= "quantum information")

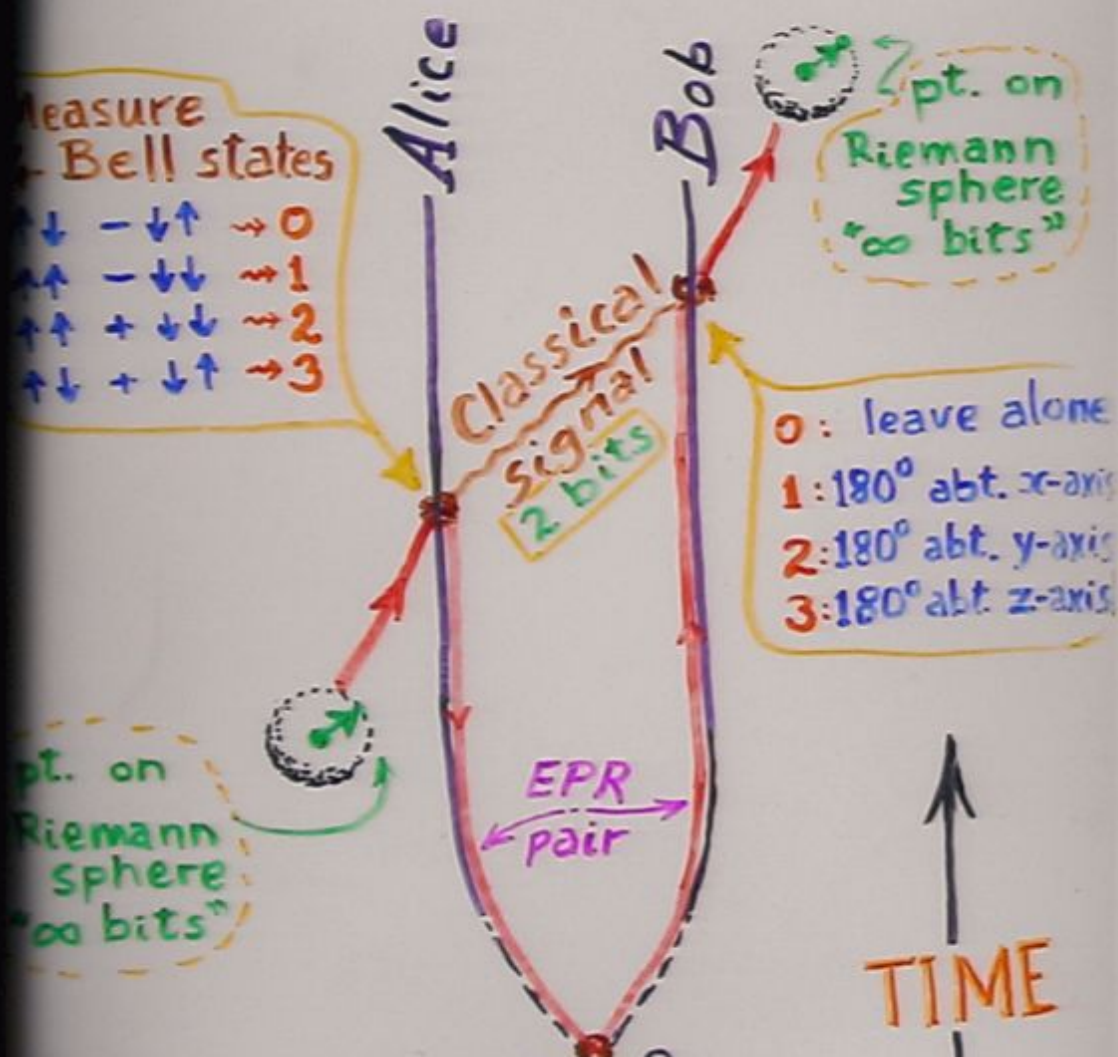
Quantum "teleportation"



Quanglement

(= "quantum information")

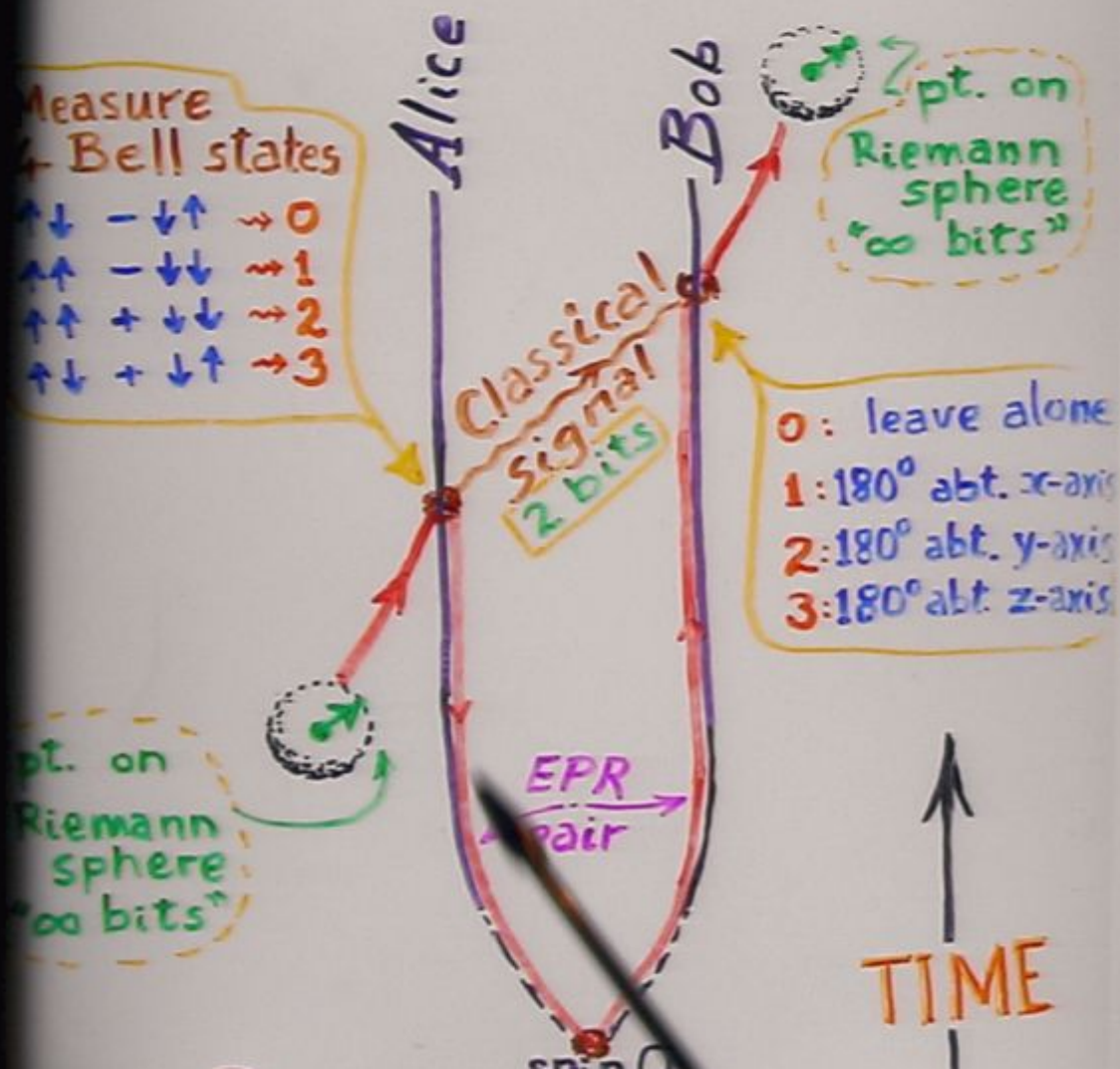
Quantum "teleportation"



Quanglement

(= "quantum information")

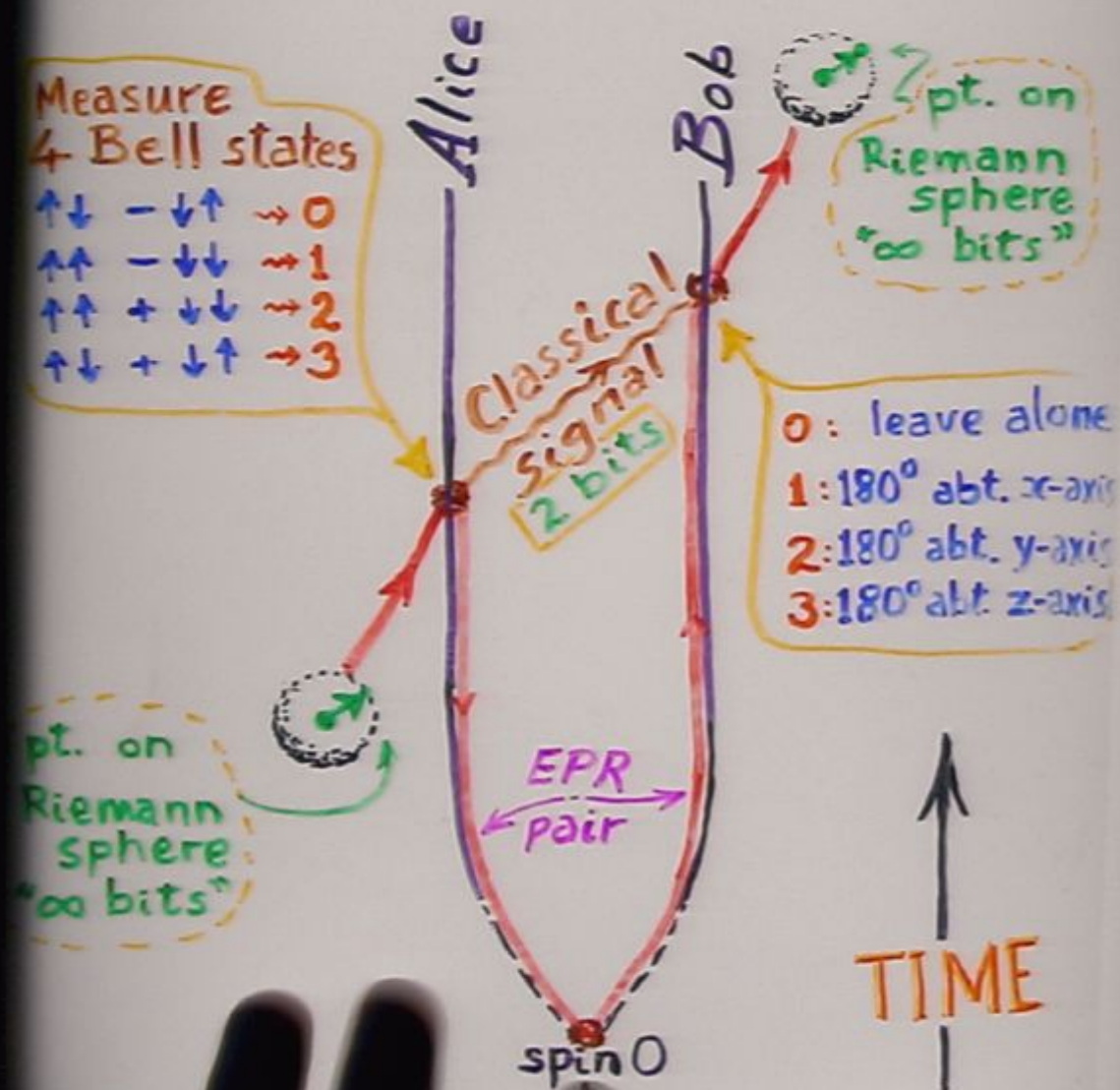
Quantum "teleportation"



Quanglement

(= "quantum information")

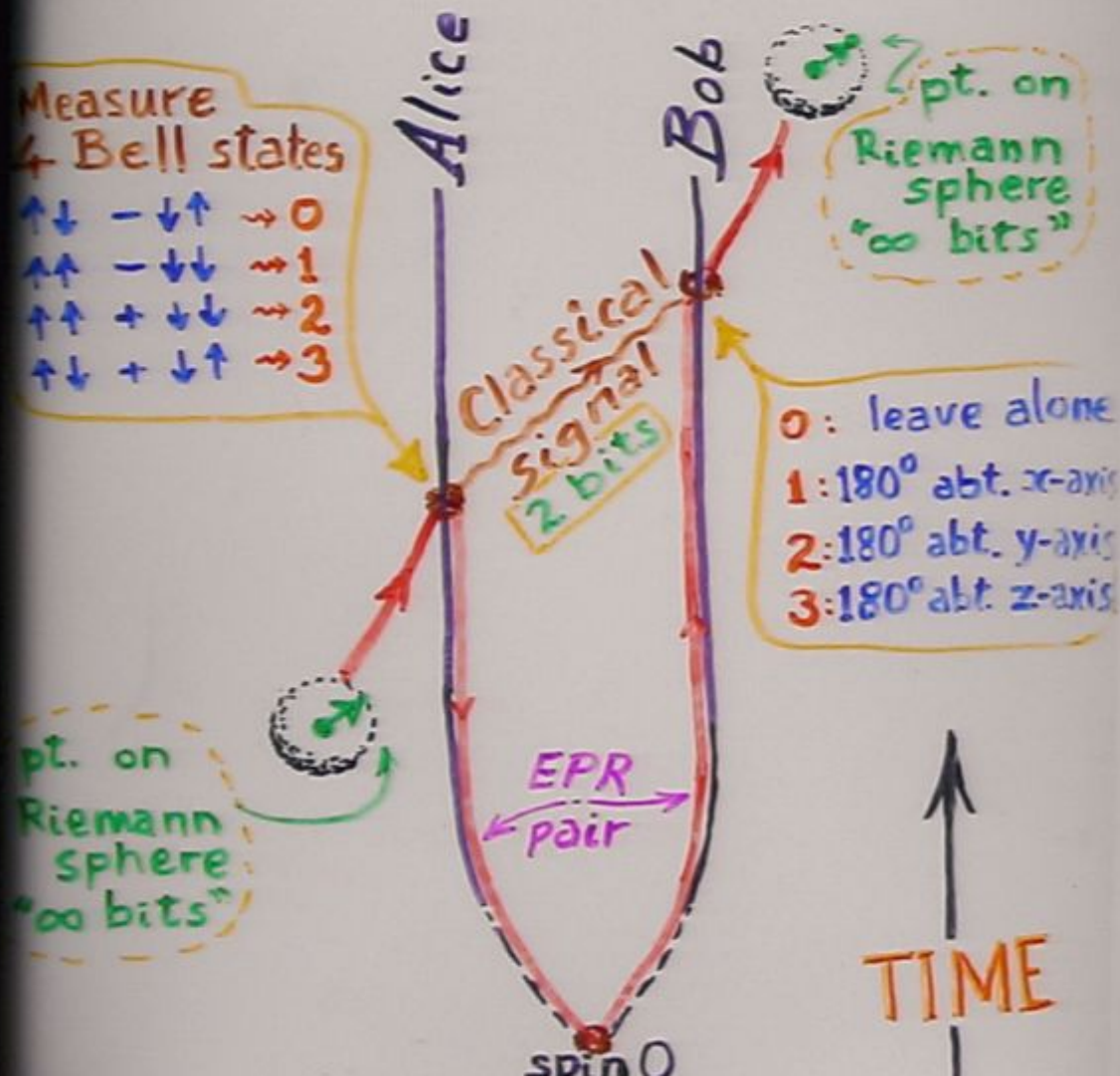
Quantum "teleportation"



Quanglement

(= "quantum information")

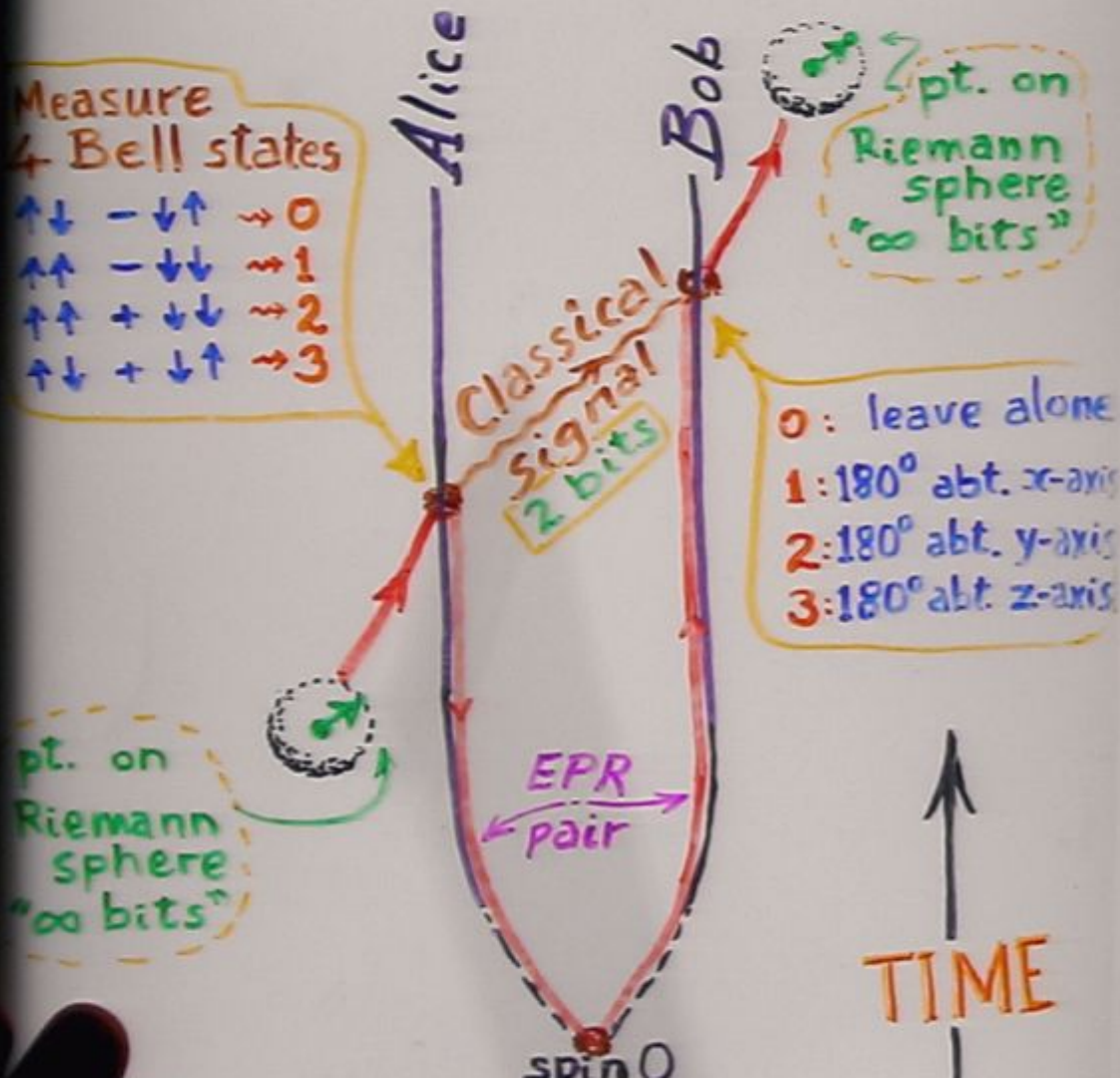
Quantum "teleportation"



Quanglement

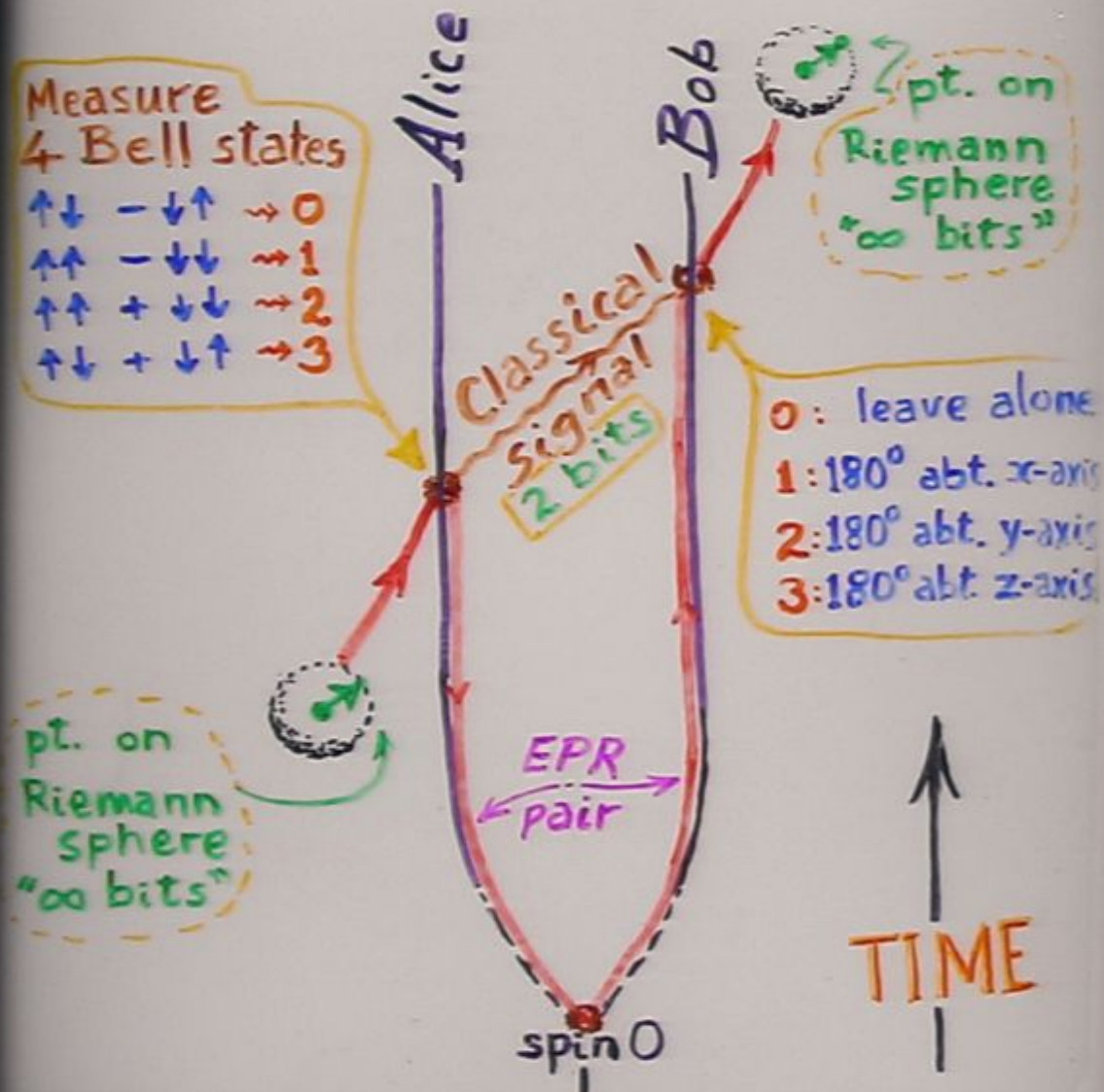
(= "quantum information")

Quantum "teleportation"



(= "quantum information")

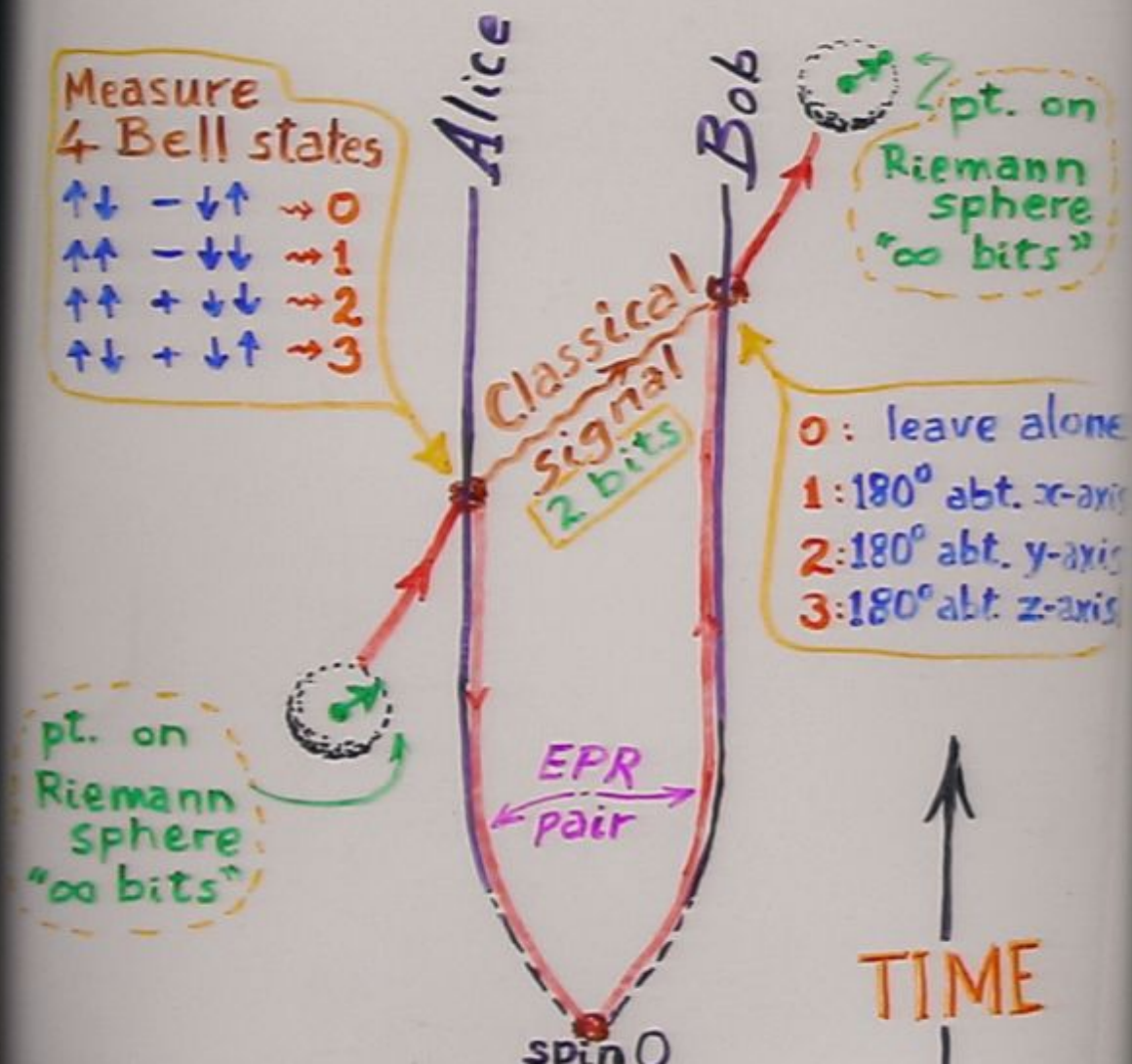
Quantum "teleportation"



