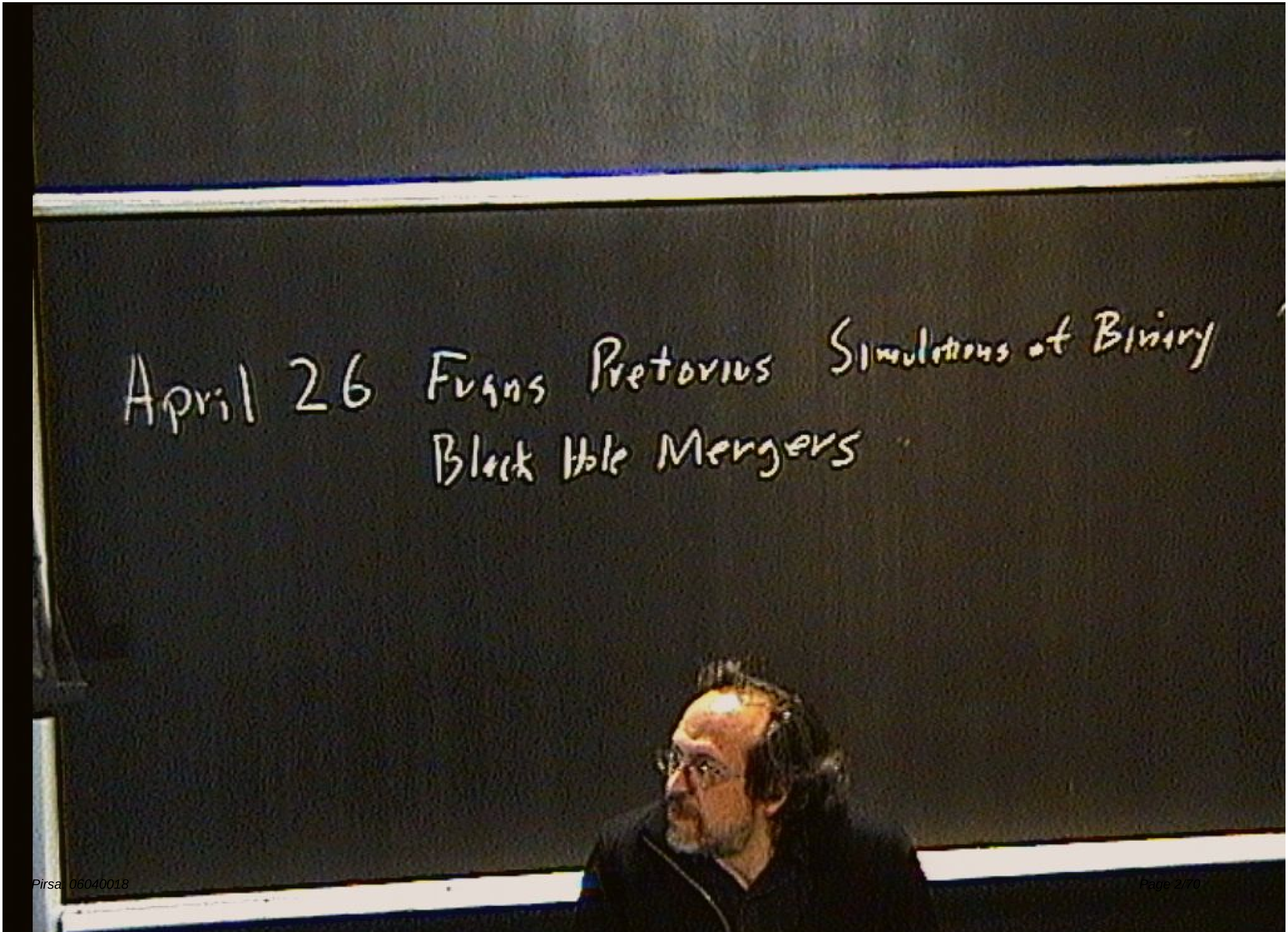
Title: Generalizing Quantum Mechanics for Quantum Spacetime

Date: Apr 19, 2006 02:00 PM

URL: http://pirsa.org/06040018

Abstract: Familiar textbook quantum mechanics assumes a fixed background spacetime to define states on spacelike surfaces and their unitary evolution between them. Quantum theory has been generalized as our conceptions of space and time have evolved. But quantum mechanics needs to be generalized further for quantum gravity where spacetime geometry is fluctuating and without definite value. This talk will review a fully four-dimensional, sum-over-histories, generalized quantum mechanics of cosmological spacetime geometry. In this generalization, states of fields on spacelike surfaces and their unitary evolution are emergent properties appropriate when spacetime geometry behaves approximately classically. The principles of generalized quantum theory would allow for further generalization that would be necessary were spacetime not fundamental. Emergent spacetime phenomena are discussed in general and illustrated with the examples of the classical spacetime geometries with large spacelike surfaces that emerge from the `no-boundary' wave function of the universe. These must be Lorentzian with one, and only one, time direction. The question will be raised as to whether quantum mechanics itself is emergent.


April 26 Frans Pretorius Simulations of Binary
Black Hole Mergers

THE QUESTION:

DOES QUANTUM MECHANICS APPLY TO SPACETIME?