Quanglement

(= "quantum information")

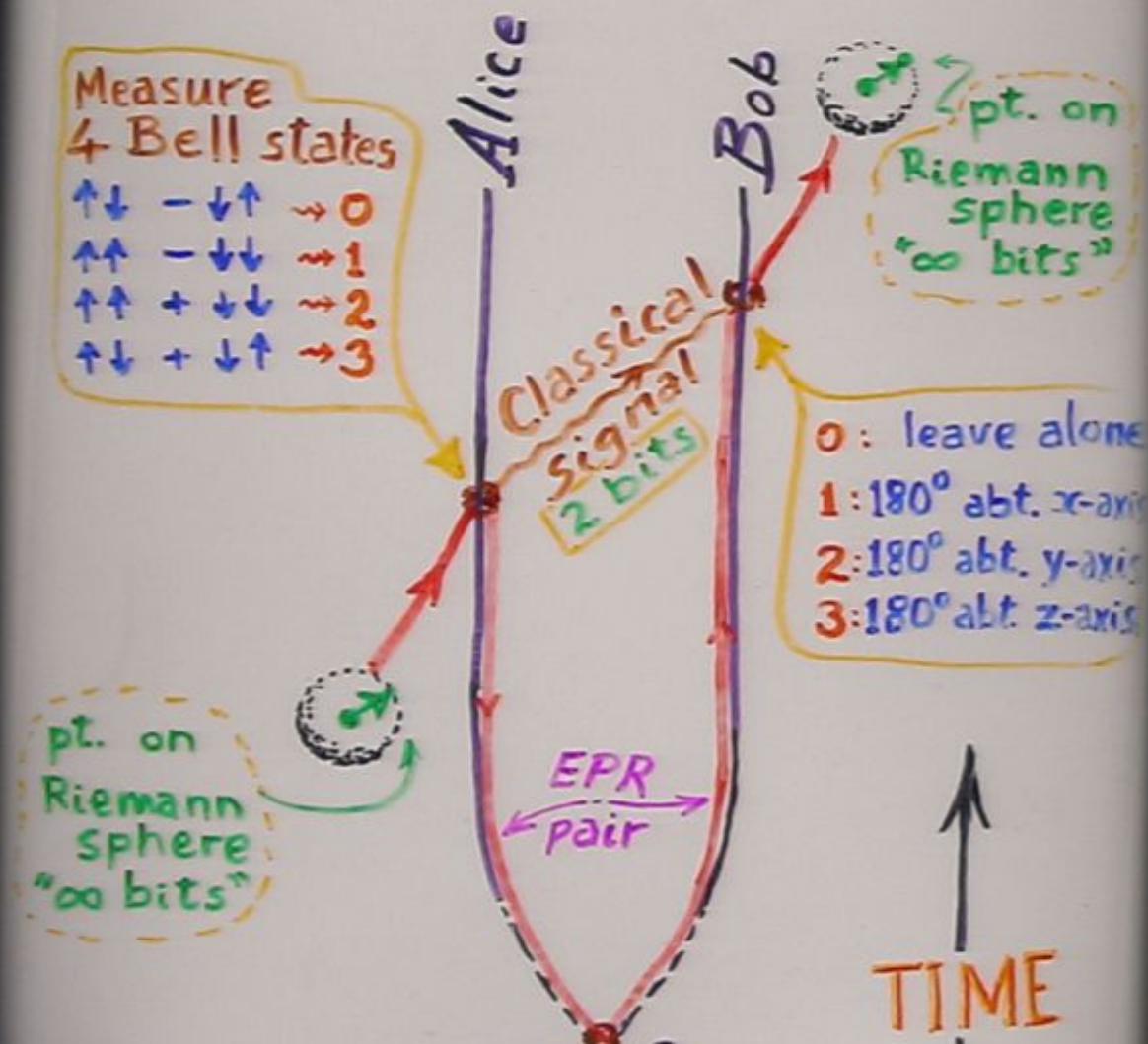
Quantum "teleportation"



Quanglement

(= "quantum information")

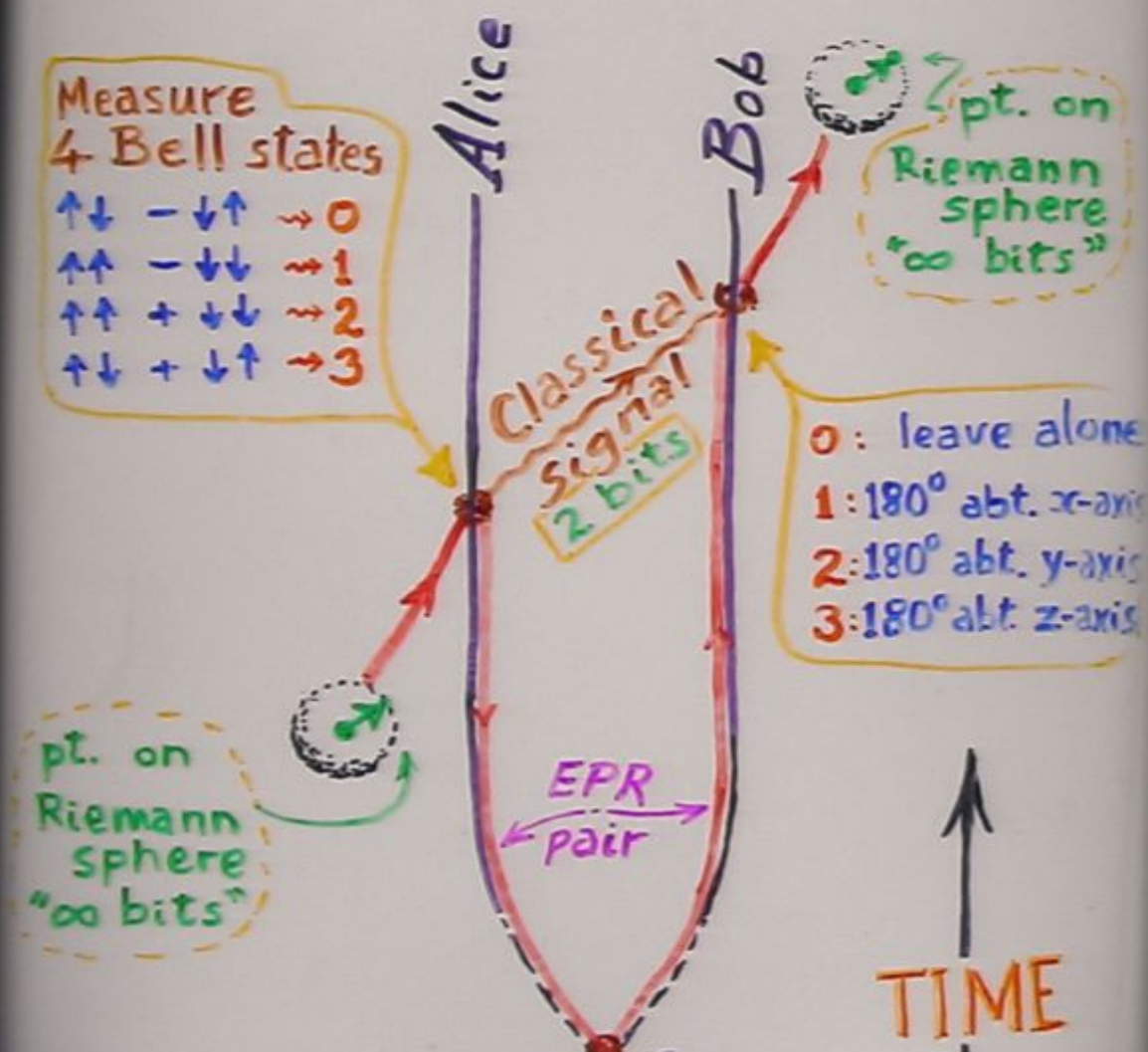
Quantum "teleportation"



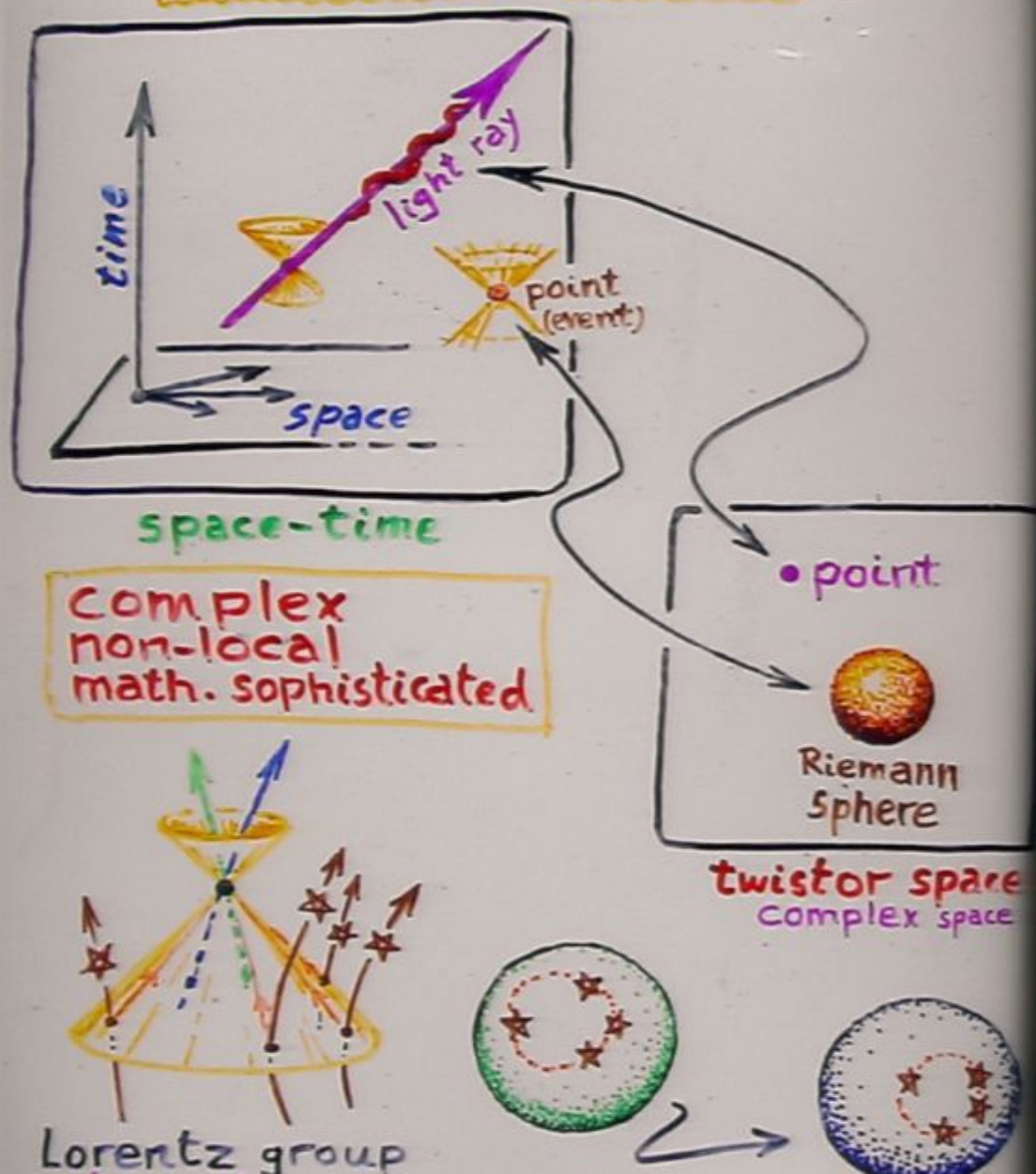
Quanglement

(= "quantum information")

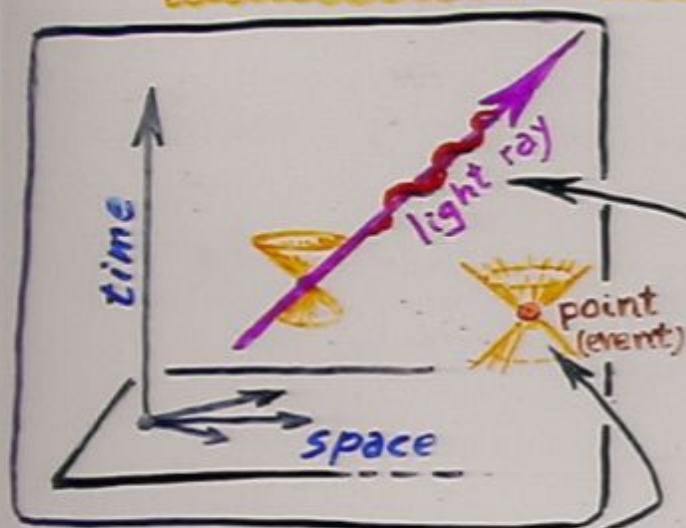
Quantum "teleportation"



Twistor Theory



Twistor Theory



space-time

complex
non-local
math. sophisticated



Lorentz group



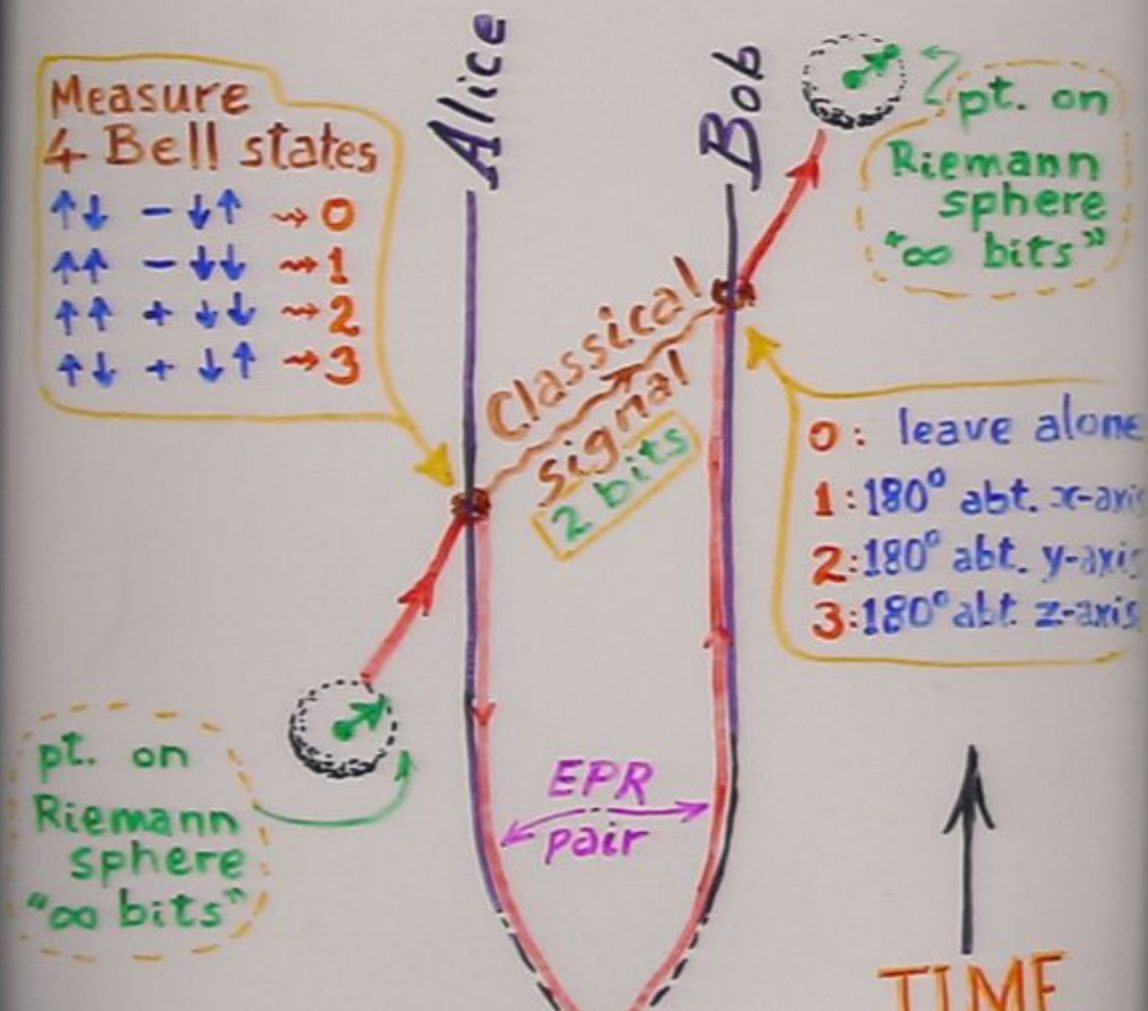
twistor space
complex space



Quanglement

(= "quantum information")

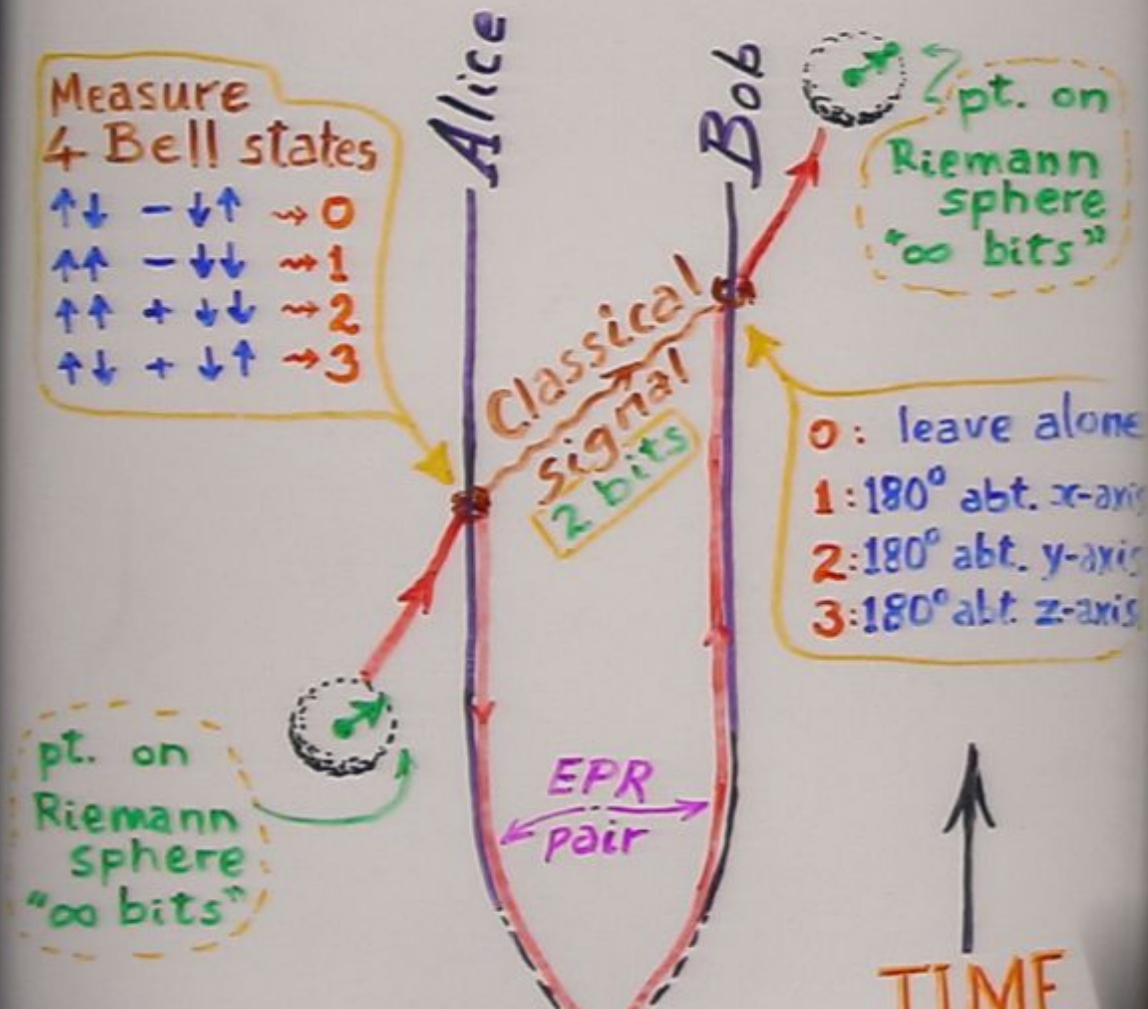
Quantum "teleportation"



Quanglement

(= "quantum information")

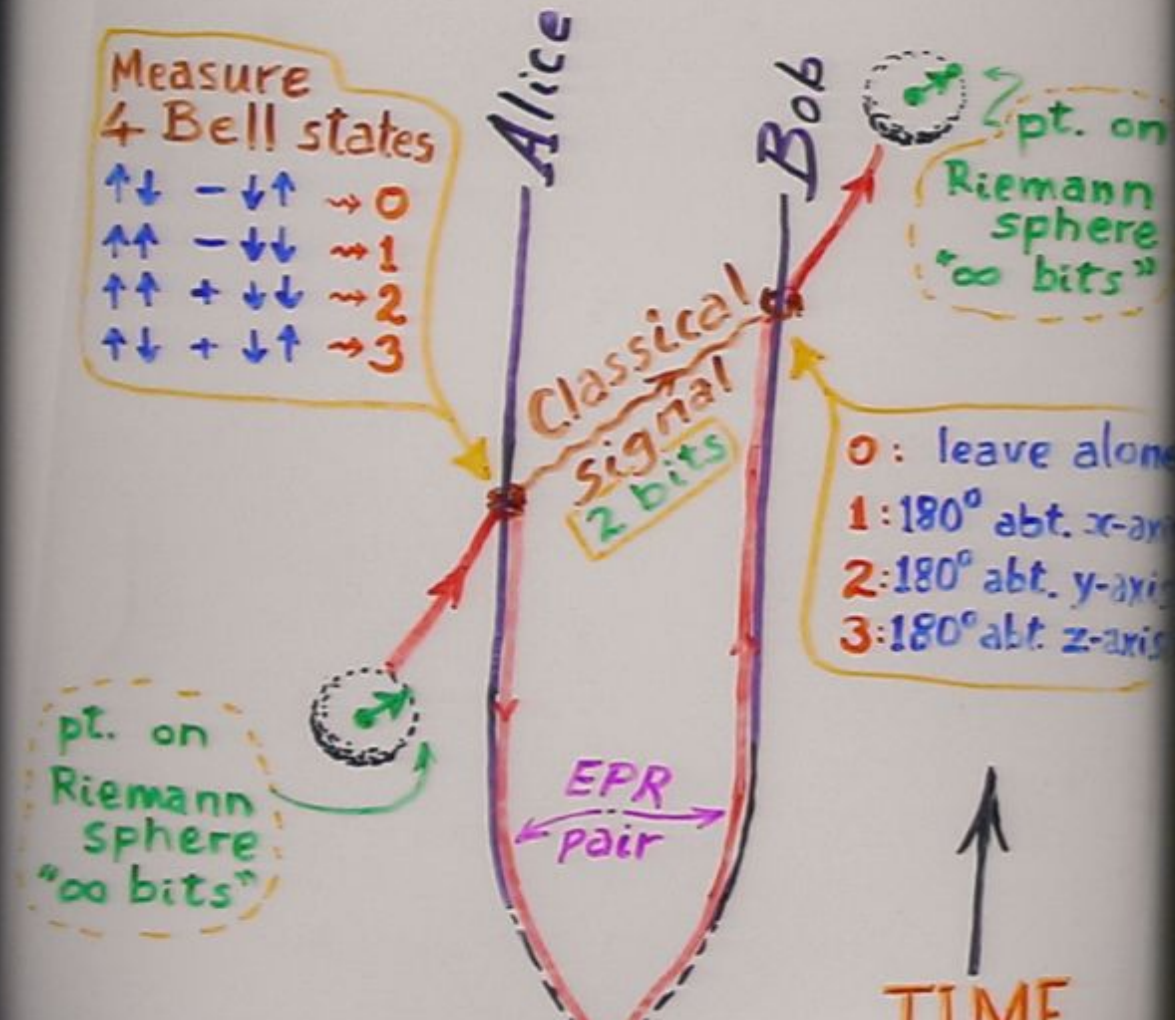
Quantum "teleportation"



Quanglement

(= "quantum information")

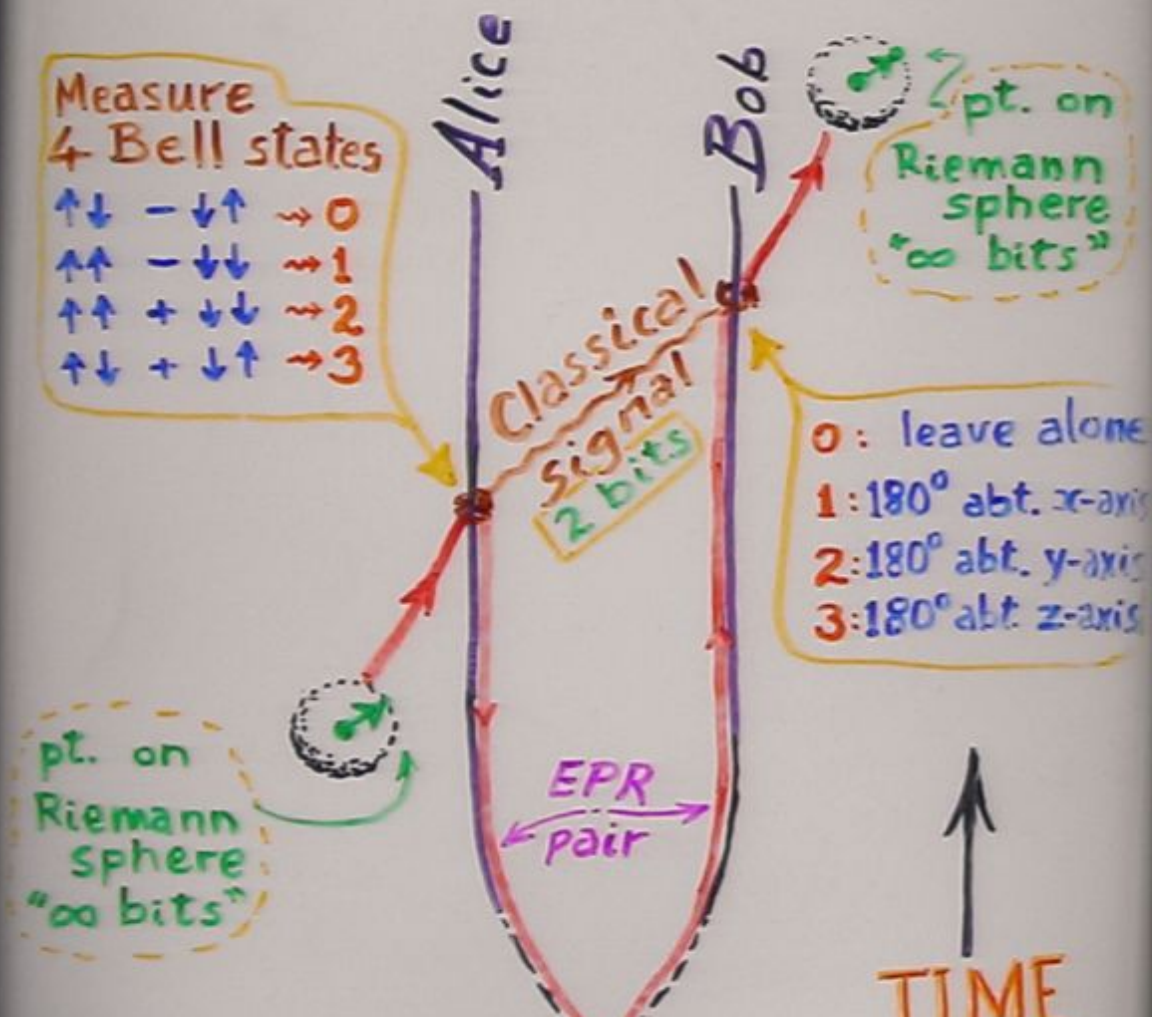
Quantum "teleportation"



Quanglement

(= "quantum information")

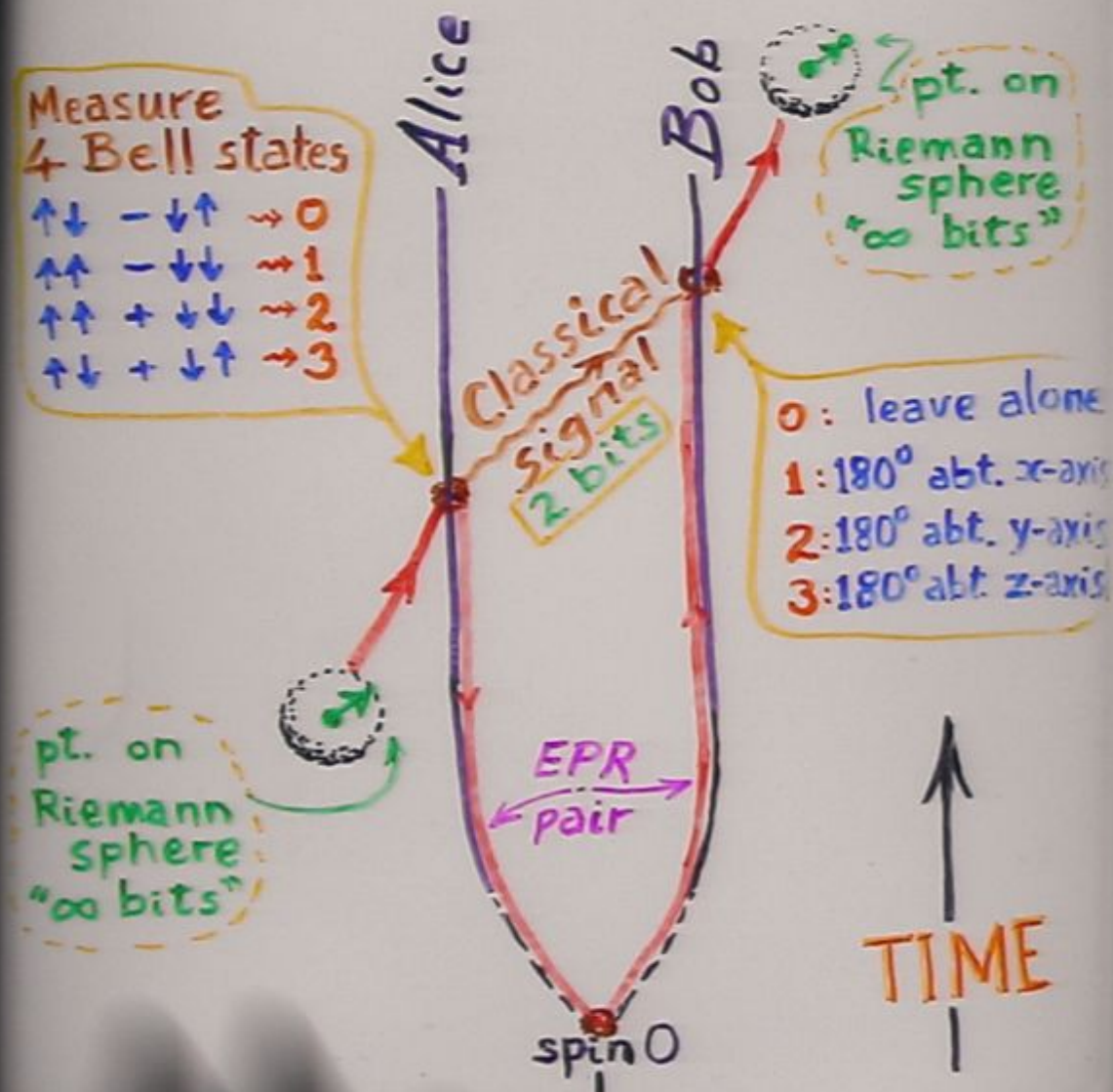
Quantum "teleportation"



Quanglement

(= "quantum information")

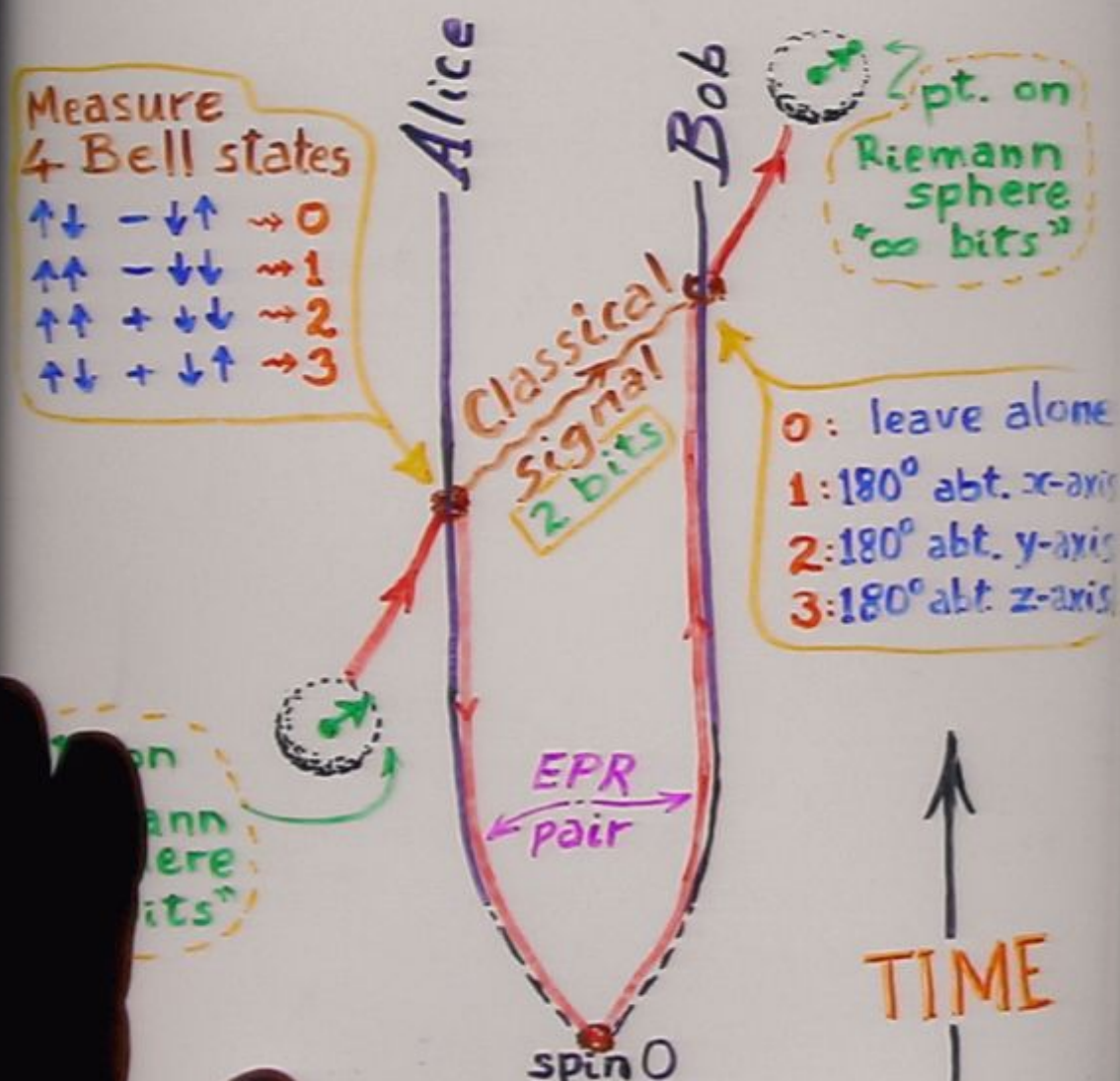
Quantum "teleportation"



Quanglement

(= "quantum information")

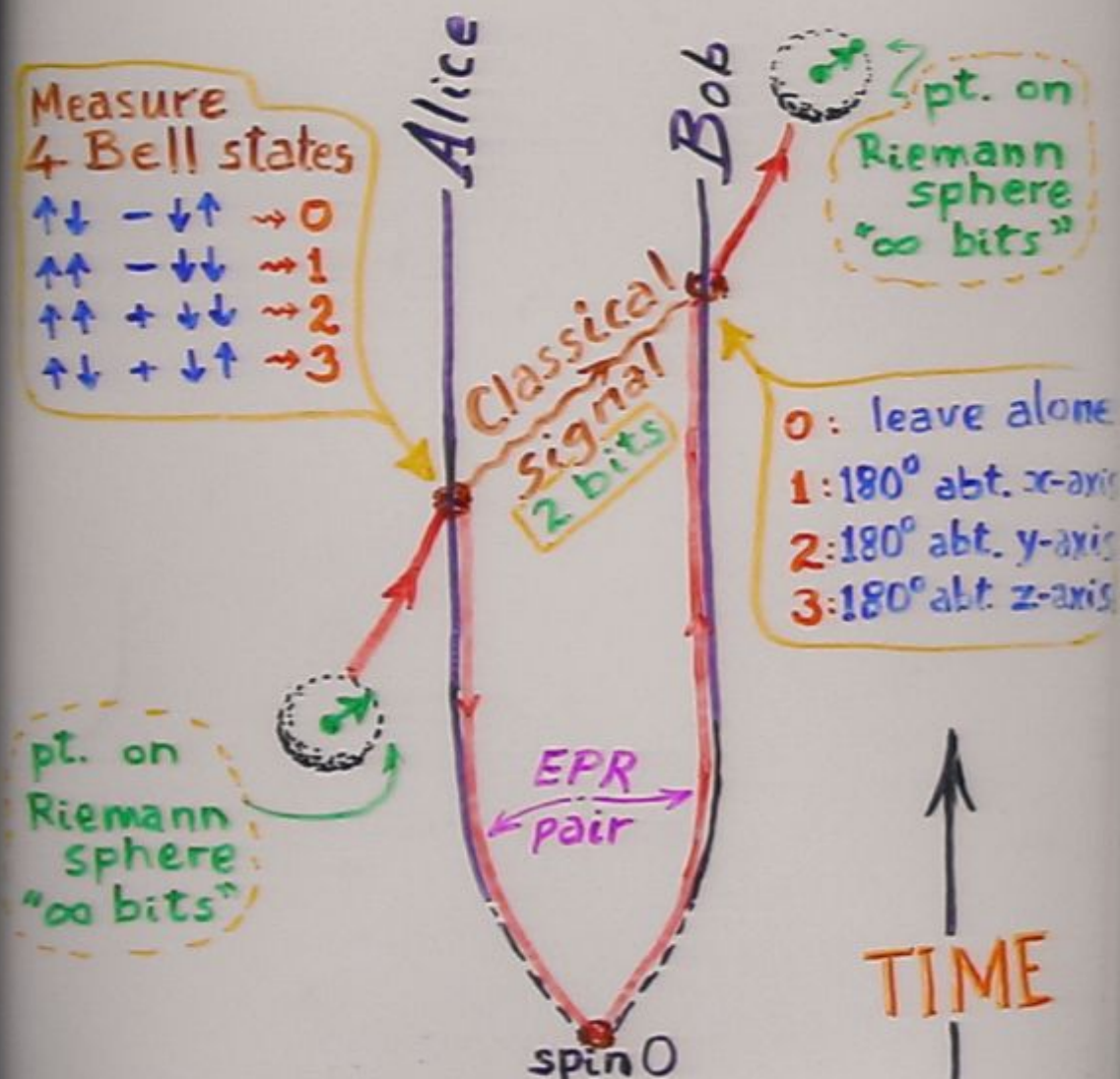
Quantum "teleportation"



Quanglement

(= "quantum information")

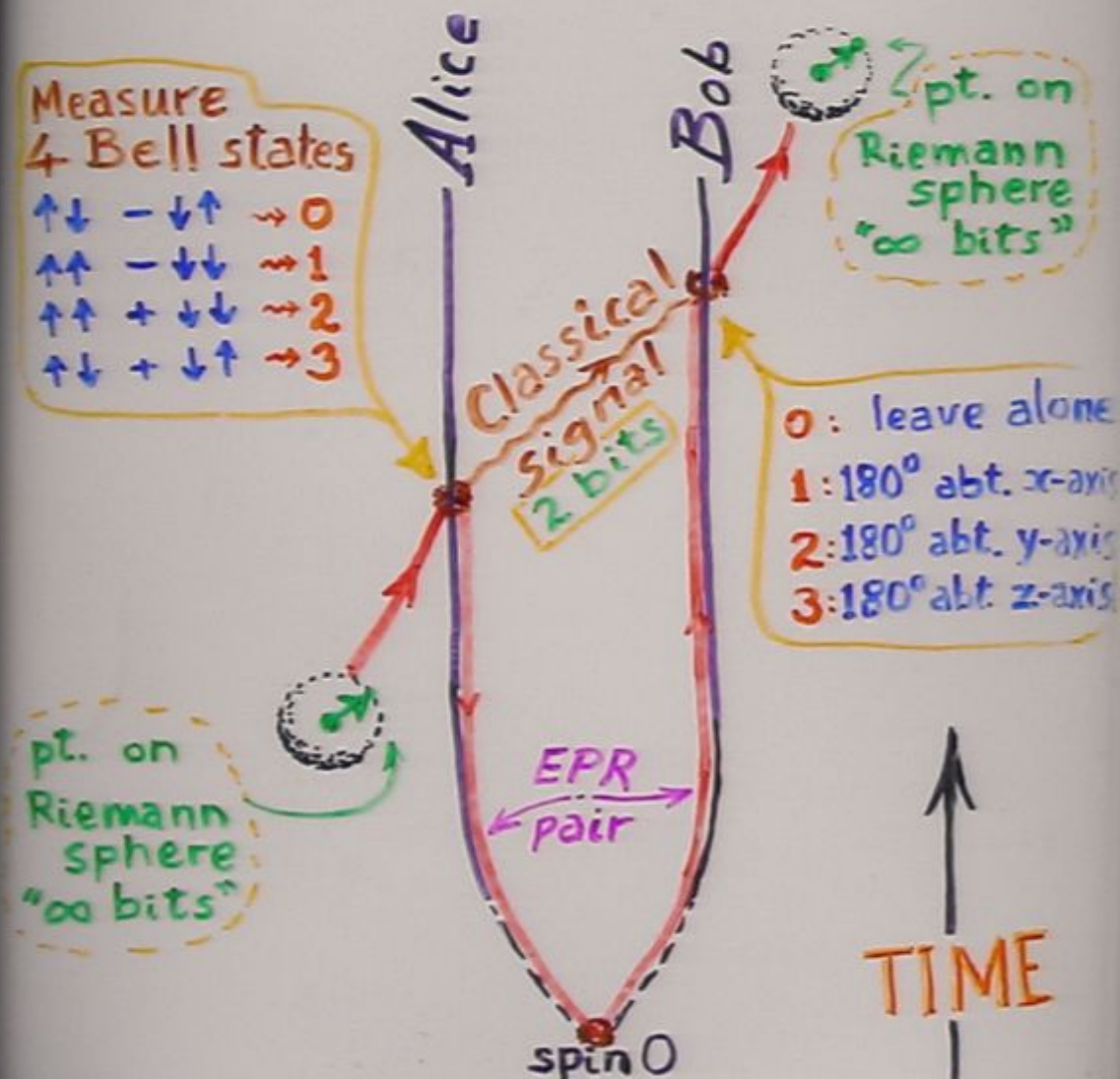
Quantum "teleportation"



Quanglement

(= "quantum information")

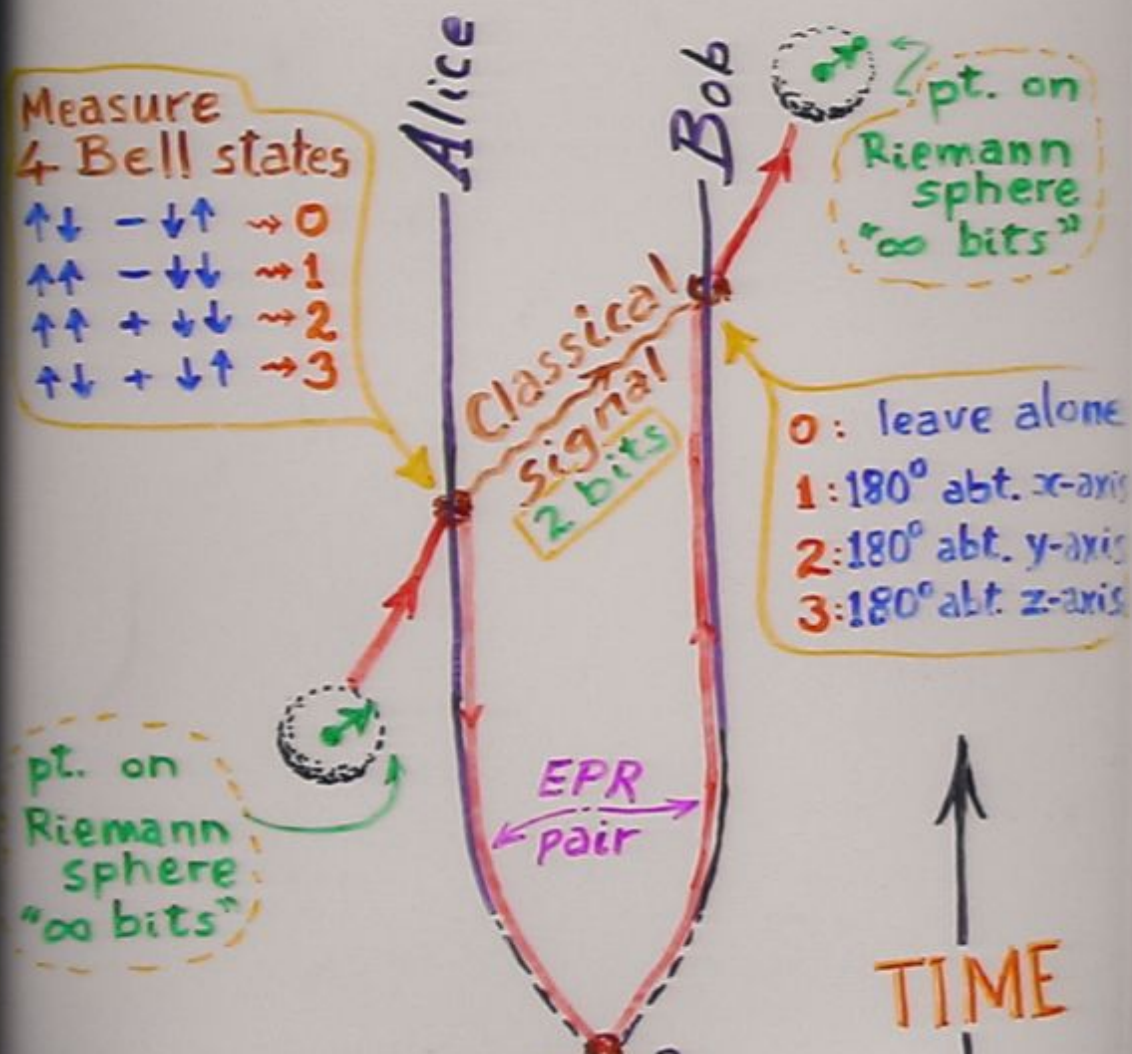
Quantum "teleportation"



Quanglement

(= "quantum information")

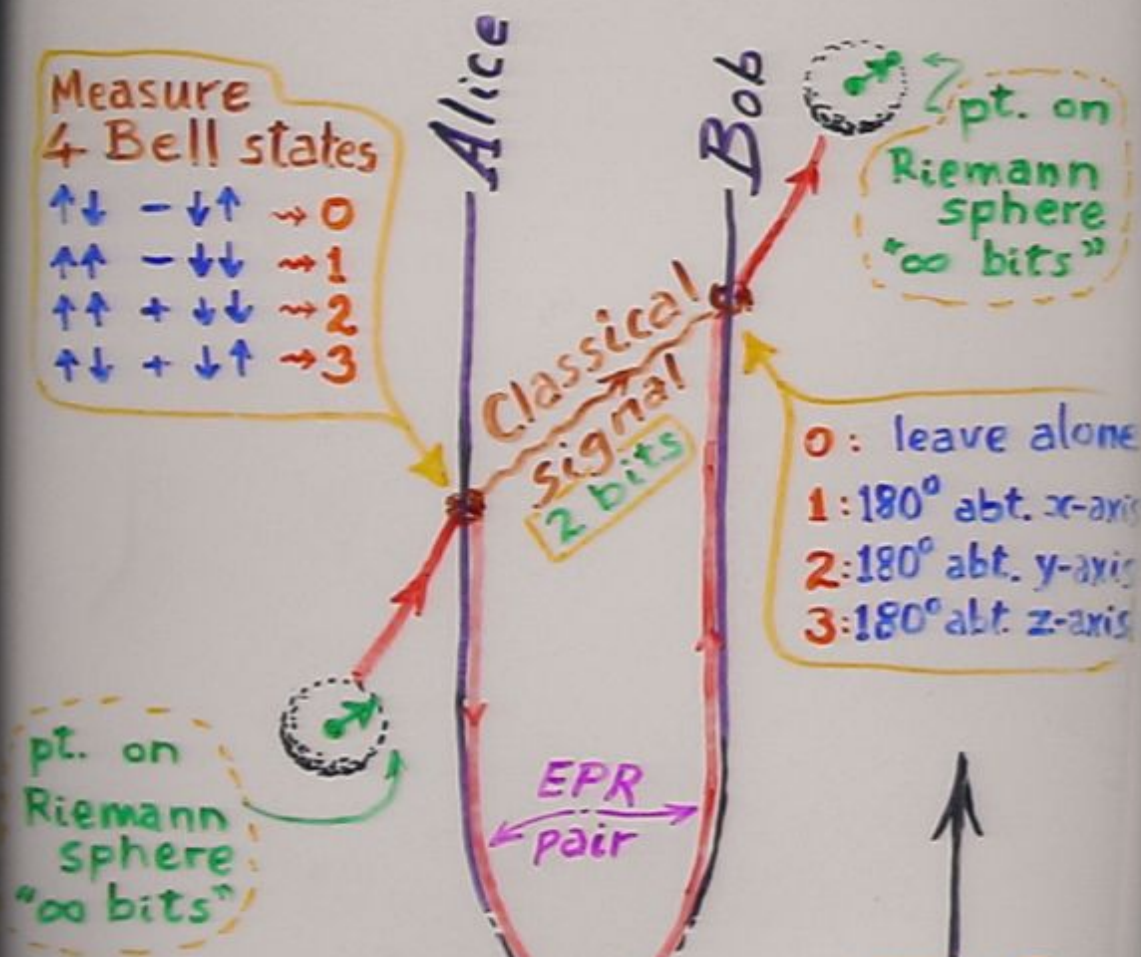
Quantum "teleportation"



Quanglement

(= "quantum information")

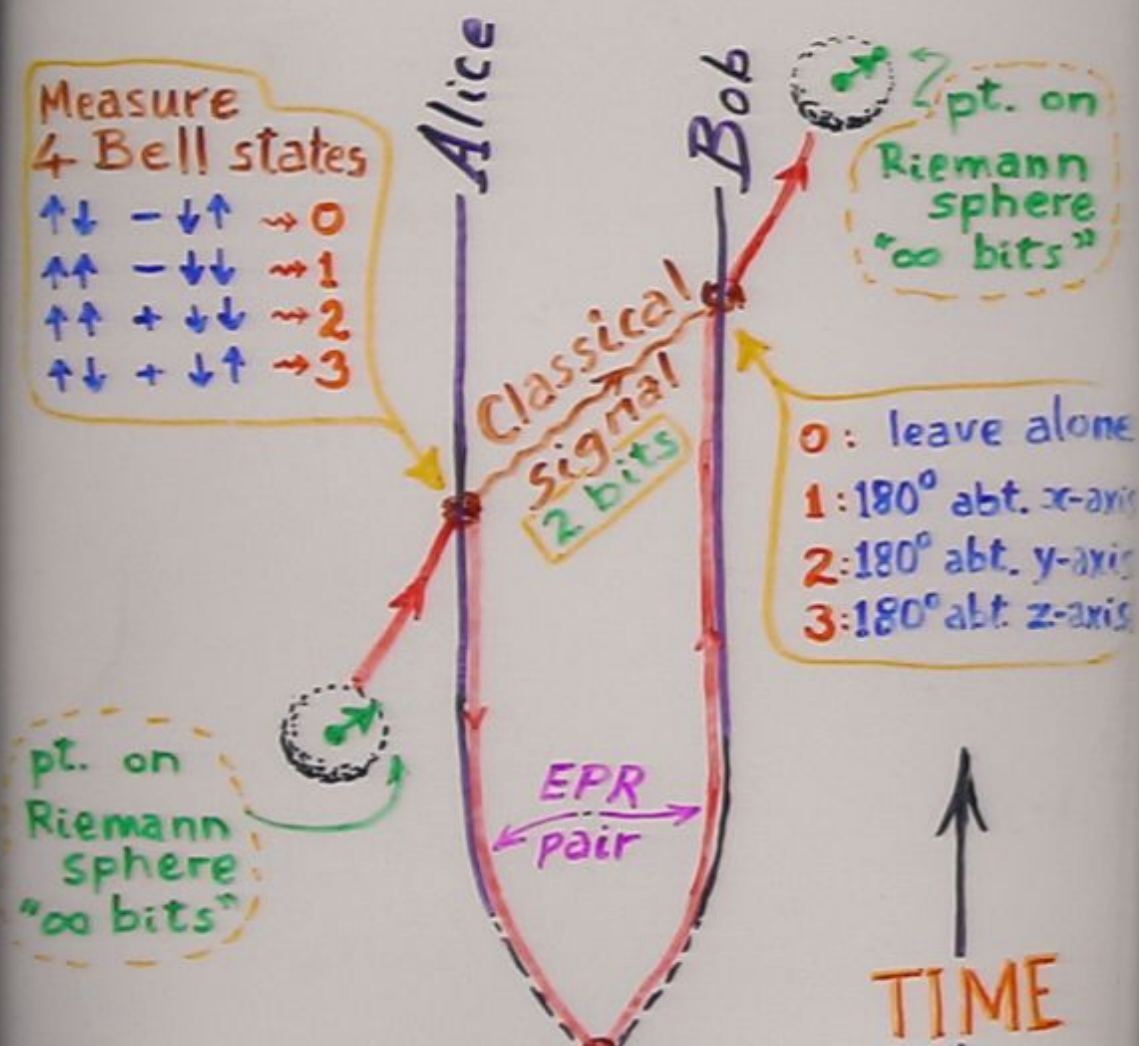
Quantum "teleportation"



Quanglement

(= "quantum information")

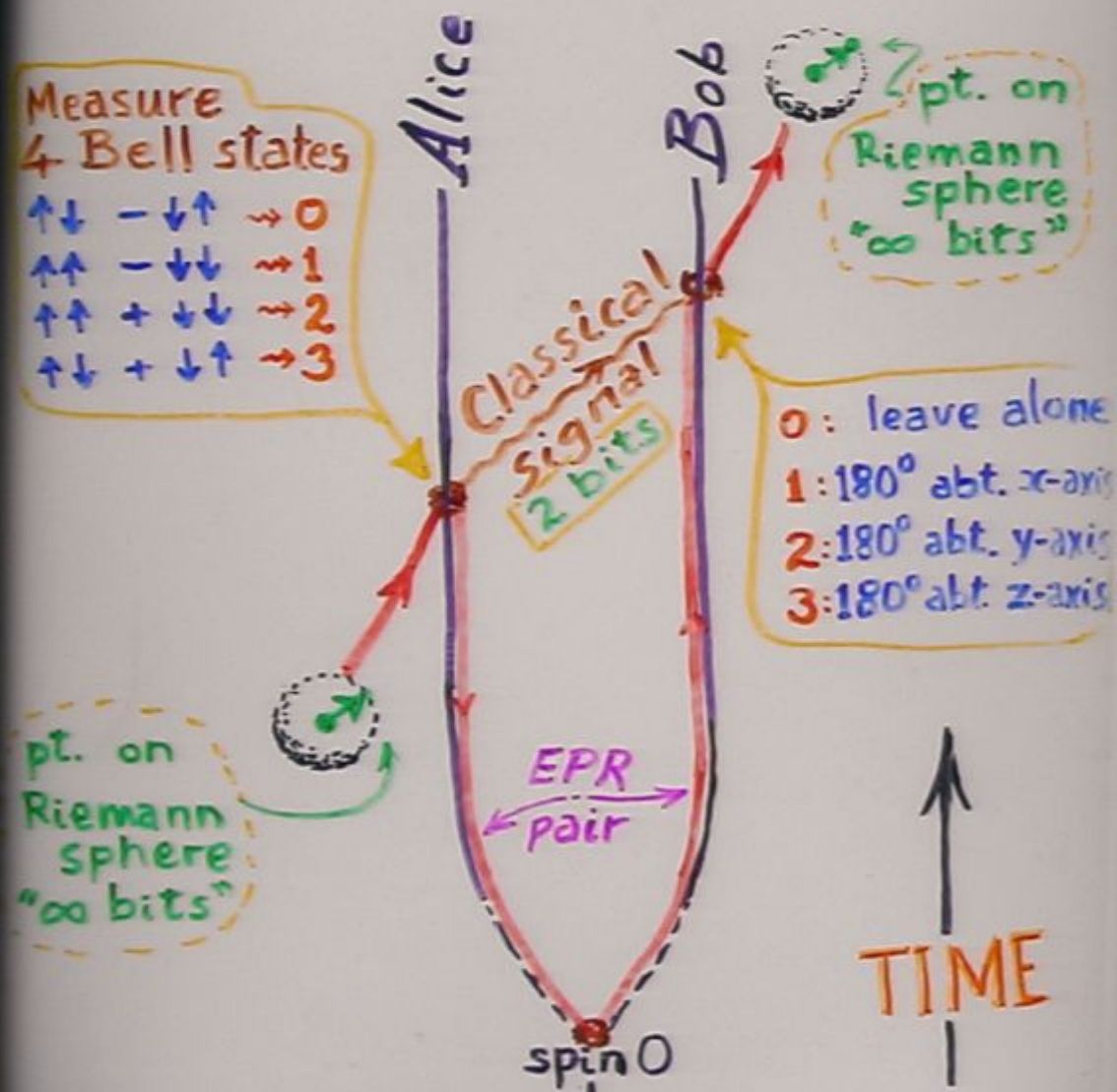
Quantum "teleportation"



Quanglement

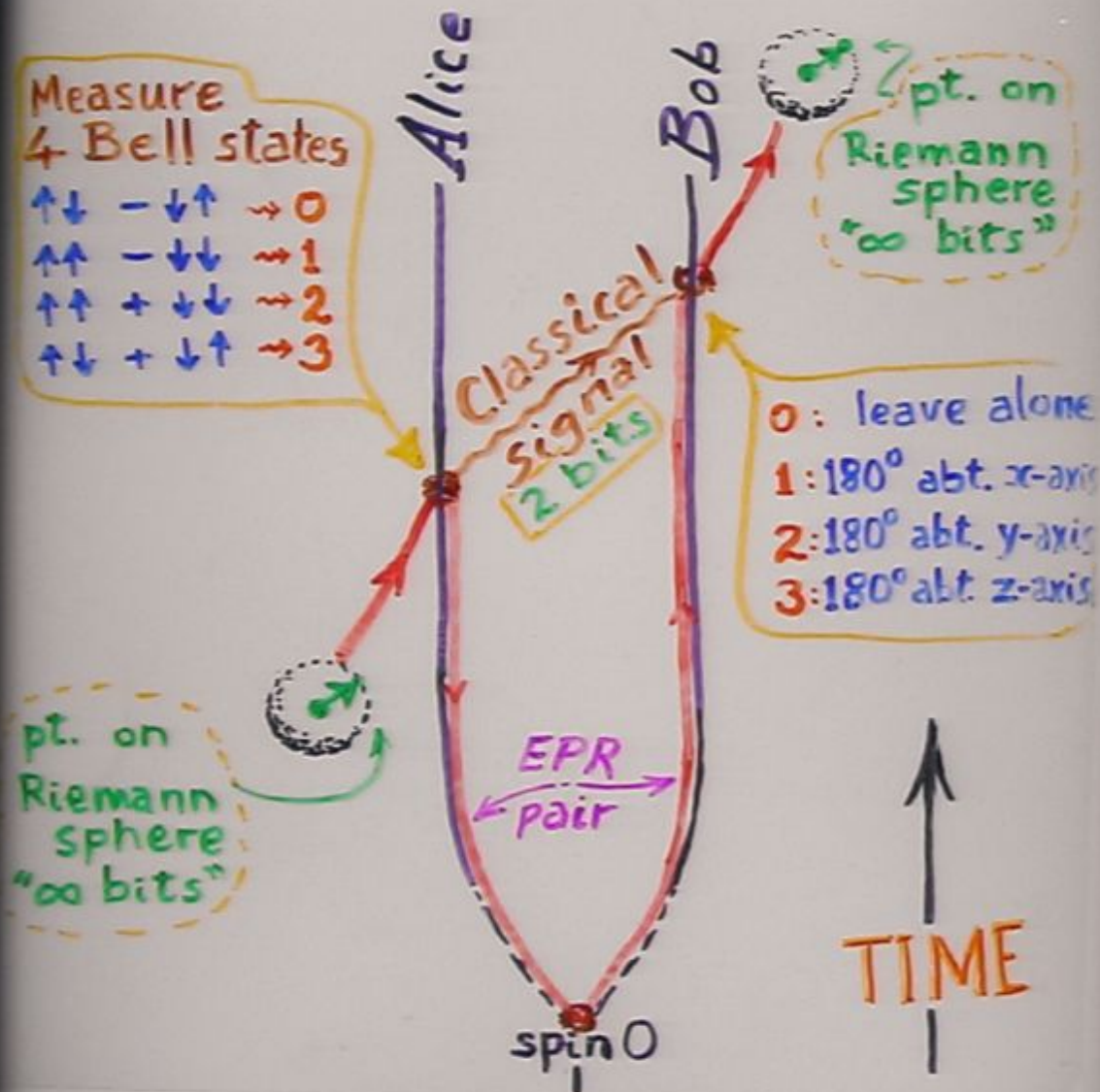
(= "quantum information")

Quantum "teleportation"

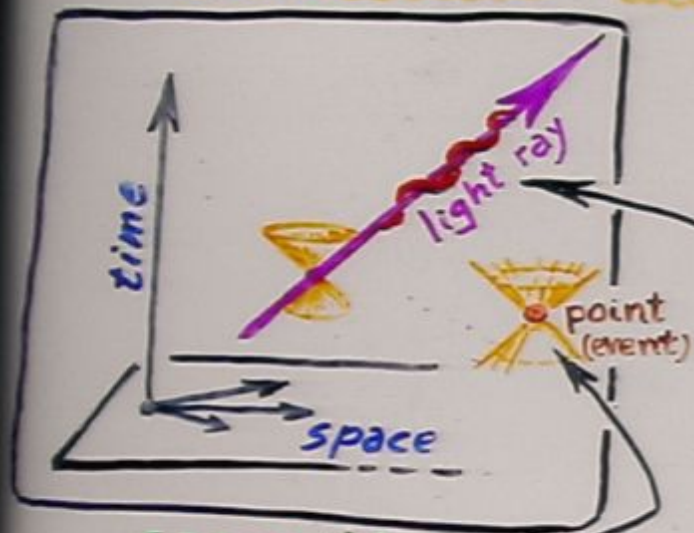


(= "quantum information")

Quantum "teleportation"



Twistor Theory



space-time

complex
non-local
math. sophisticated



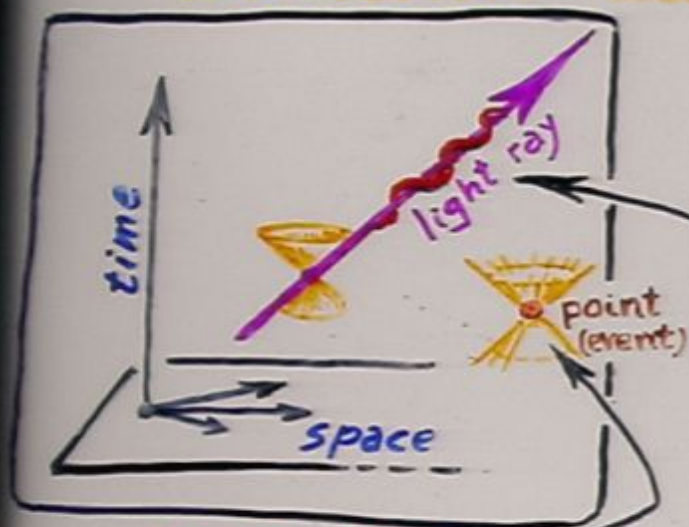
Lorentz group



twistor space
complex space



Twistor Theory



space-time

complex
non-local
math. sophisticated



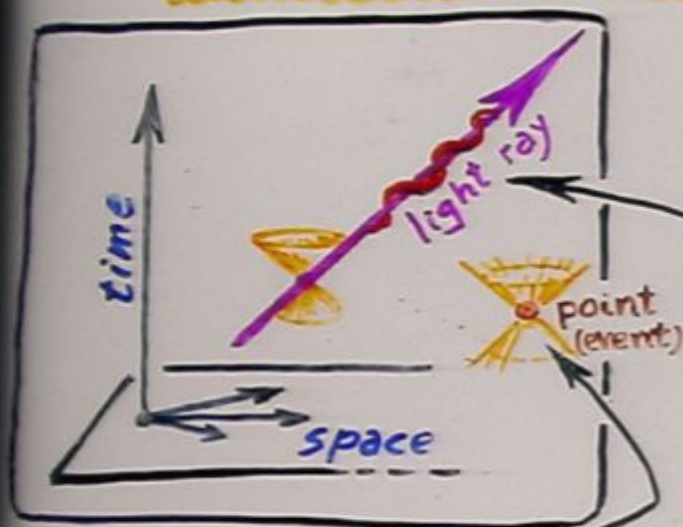
Lorentz group



twistor space
complex space



Twistor Theory



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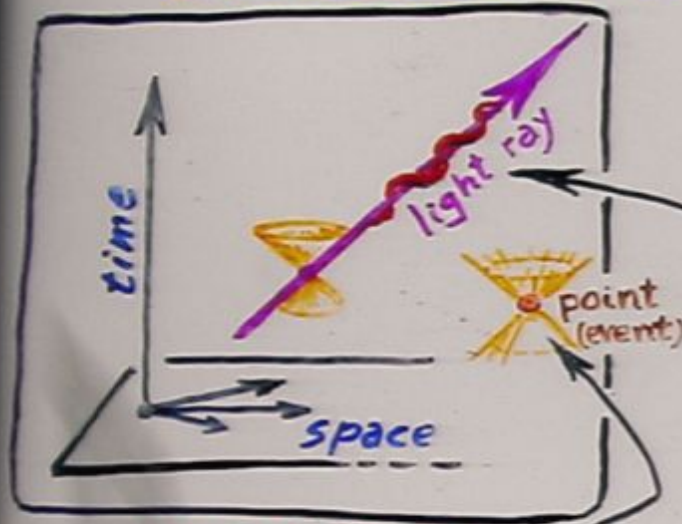
Lorentz group



twistor space
complex space



Twistor Theory



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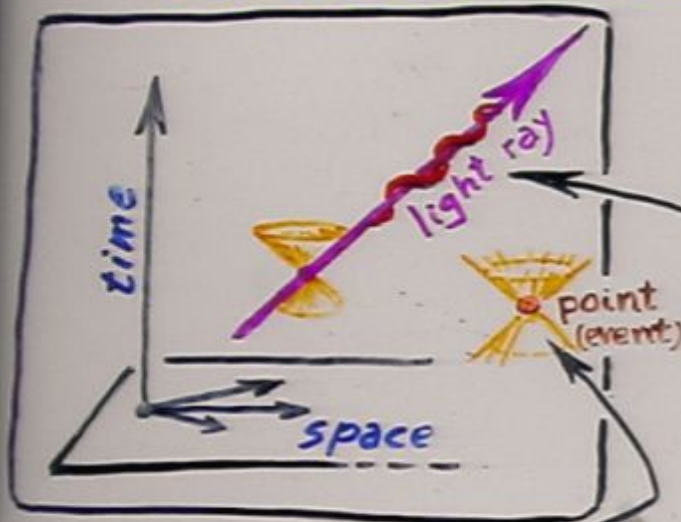
Lorentz group



twistor space
complex space



Twistor Theory



space-time

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non-local
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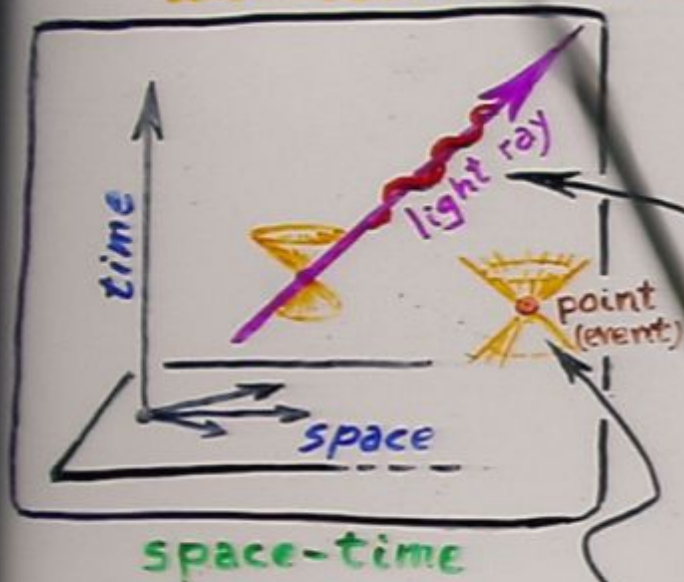
Lorentz group
celestial mechanics



twistor space
complex space



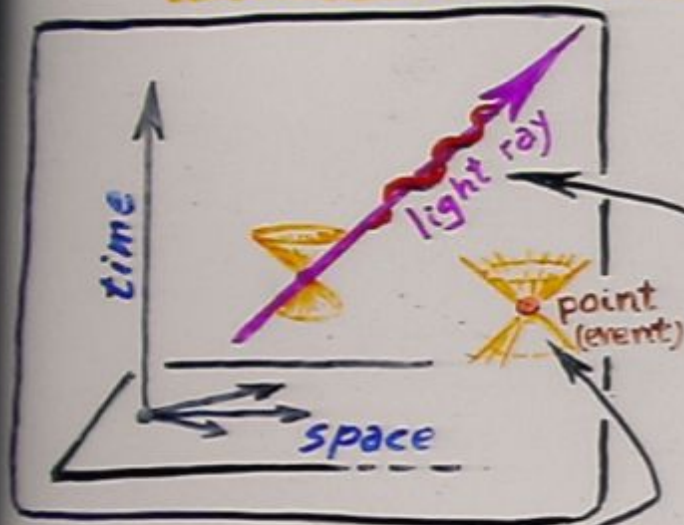
Twistor Theory



complex
non-local
math. sophisticated



Twistor Theory



space-time

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non-local
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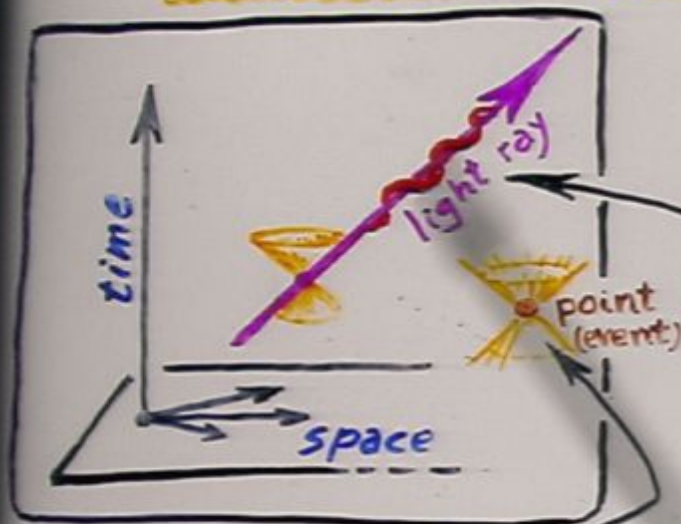
Lorentz group



twistor space
complex space



Twistor Theory



space-time

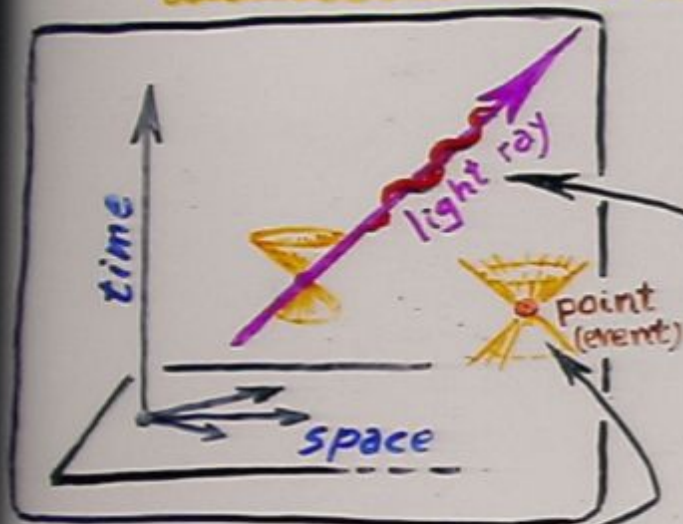
Complex
non-local
math. sophisticated



twistor space
complex space



Twistor Theory



space-time

complex
non-local
math. sophisticated



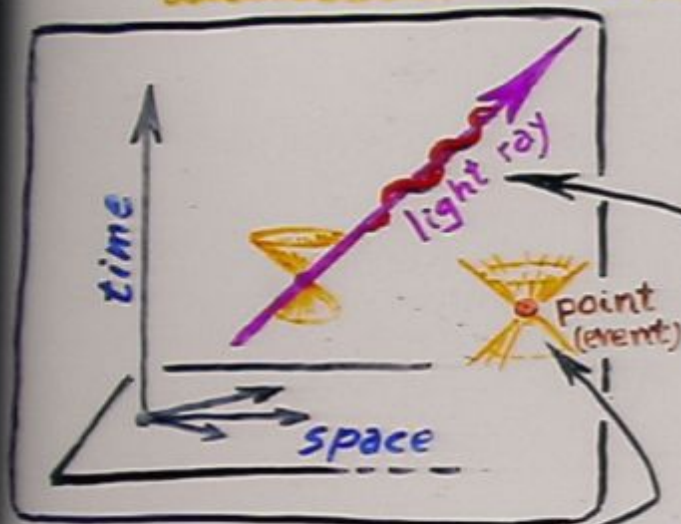
Lorentz group



twistor space
complex space



Twistor Theory



space-time

complex
non-local
math. sophisticated



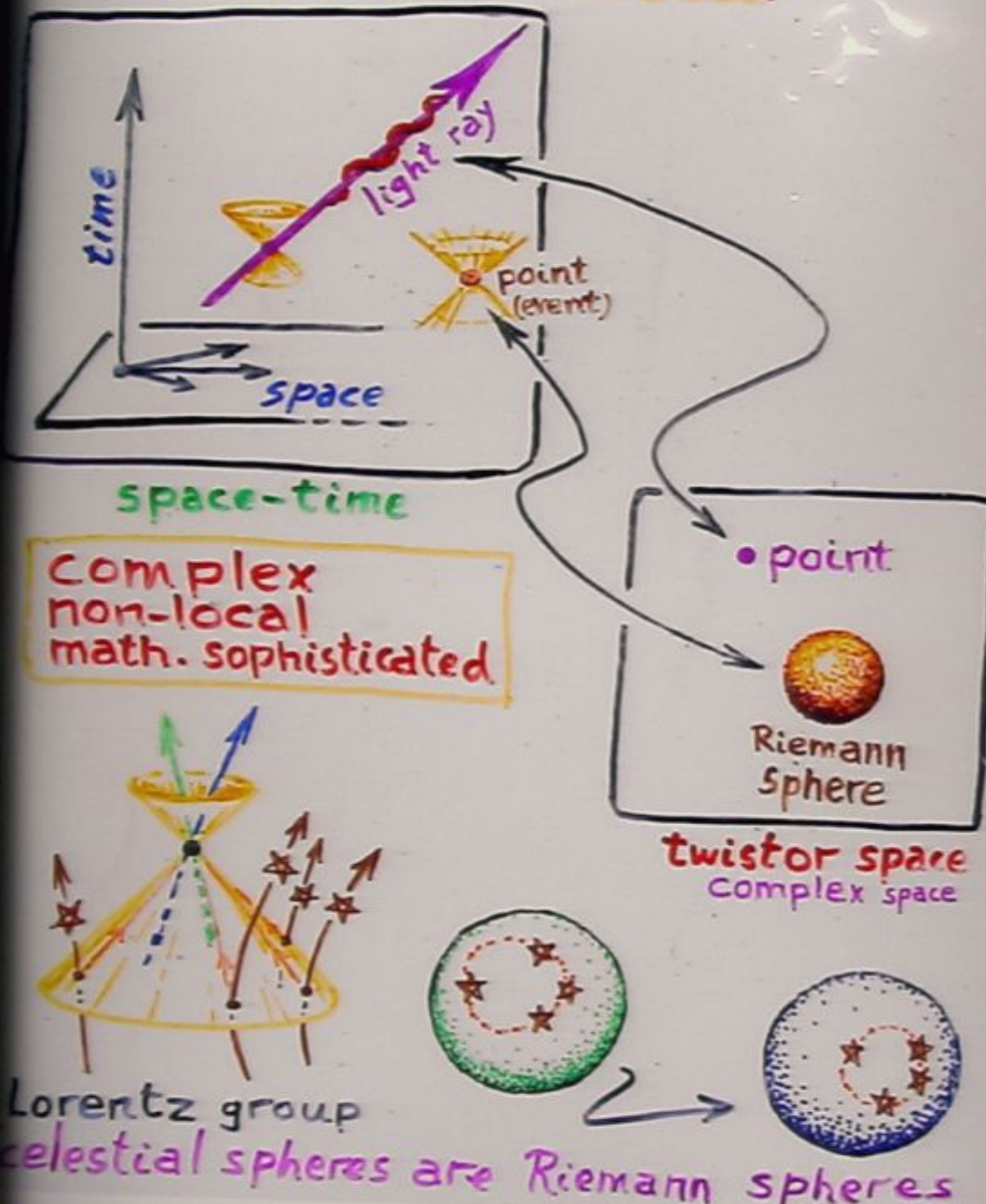
Lorentz group



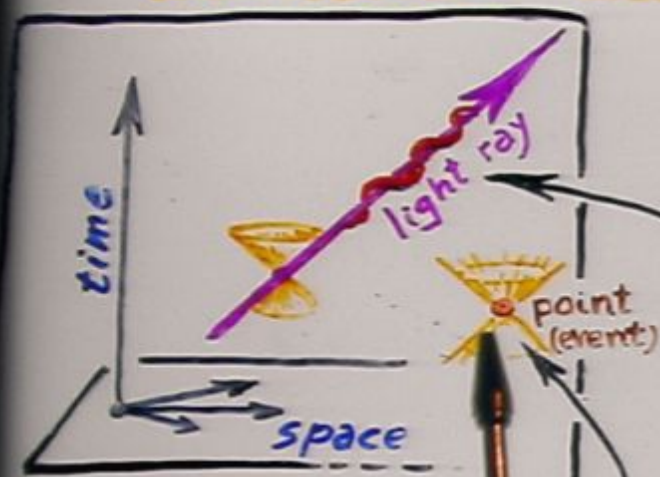
twistor space
complex space



Twistor Theory



Twistor Theory



space-time

complex
non-local
math. sophisticated



Lorentz group

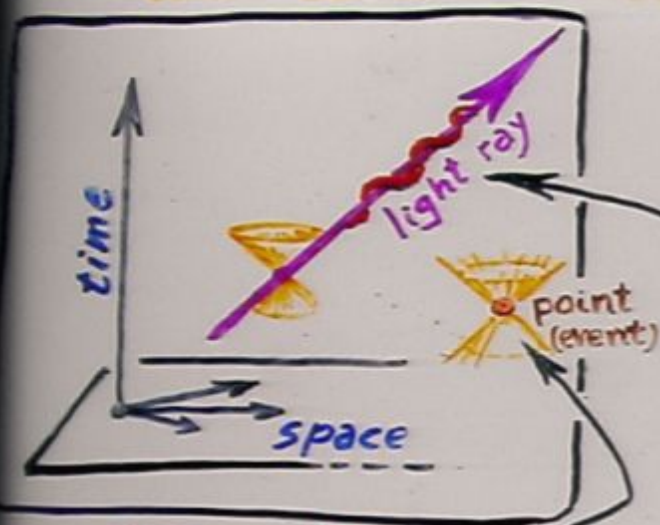


twistor space
complex space



celestial spheres are Riemann spheres

Twistor Theory



space-time

Complex
non-local
math. sophisticated



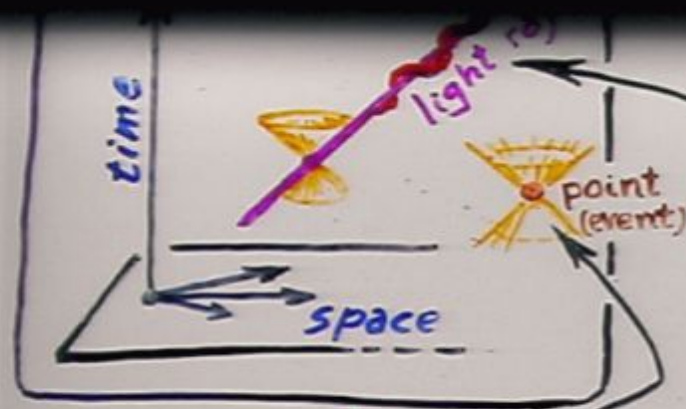
Lorentz group

celestial spheres are Riemann spheres



twistor space
complex space





space-time

complex
non-local
math. sophisticated



Lorentz group

celestial spheres are Riemann spheres

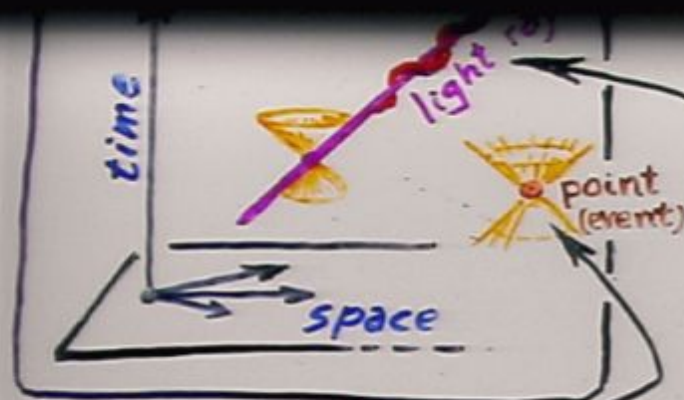
point



Riemann
sphere

twistor space
complex space





space-time

complex
non-local
math. sophisticated



Lorentz group

celestial spheres are Riemann spheres

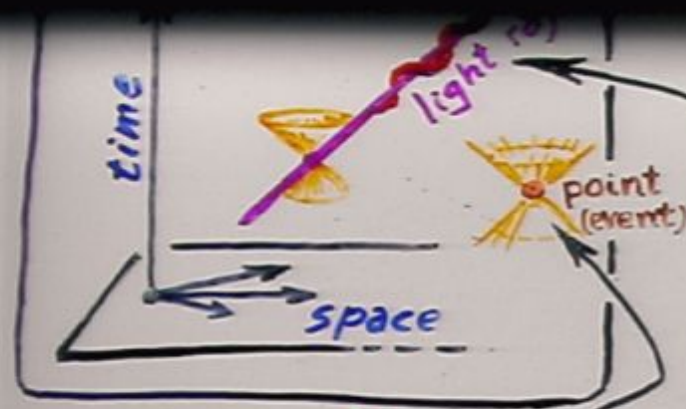
point



Riemann
sphere

twistor space
complex space





space-time

complex
non-local
math. sophisticated



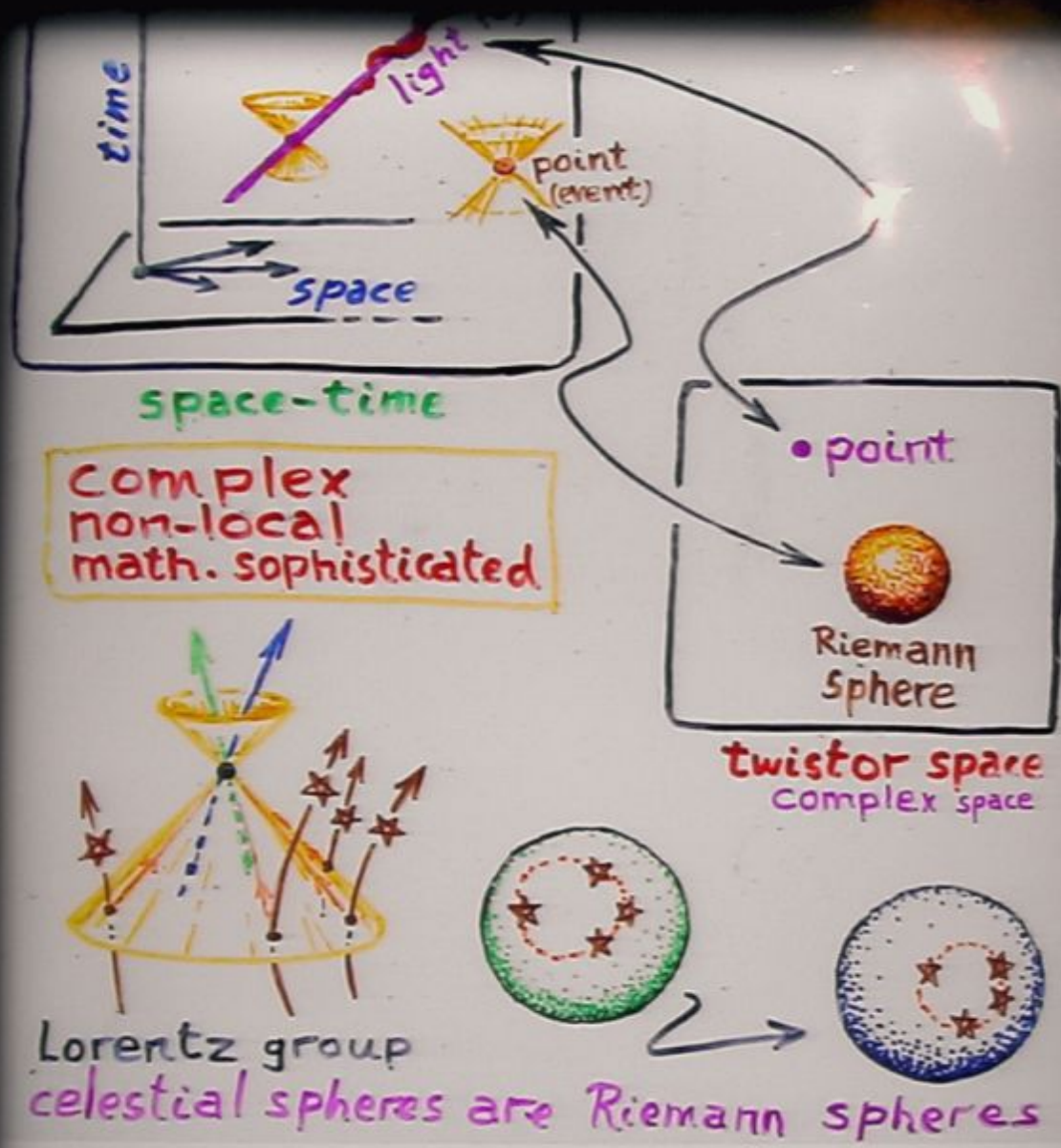
Lorentz group

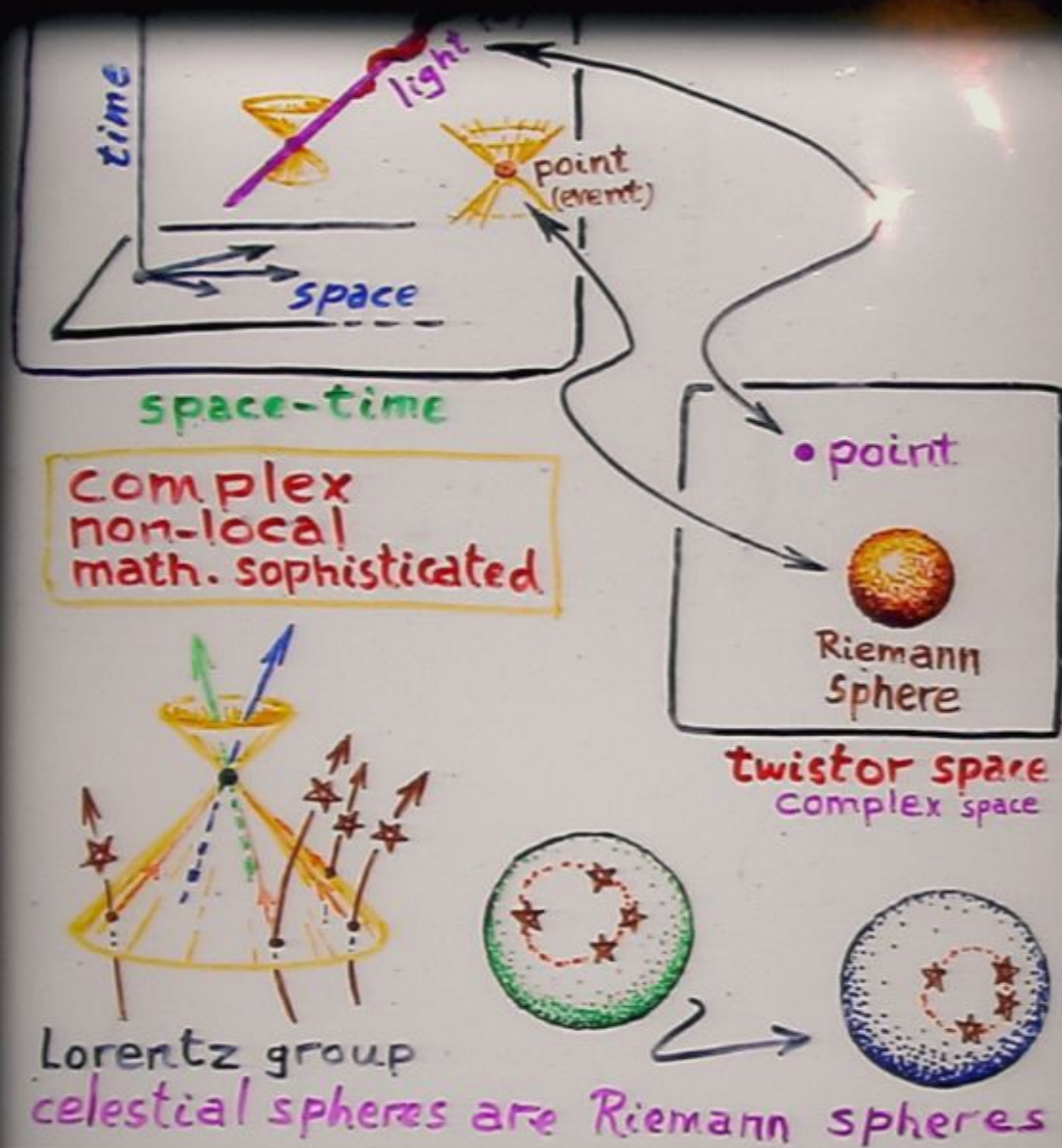
celestial spheres are Riemann spheres



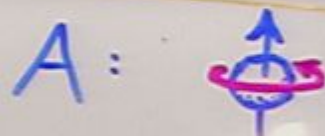
twistor space
complex space



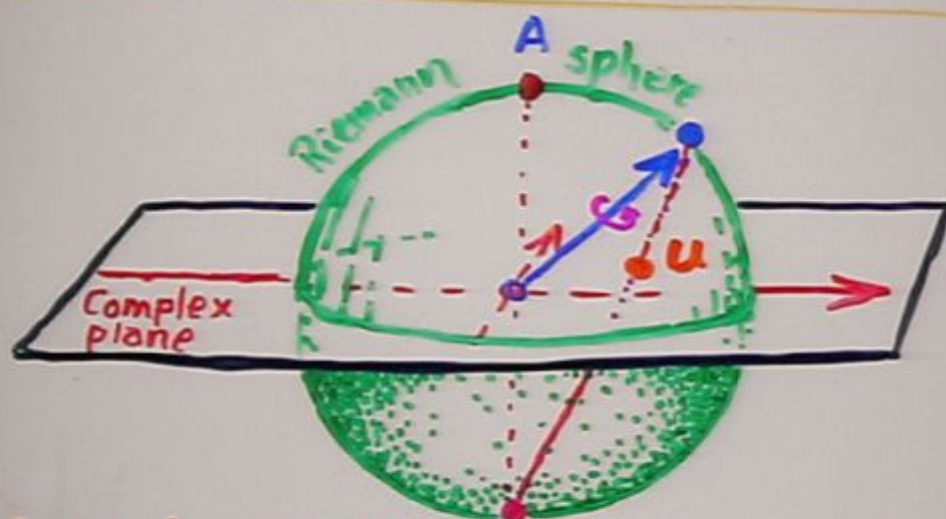




Basis states

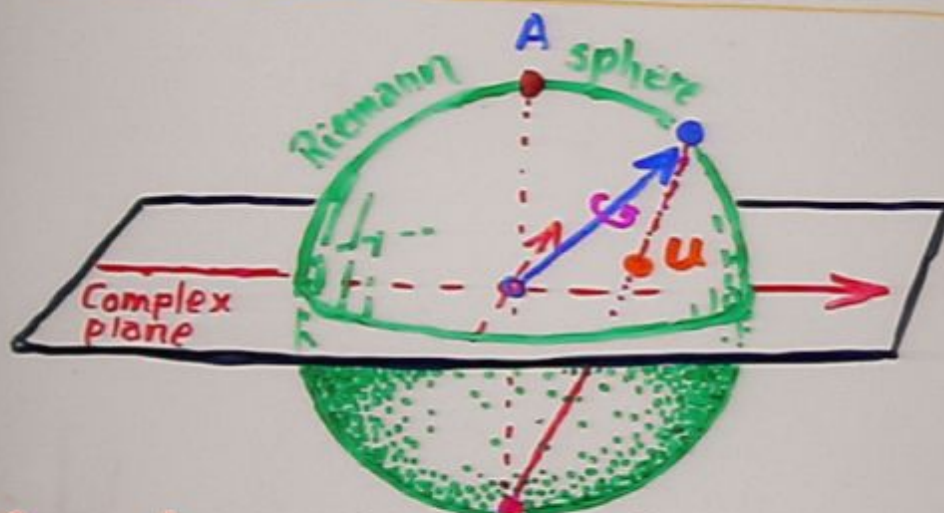
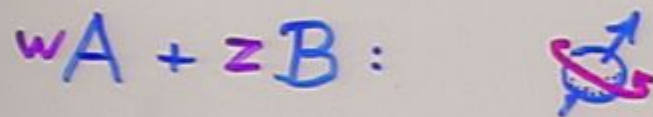
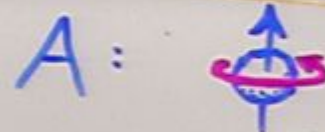


$wA + zB:$



Complex ratio: $z/w = u$

Basis states



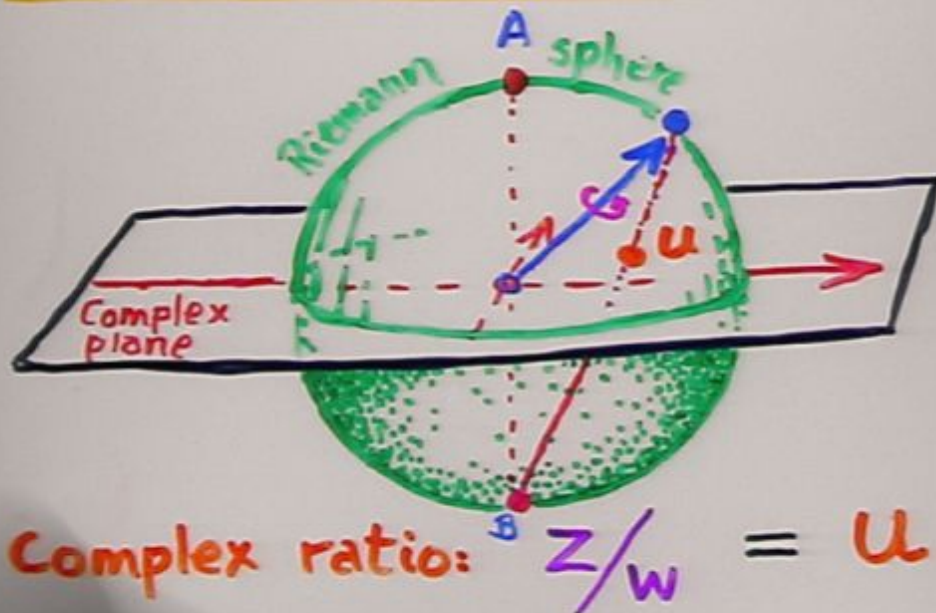
Complex ratio: $z/w = u$

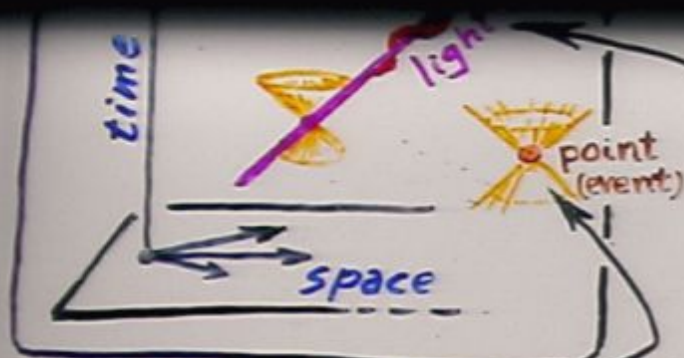
Quantum-mechanical spin [— for spin $\frac{1}{2}$ eg. electron, proton, neutron quark, ...]

Basis states A : 

B : 

$wA + zB$: 





space-time

complex
non-local
math. sophisticated

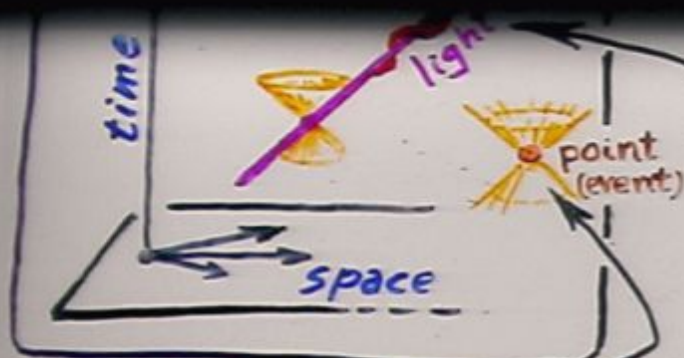


Lorentz group
celestial spheres are Riemann spheres



twistor space
complex space





space-time

complex
non-local
math. sophisticated



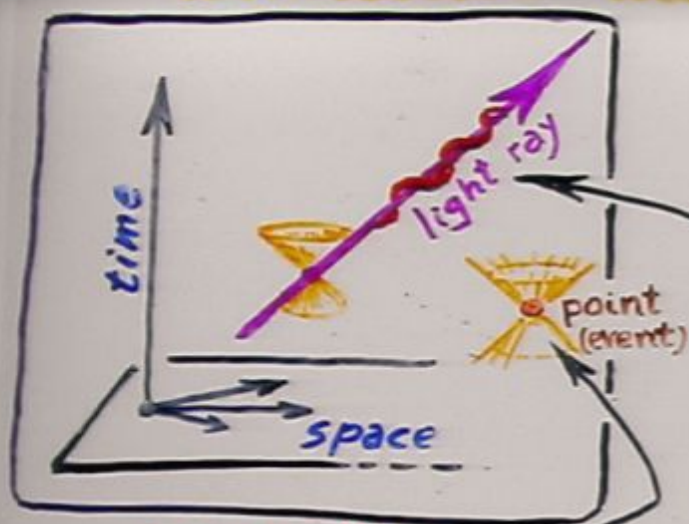
Lorentz group
celestial spheres are Riemann spheres



twistor space
complex space



TWISTOR THEORY



space-time

complex
non-local
math. sophisticated



Lorentz group

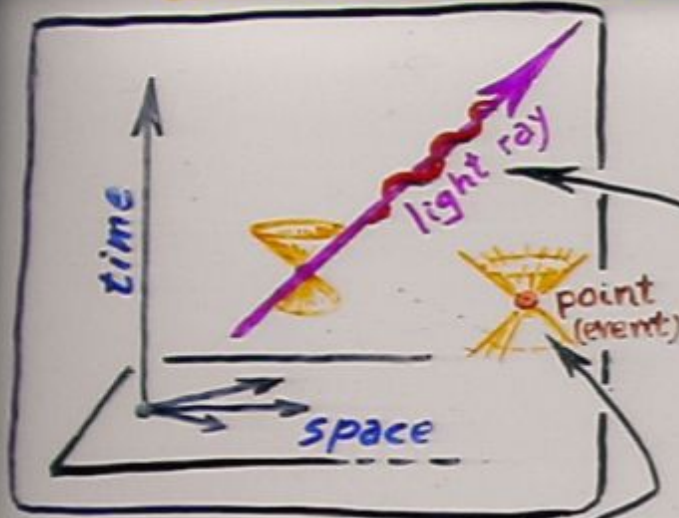
celestial spheres are Riemann spheres



twistor space
complex space



twistor theory



space-time

complex
non-local
math. sophisticated

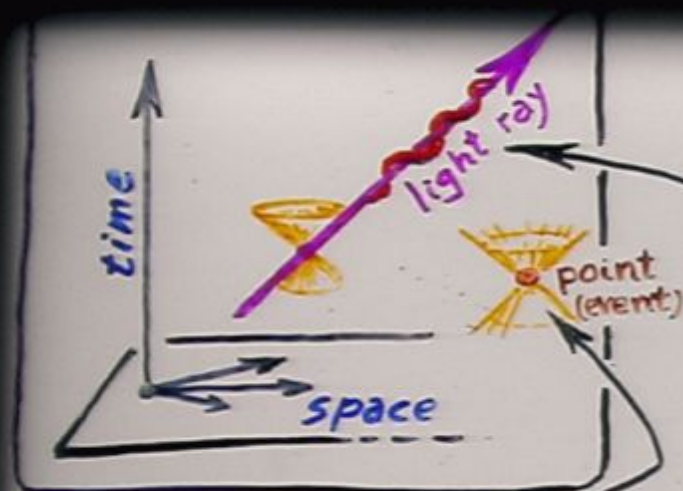


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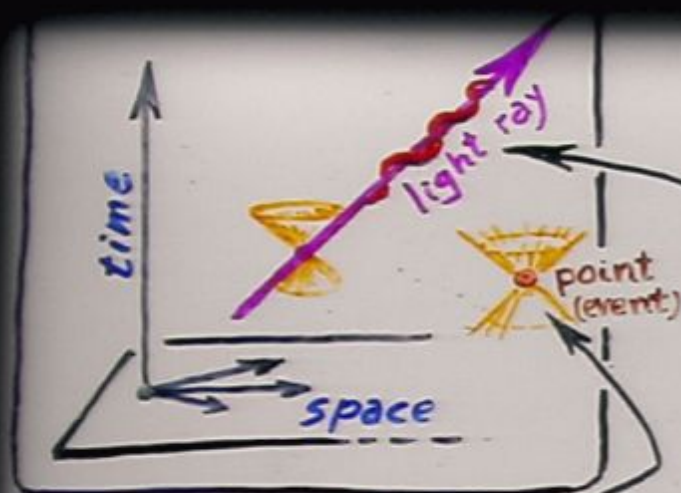
Lorentz group

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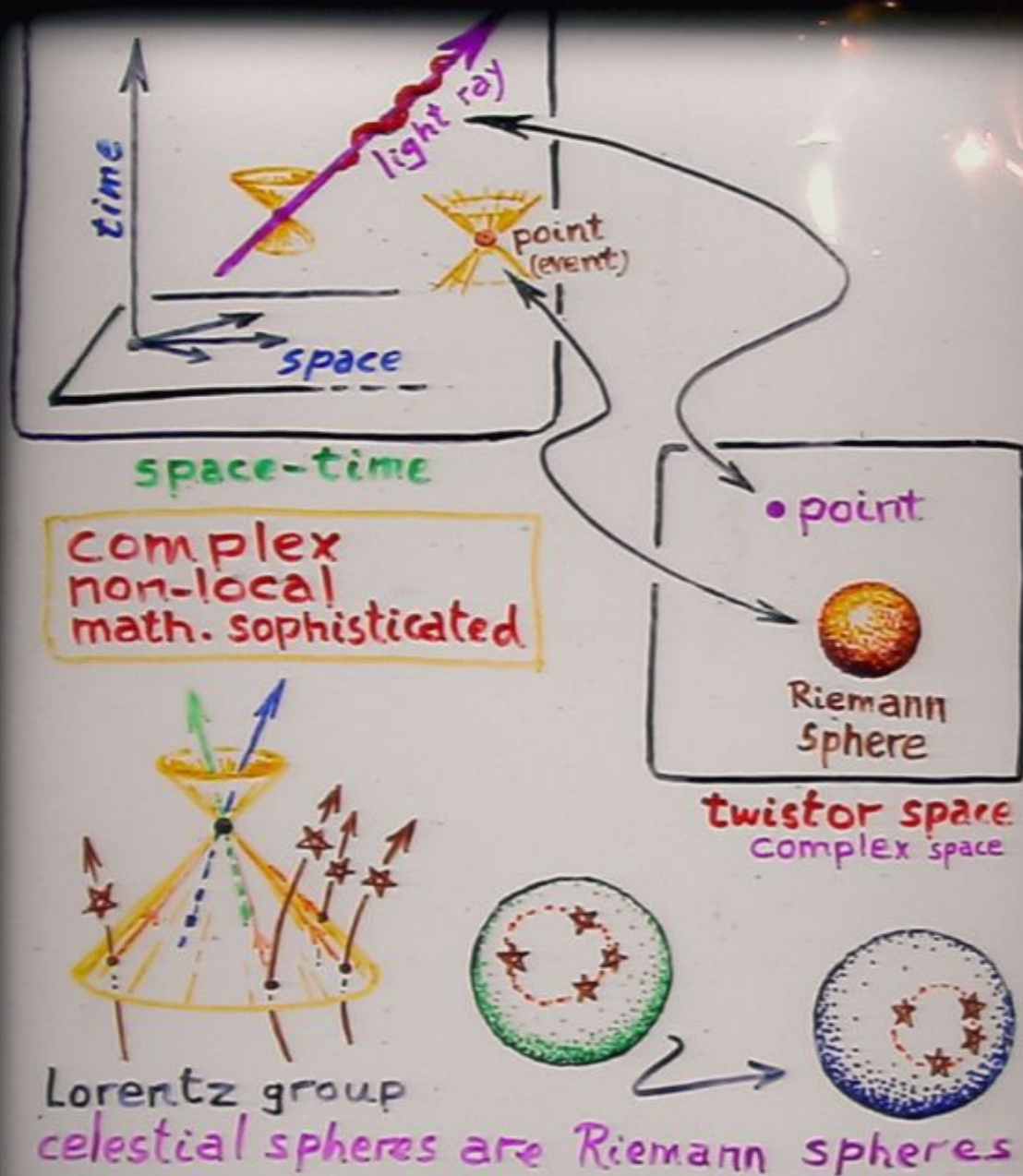


Lorentz group
celestial spheres are Riemann spheres

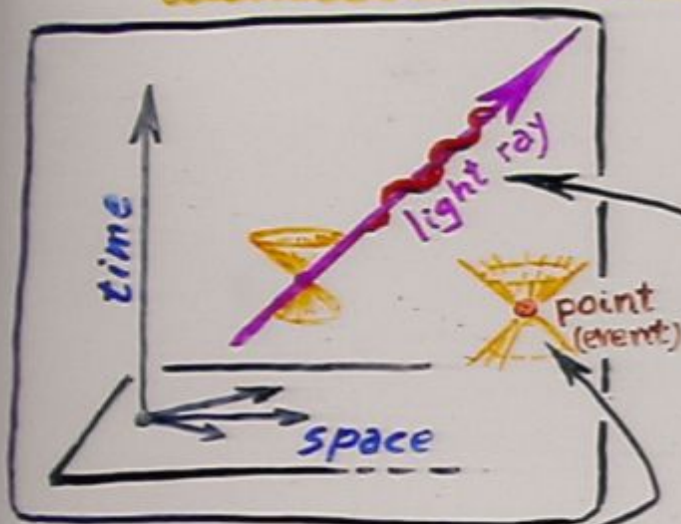


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Twistor Theory



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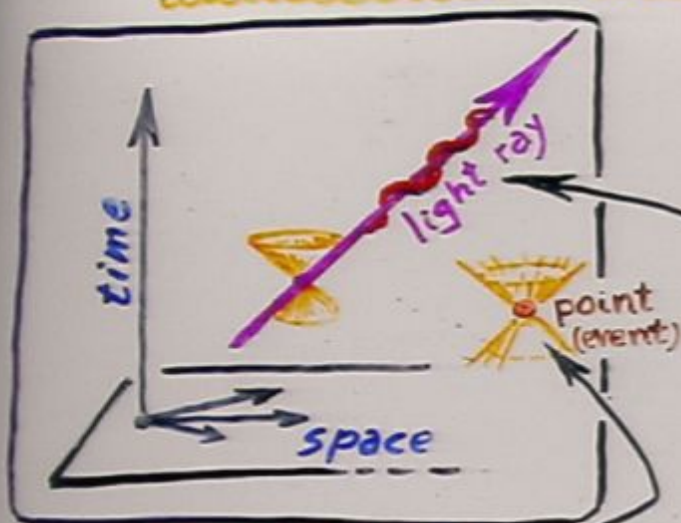
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Lorentz group

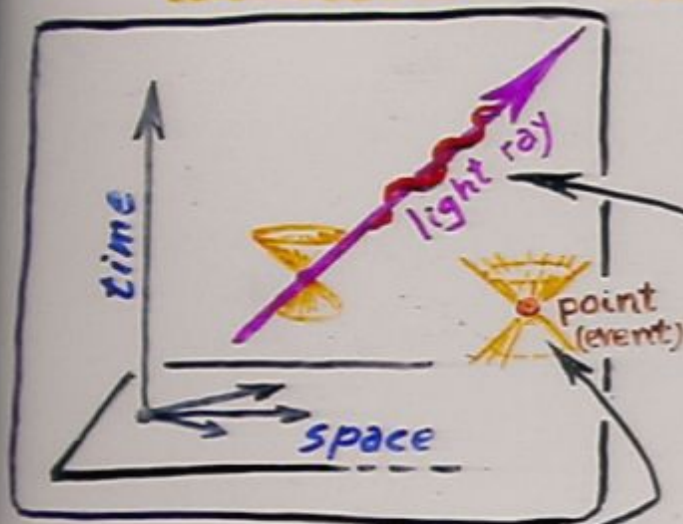
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Lorentz group

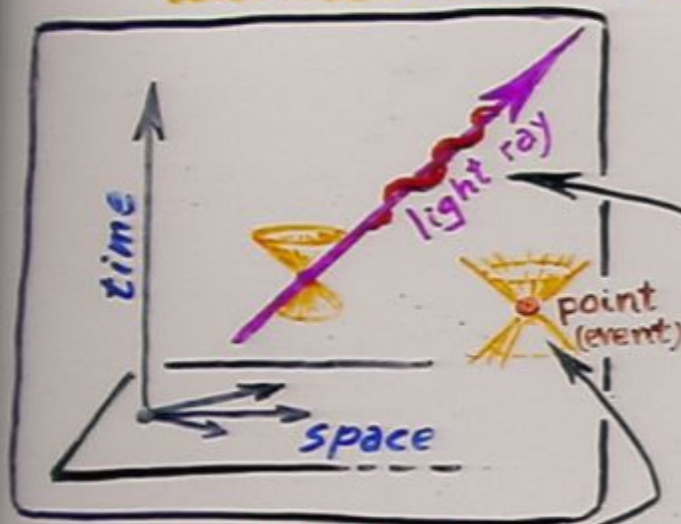
celestial sphere as P^1



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Lorentz group

celestial spheres are Riemann spheres



twistor space
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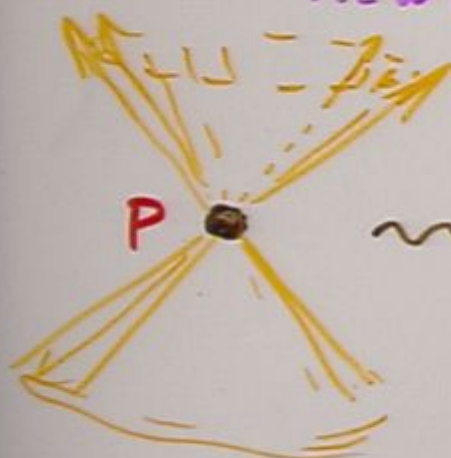


Quantum Geometry?

A commonly expressed view:
Quantized metric $\rightsquigarrow$ "fuzzy light cone"



Twistor view:



"fuzzy point"

Quantum Geometry?

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Twistor view:



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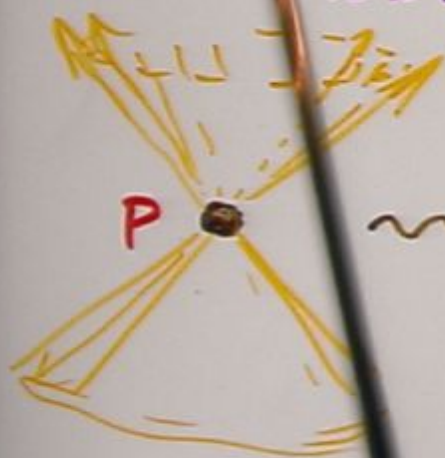
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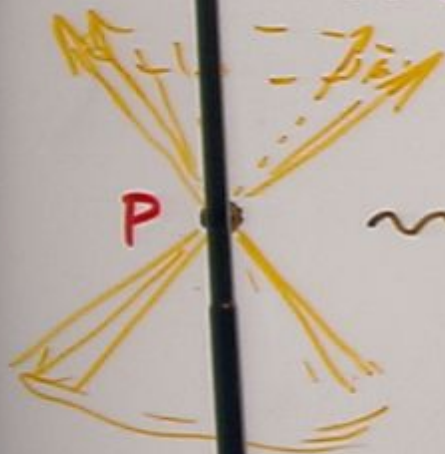
Quantum Geometry?

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Twistor view:



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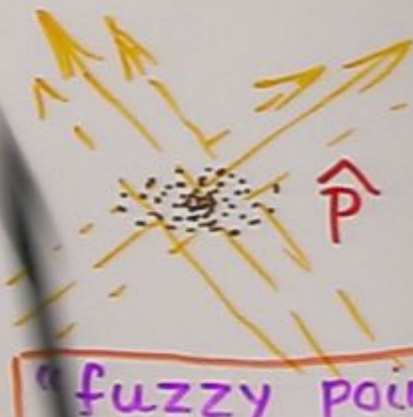
Quantum Geometry?

A commonly expressed view:

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Twistor view:



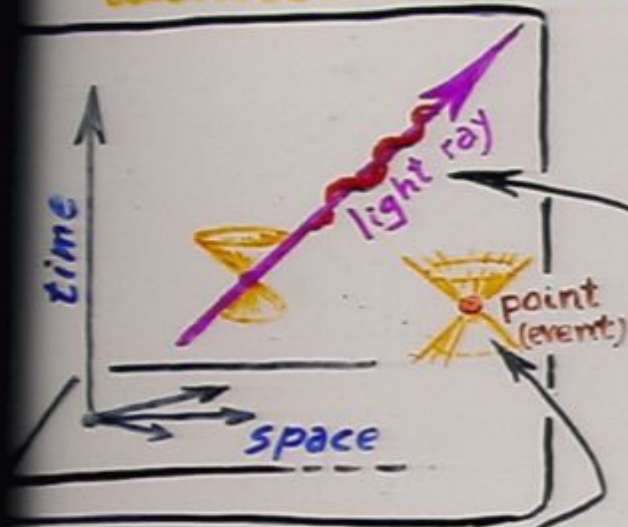
A commonly expressed view:
Quantized metric $\rightsquigarrow$ "fuzzy light cone"



Twistor view:



Twistor Theory



space-time

complex
non-local
math. sophisticated



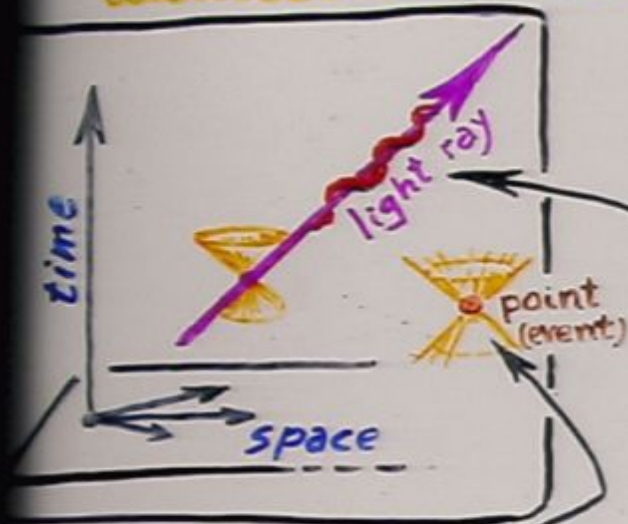
Lorentz group



twistor space
complex space



Twistor Theory



space-time

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non-local
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Lorentz group



twistor space
complex space



A commonly expressed view:

Quantized metric $\rightsquigarrow$ "fuzzy light cone"



Twistor view:



"fuzzy point"

A commonly expressed view:
Quantized metric $\rightsquigarrow$ "fuzzy
light cone"

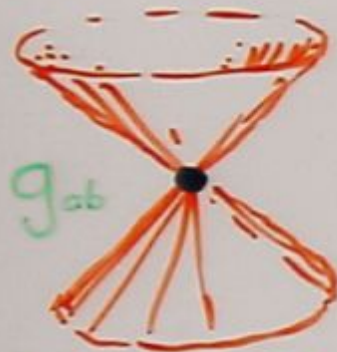


Twistor view:



"fuzzy point"

A commonly expressed view:
Quantized metric $\rightsquigarrow$ "fuzzy light cone"
 g_{ab}



Twistor view:



"fuzzy point"

A commonly expressed view:

Quantized metric $\rightsquigarrow$ "fuzzy light cone"

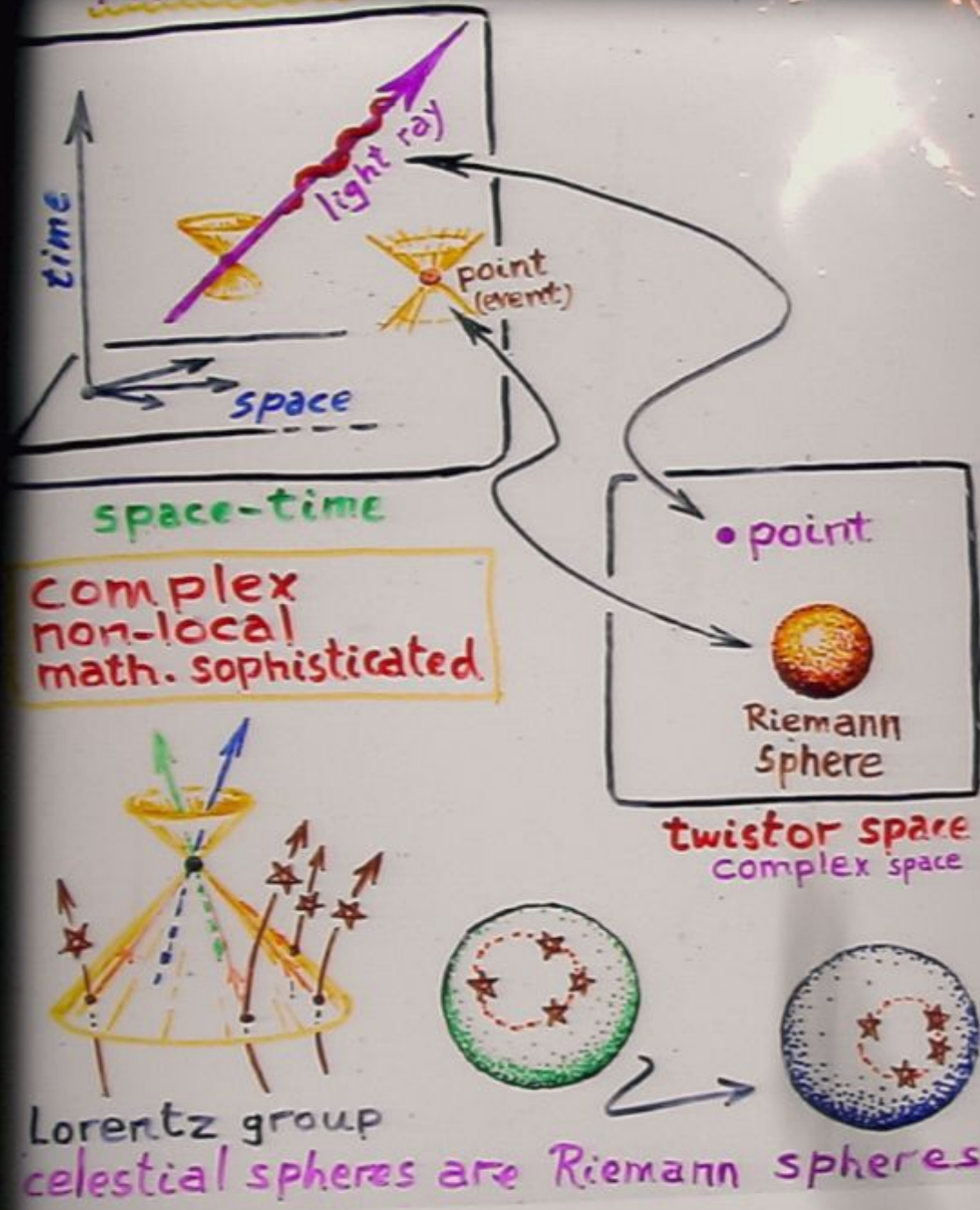


Twistor view:



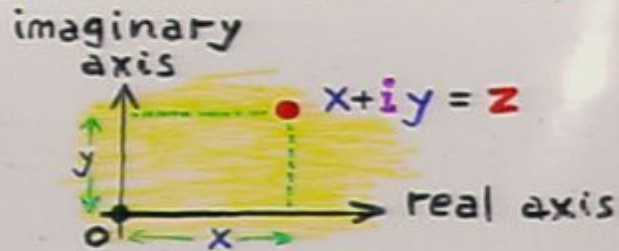
"fuzzy point"

twistor



Complex plane

$$i = \sqrt{-1}$$

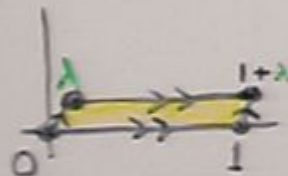
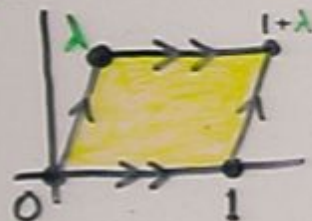


Piece together

Riemann surface



Moduli



Complex plane

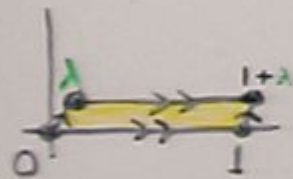


Piece together

Riemann surface



Moduli



Complex plane

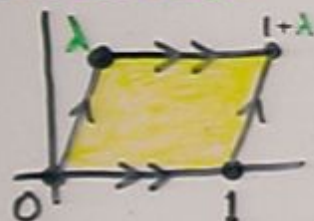


Piece together

Riemann surface

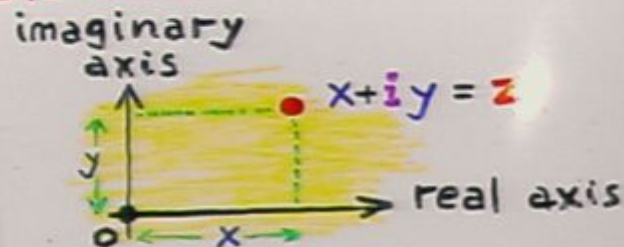


Moduli



Complex plane

$$i = \sqrt{-1}$$



Piece together

• point



Riemann sphere

Riemann surface



twistor space
complex space

Moduli



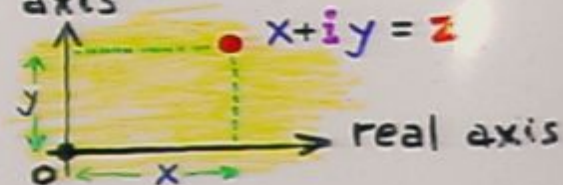
Riemann spheres



Complex plane

$$i = \sqrt{-1}$$

imaginary axis



Piece together

• point



Riemann sphere

Riemann surface



istor space
complex space

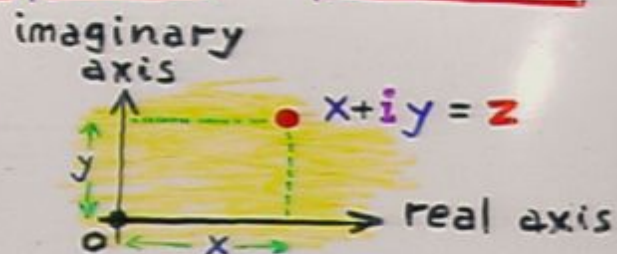
Moduli

spheres



Complex plane

$$i = \sqrt{-1}$$

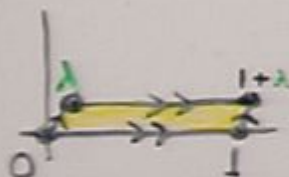
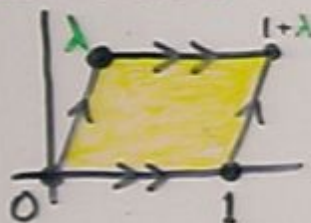


Piece together

Riemann surface

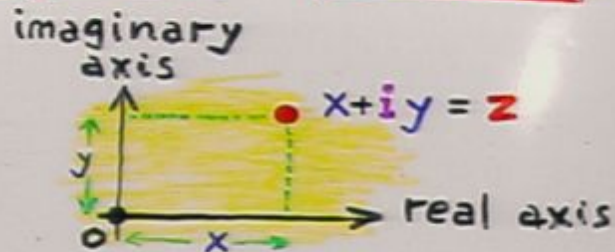


Moduli



Complex plane

$$i = \sqrt{-1}$$

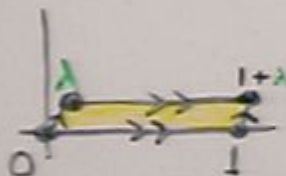


Piece together

Riemann surface

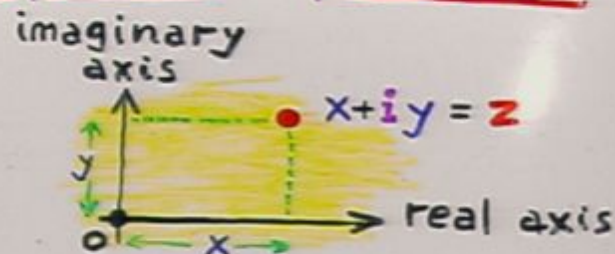


Moduli



Complex plane

$$i = \sqrt{-1}$$

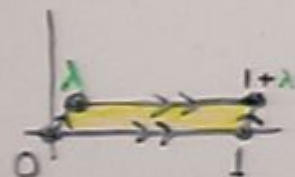
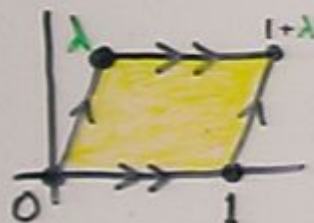


Piece together

Riemann
surface



Moduli



Complex plane

$$i = \sqrt{-1}$$



Piece together

Riemann surface

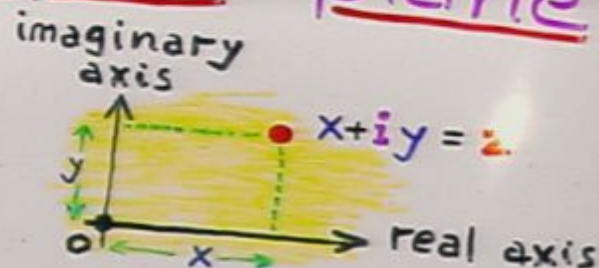


Moduli



Complex plane

$$i = \sqrt{-1}$$

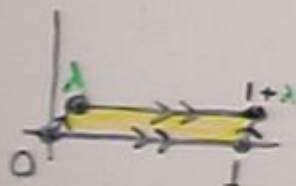
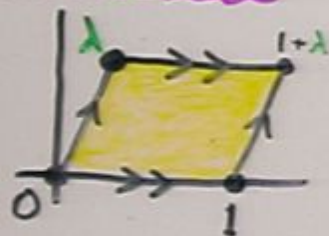


Piece together

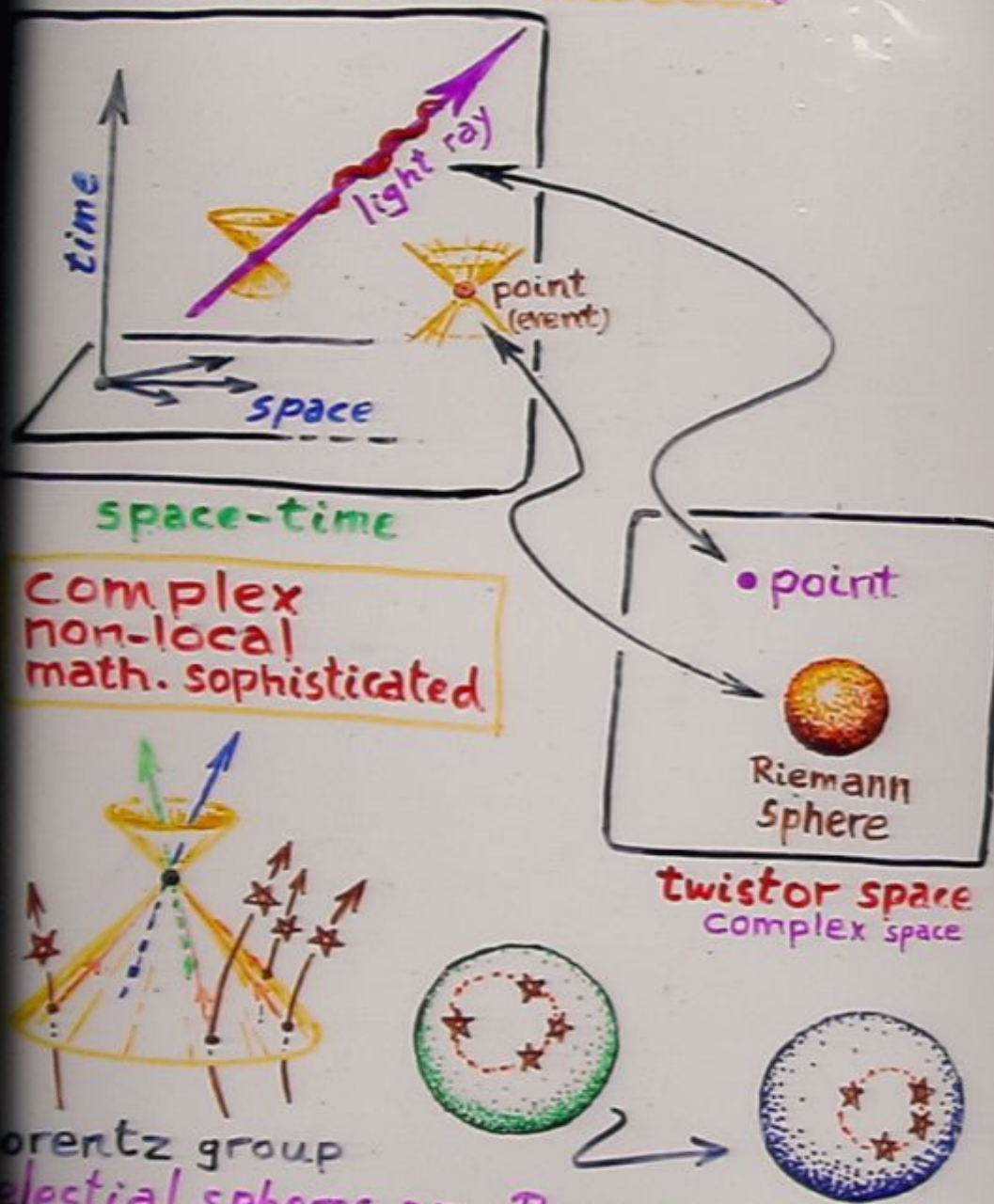
Riemann surface



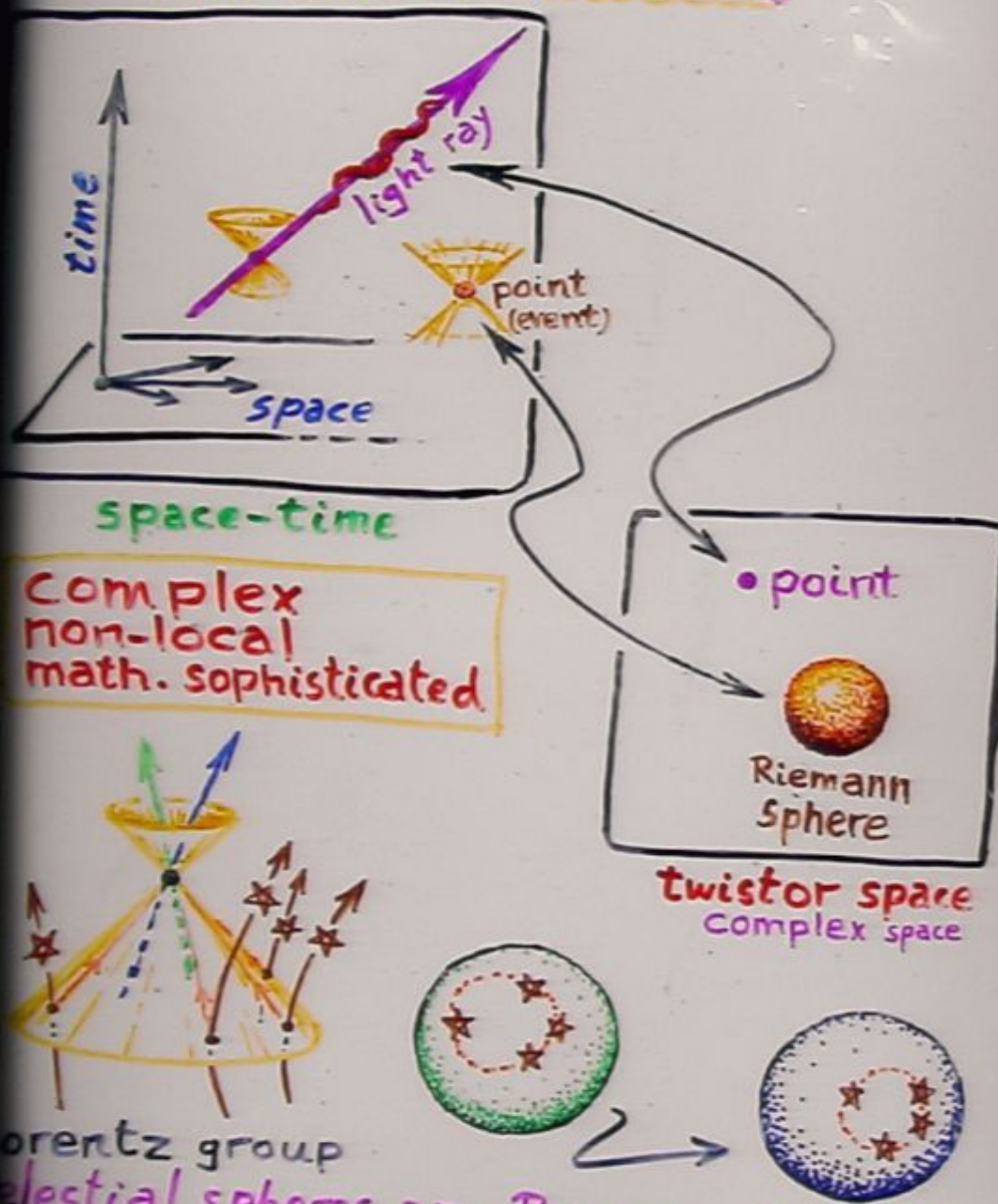
Moduli



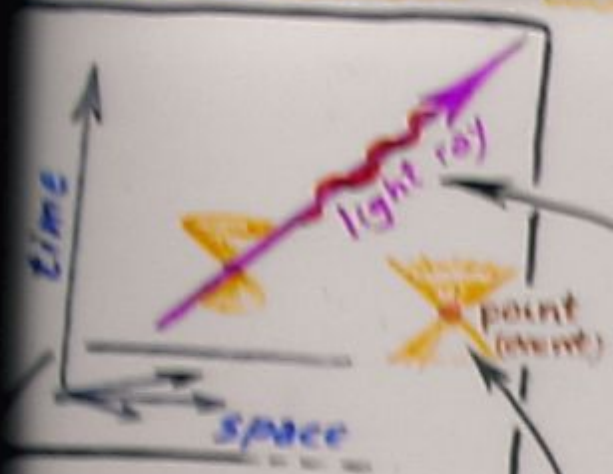
Twistor Theory



Twistor Theory



RELEVANT THEORY



space-time

complex
non-local
math. sophisticated



Complex plane

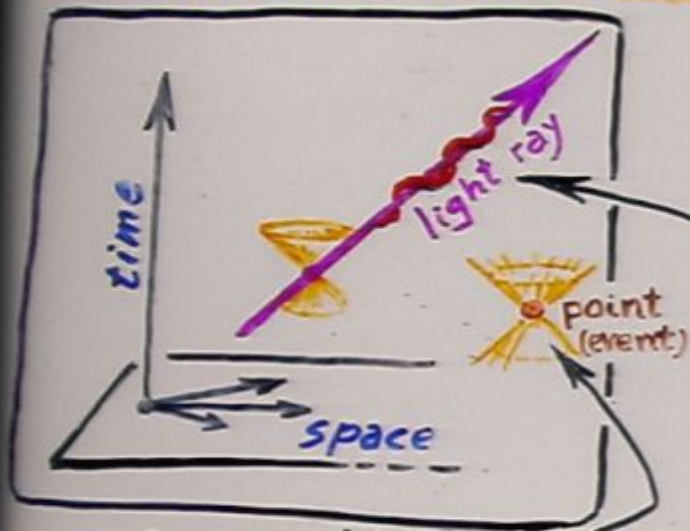


Piece together

are Riemann spheres

R.

Twistor Theory



space-time

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non-local
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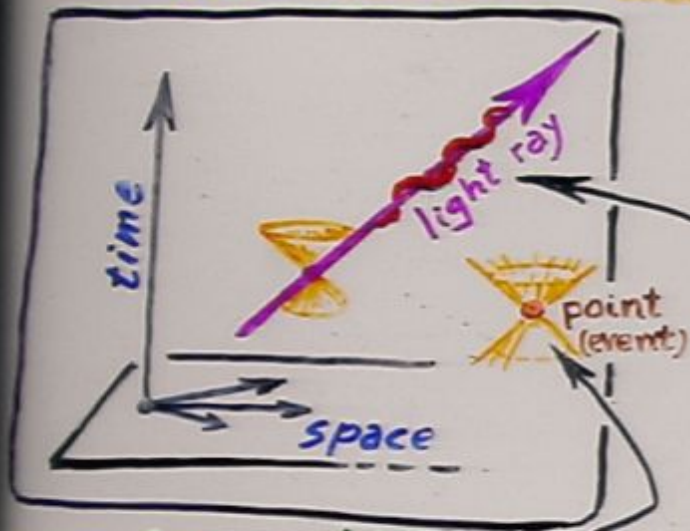
Lorentz group



twistor space
complex space



Twistor Theory



space-time

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non-local
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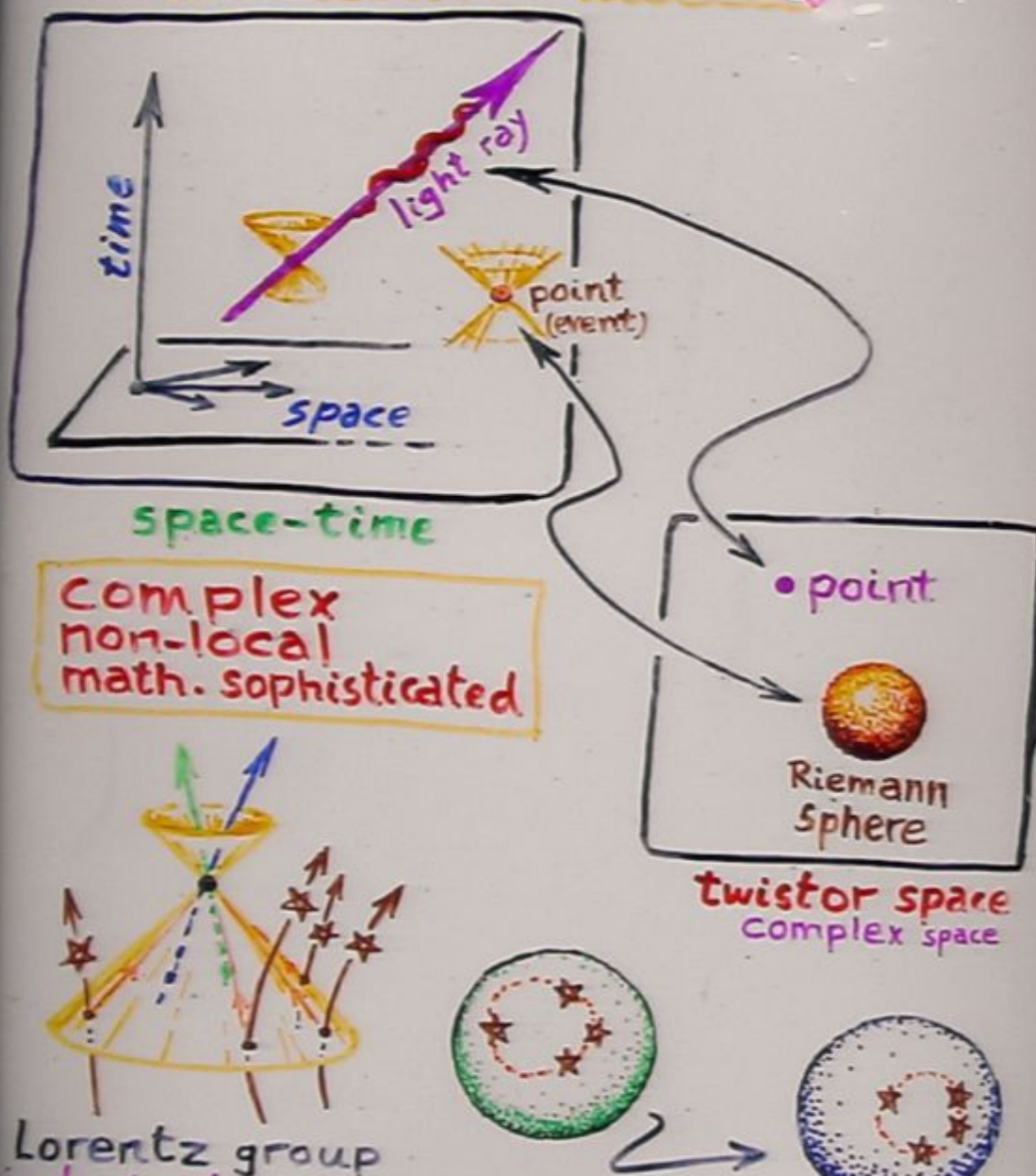
Lorentz group



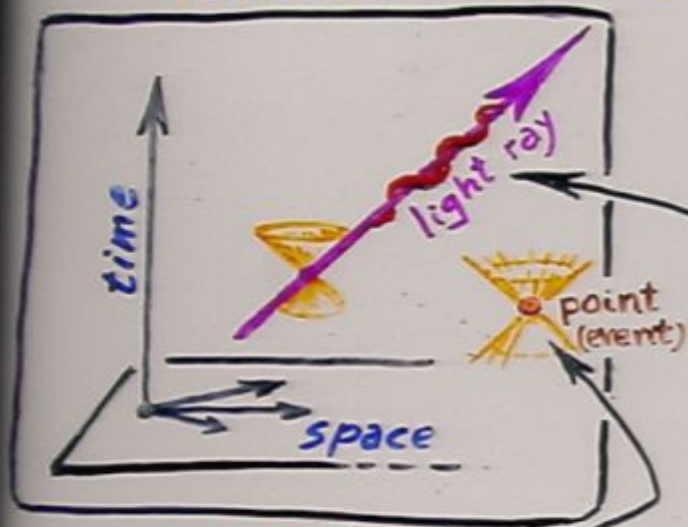
twistor space
complex space



Twistor Theory



Twistor Theory



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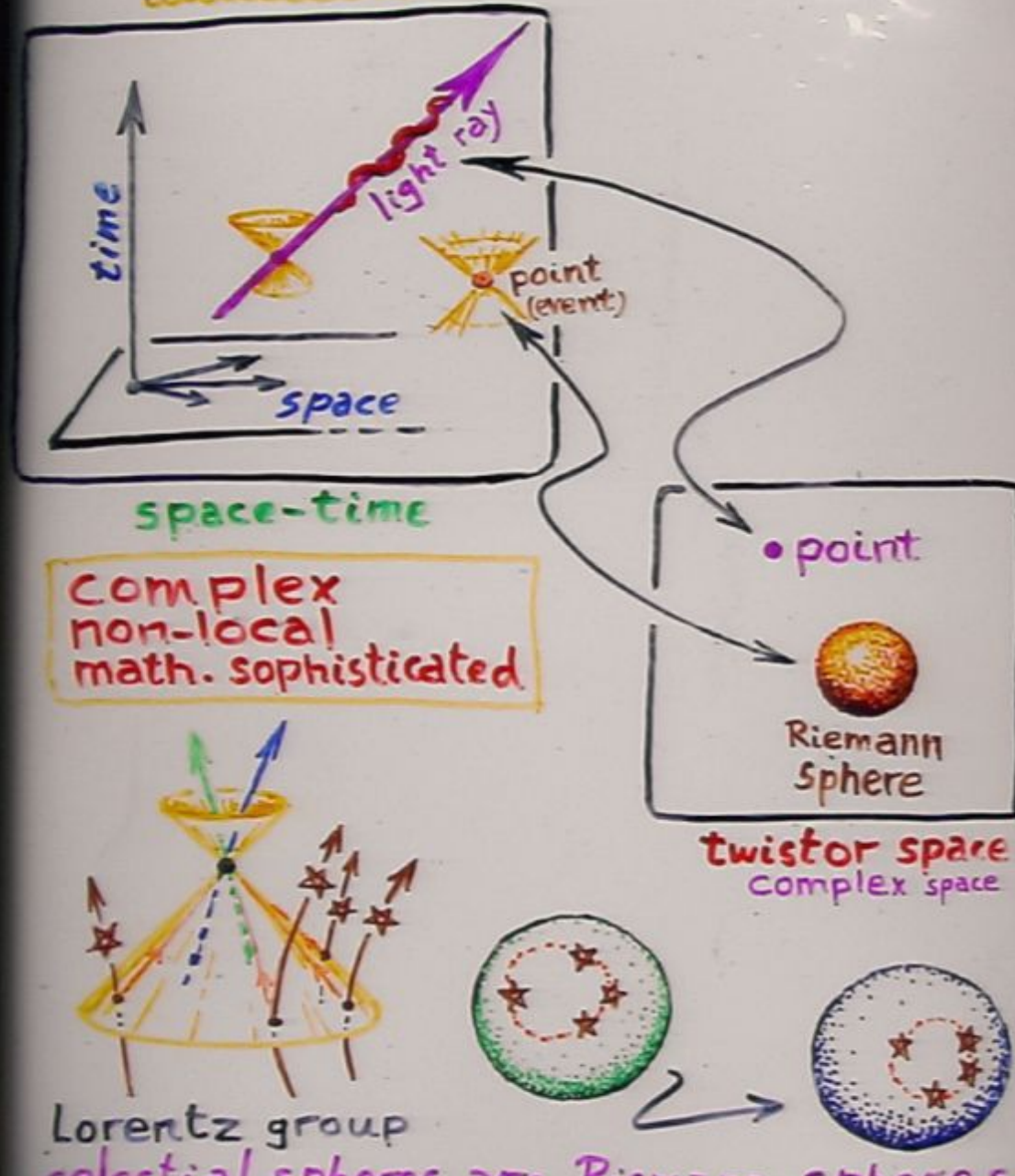
Lorentz group



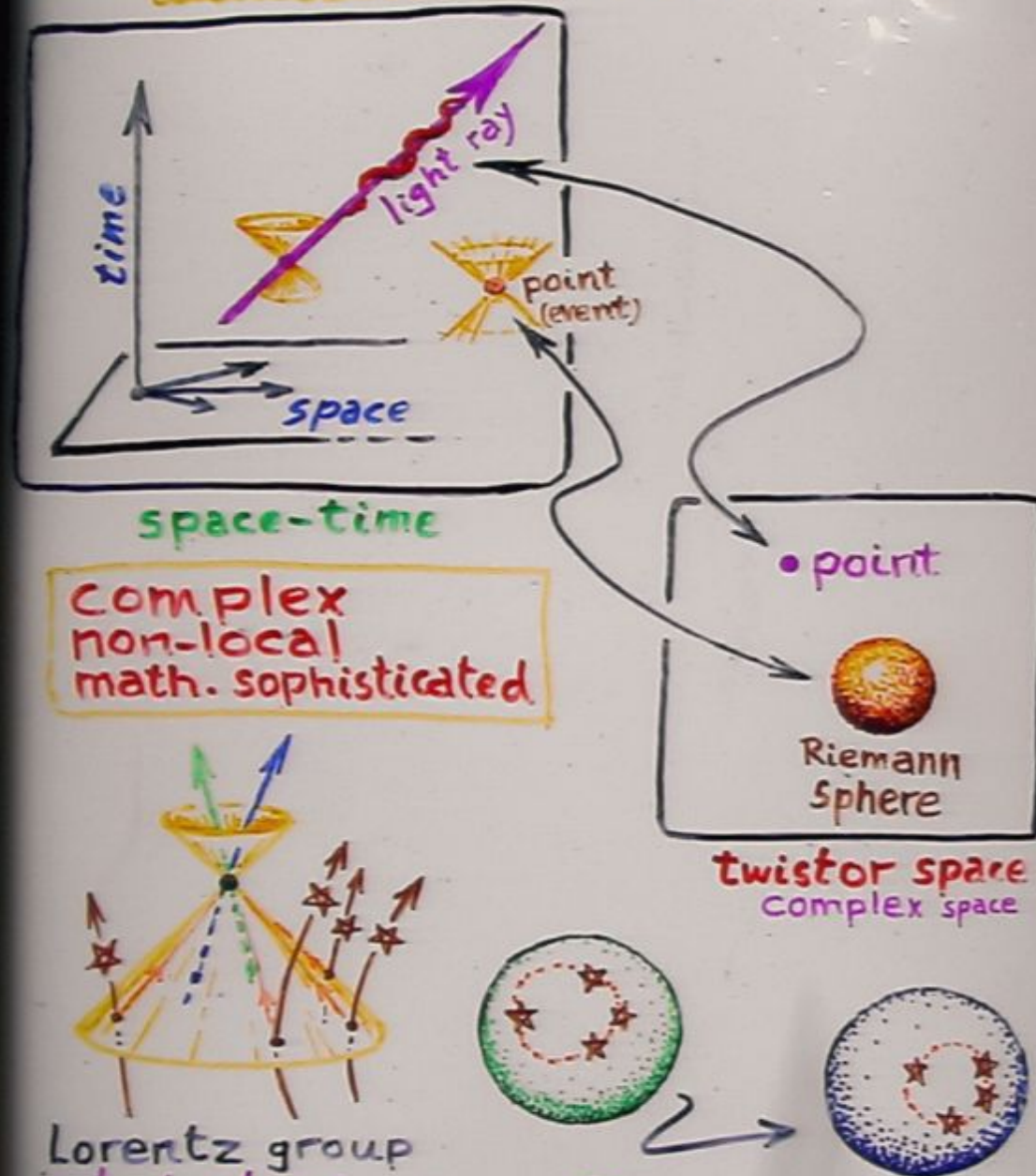
twistor space
complex space



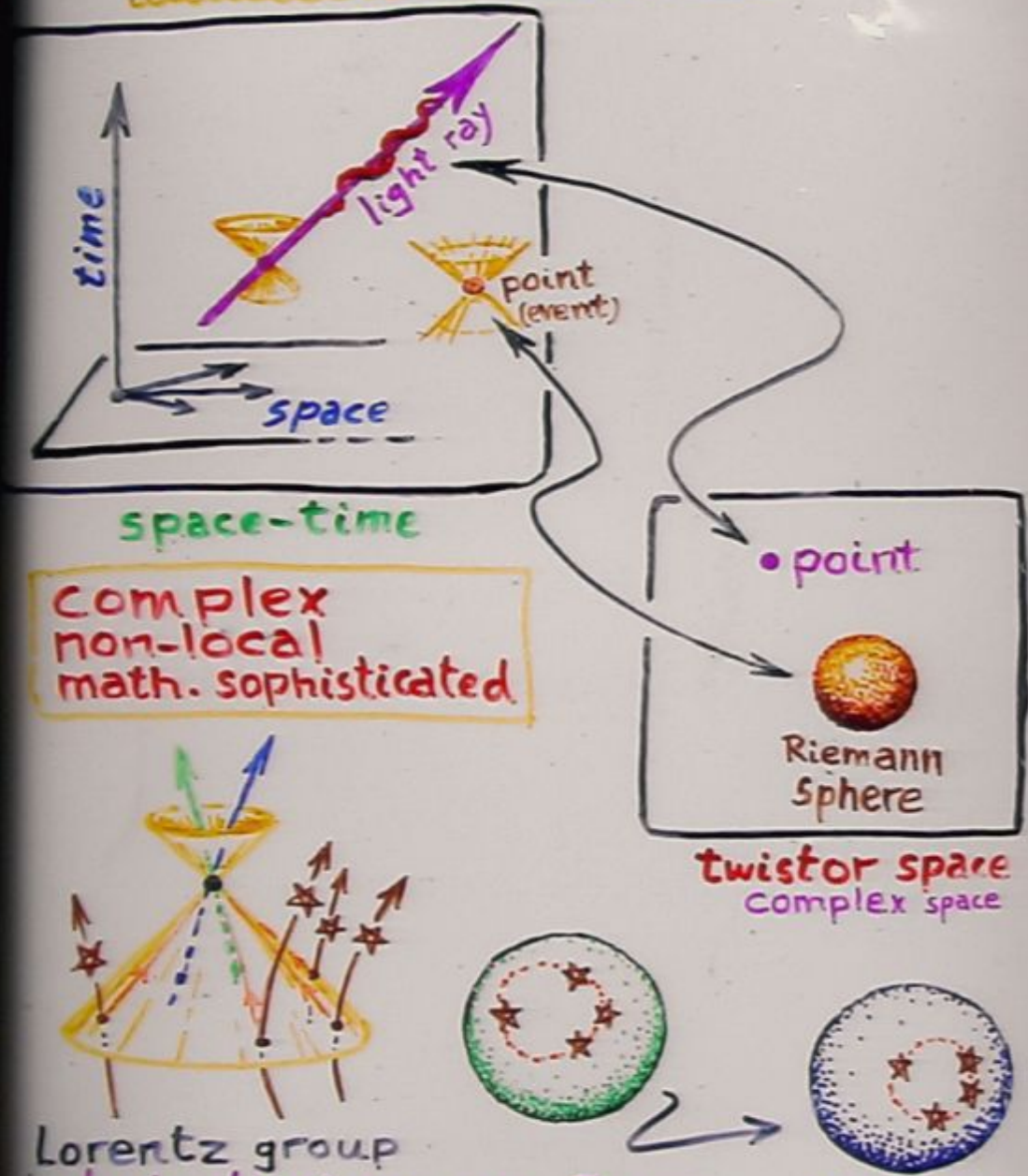
Twistor Theory



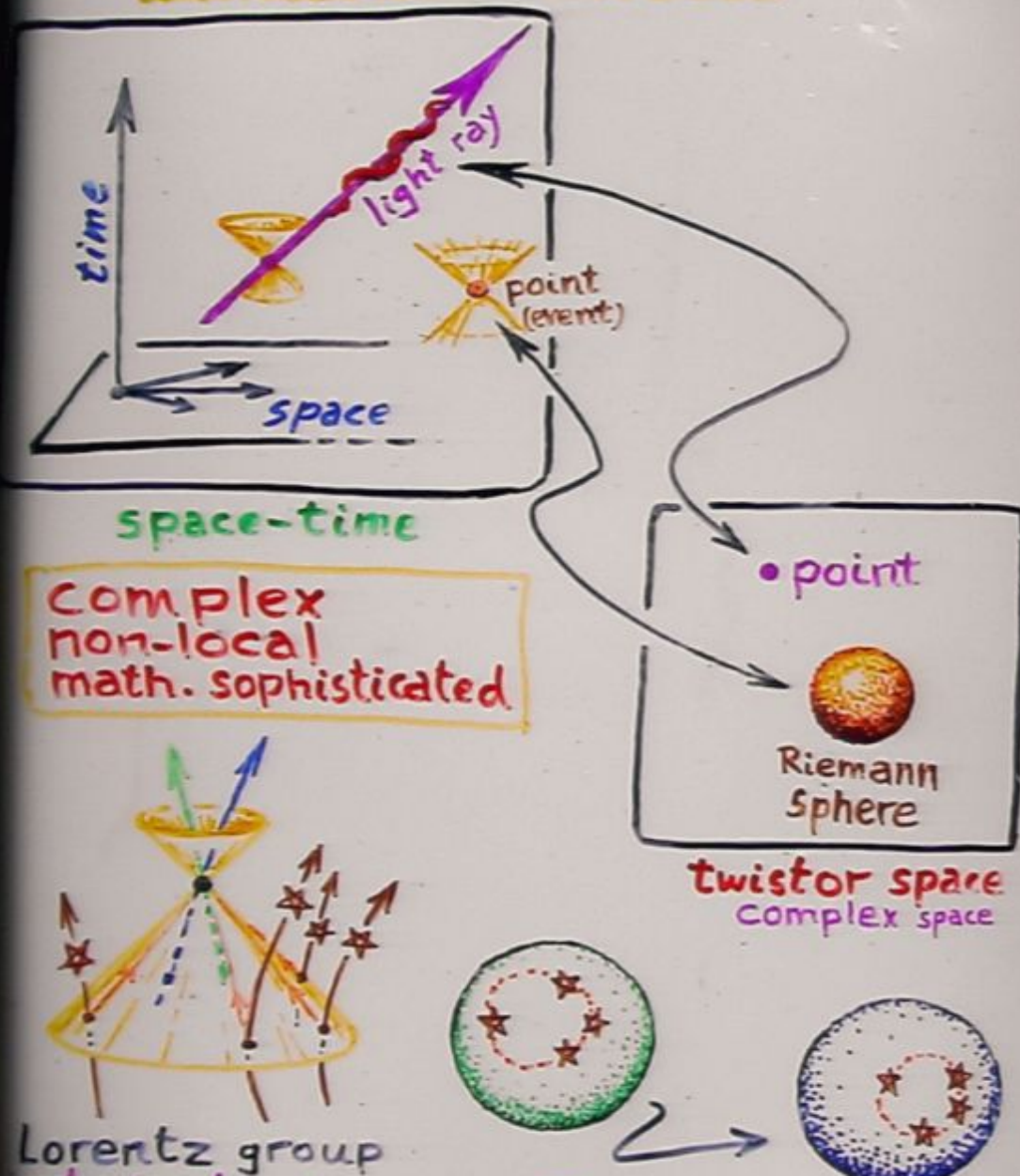
Twistor Theory



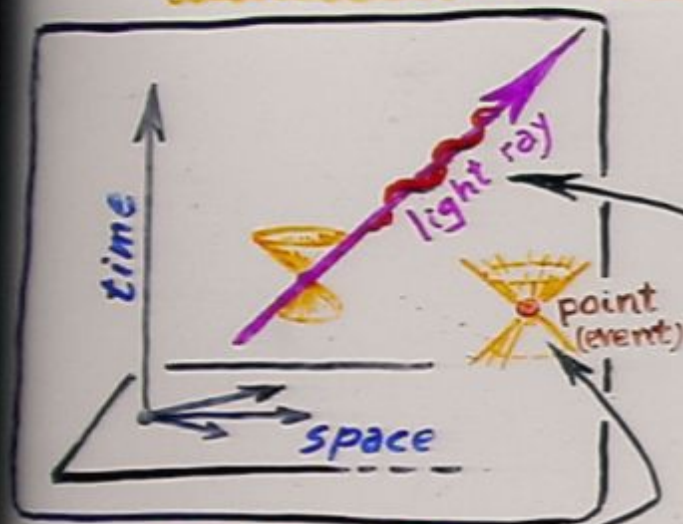
Twistor Theory



Twistor Theory



Twistor Theory



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Lorentz group

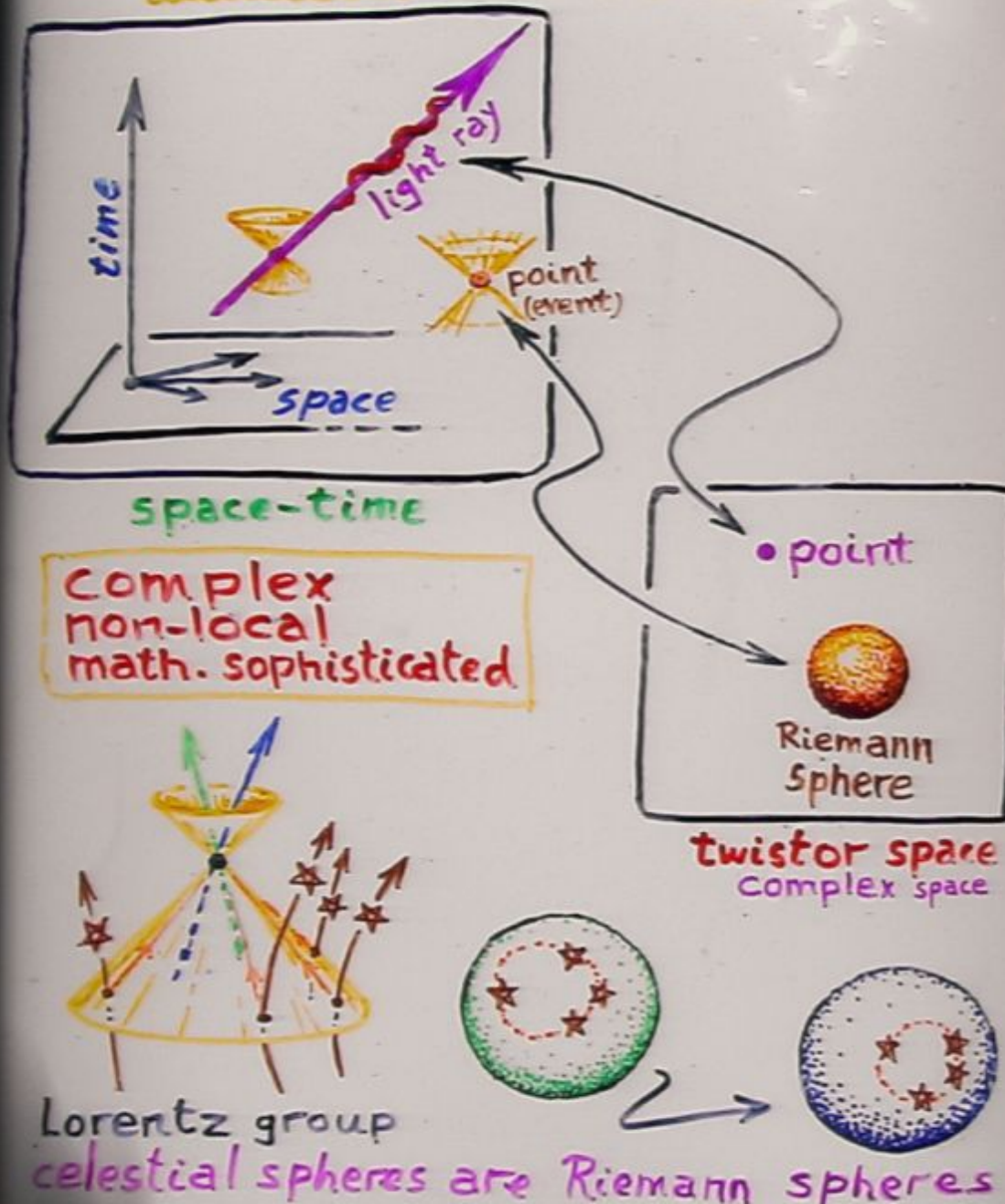
celestial spheres are Riemann spheres



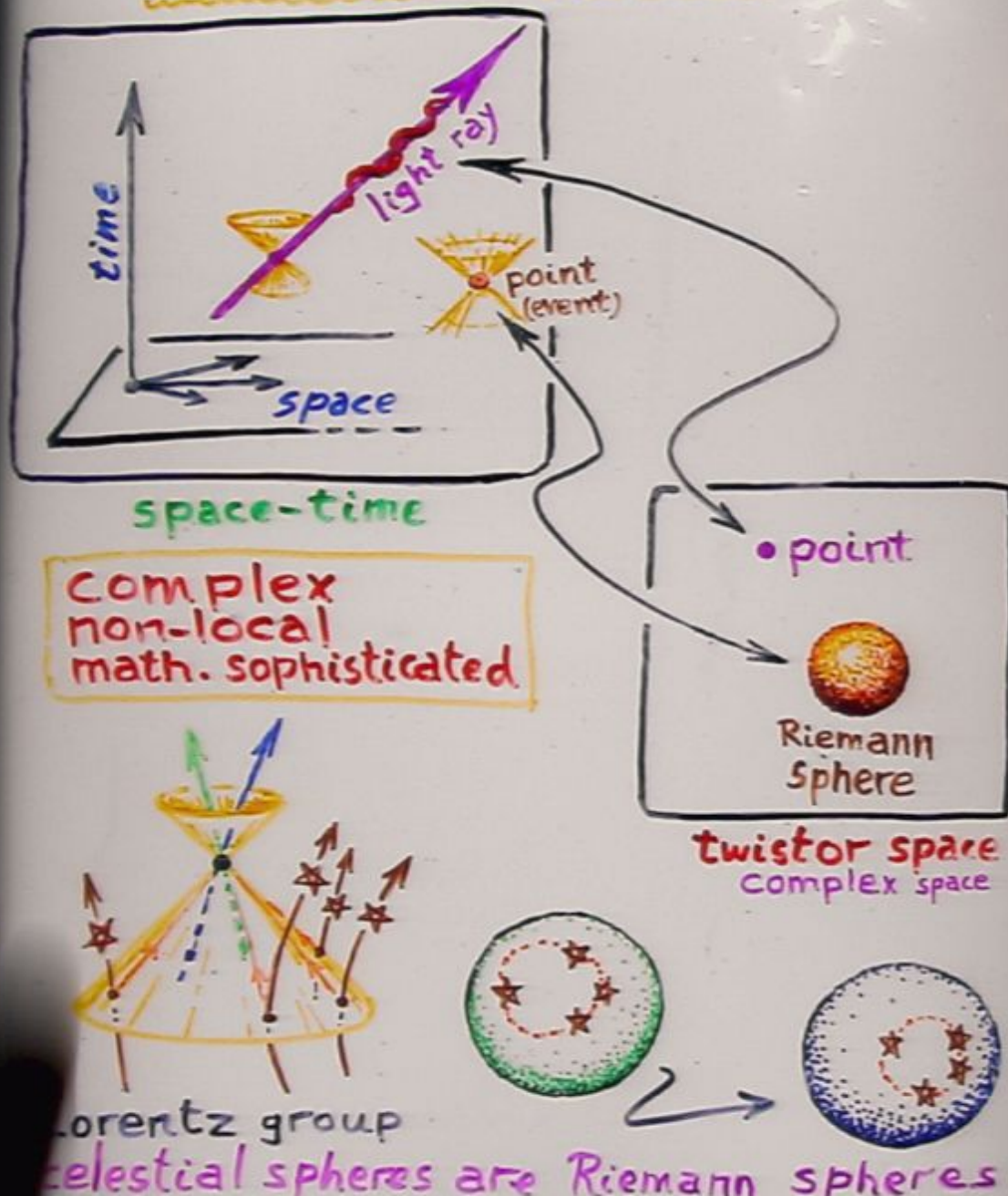
twistor space
complex space



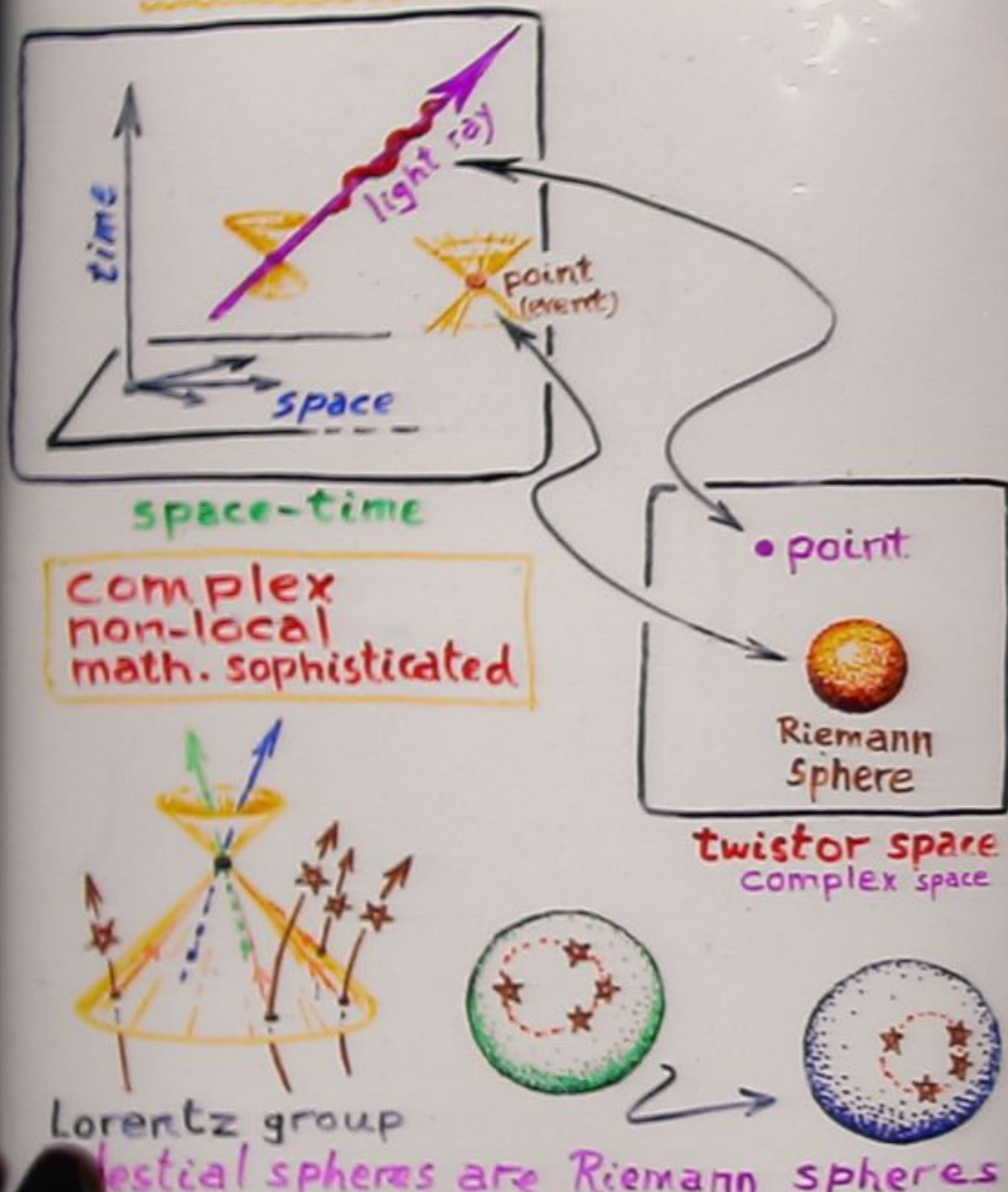
Twistor Theory



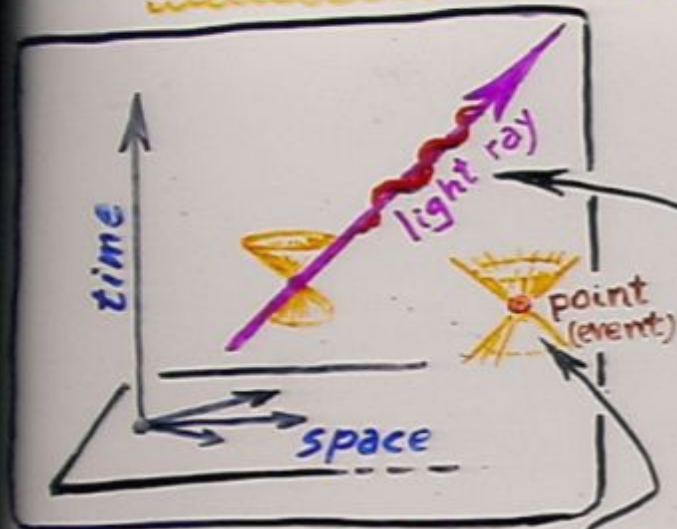
Twistor Theory



Twistor Theory



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Lorentz group

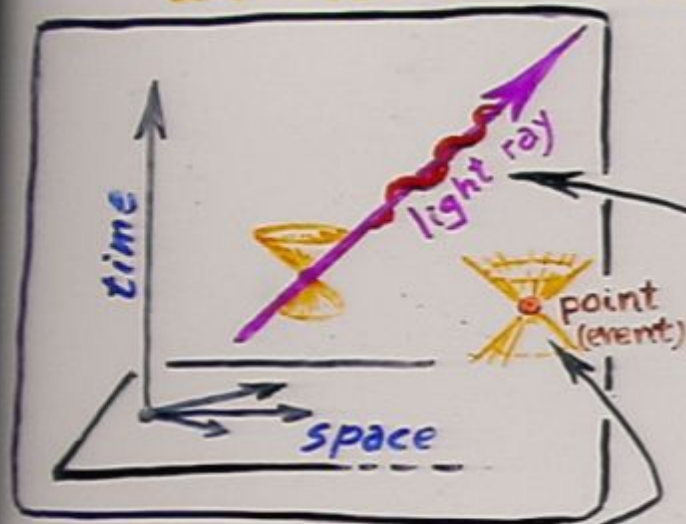
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twistor space
complex space



Twistor Theory



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Lorentz group

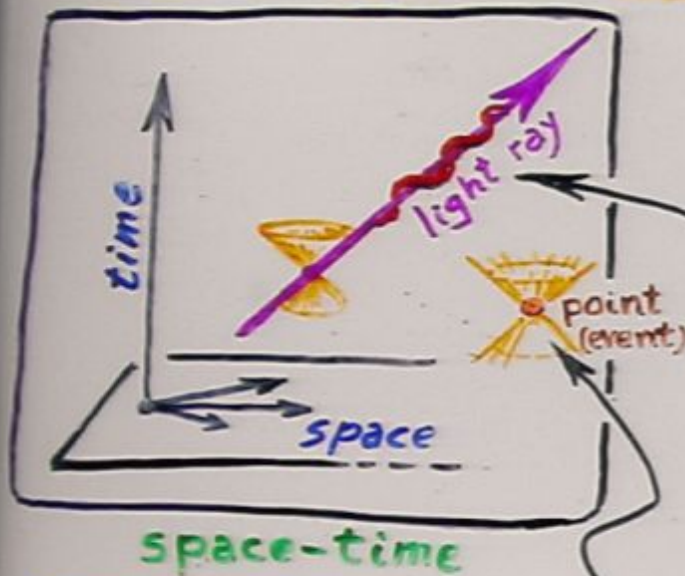
celestial spheres are P^1



twistor space
complex space



Twistor Theory



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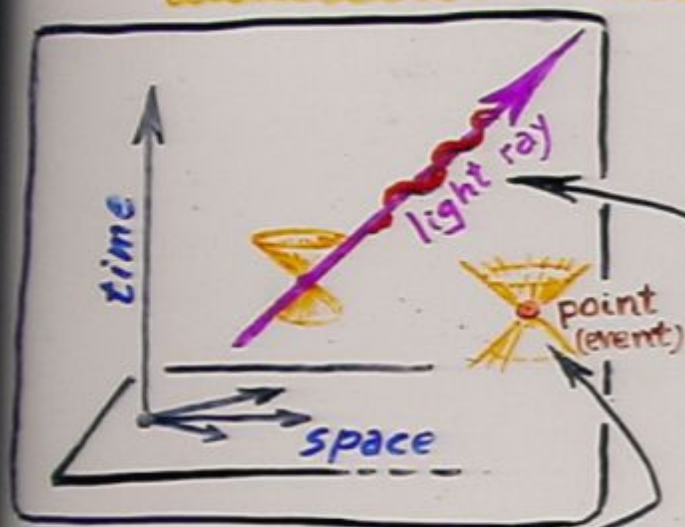
Lorentz group
celestial sphere



twistor space
complex space



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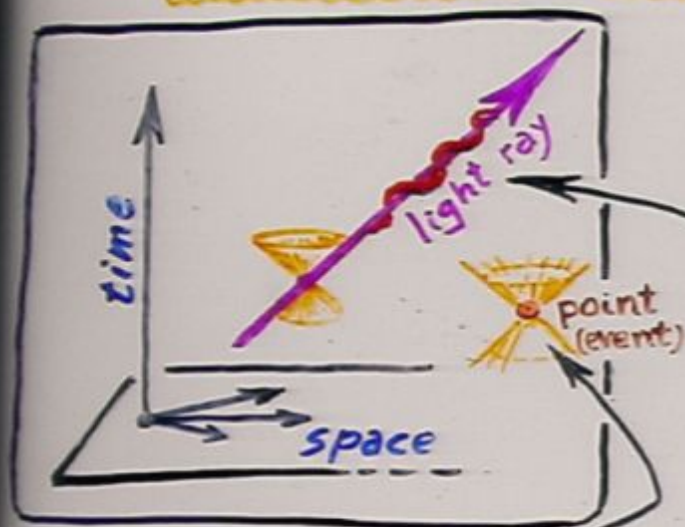
Lorentz group



twistor space
complex space



Twistor Theory



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Lorentz group

celestial sphere



twistor space
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