THE ANSWER:

YES, BUT THE USUAL TEXTBOOK FORMULATION MUST BE GENERALIZED TO DO SO.

1. QUANTUM MECHANICS IS PROBABL
THE MOST SUCCESSFUL OF PHYSICAL
THEORIES, PAST OR PRESENT.

2. DESPITE THIS, MANY OF OUR MOST
BRILLIANT MINDS HAVE SOUGHT TO
REPLACE IT:

EINSTEIN	LEGGETT
SCHRÖDINGER	't HOOFT
DE BROGLIE	PENROSE
BOHM	ADLER

3. DESPITE THIS, AFTER 70 YEARS,
THERE IS **NO** VIABLE ALTERNATIV
TO QM THAT FITS WELL WITH

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3. DESPITE THIS, AFTER 70 YEARS, THERE IS **NO** VIABLE ALTERNATIV[E] TO QM THAT FITS WELL WITH THE REST OF PHYSICS, SPECIAL RELATIVITY, QUANTUM FIELD THEORY, ...

THEORIES, PAST OR PRESENT.

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EINSTEIN	LEGGETT
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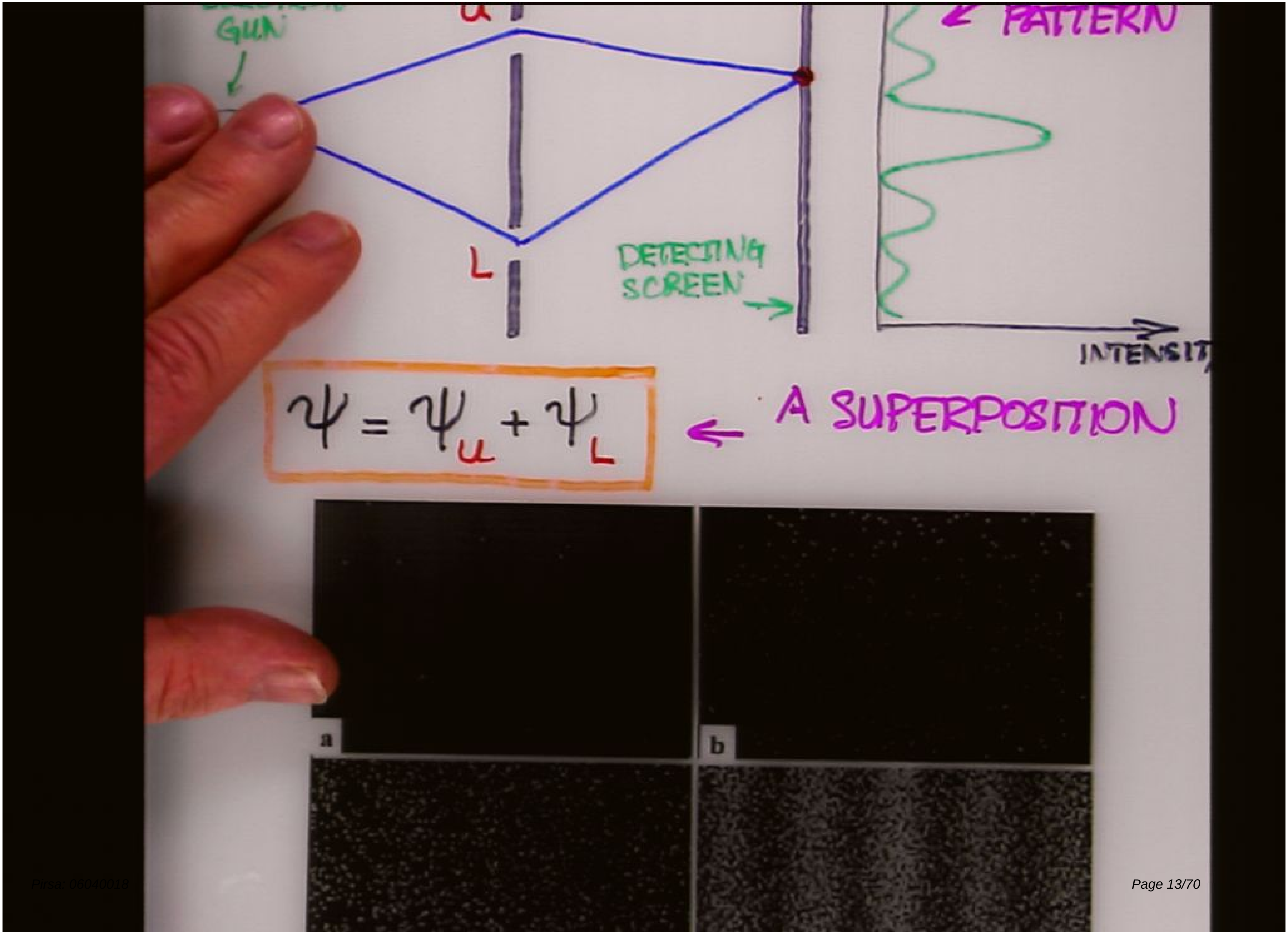
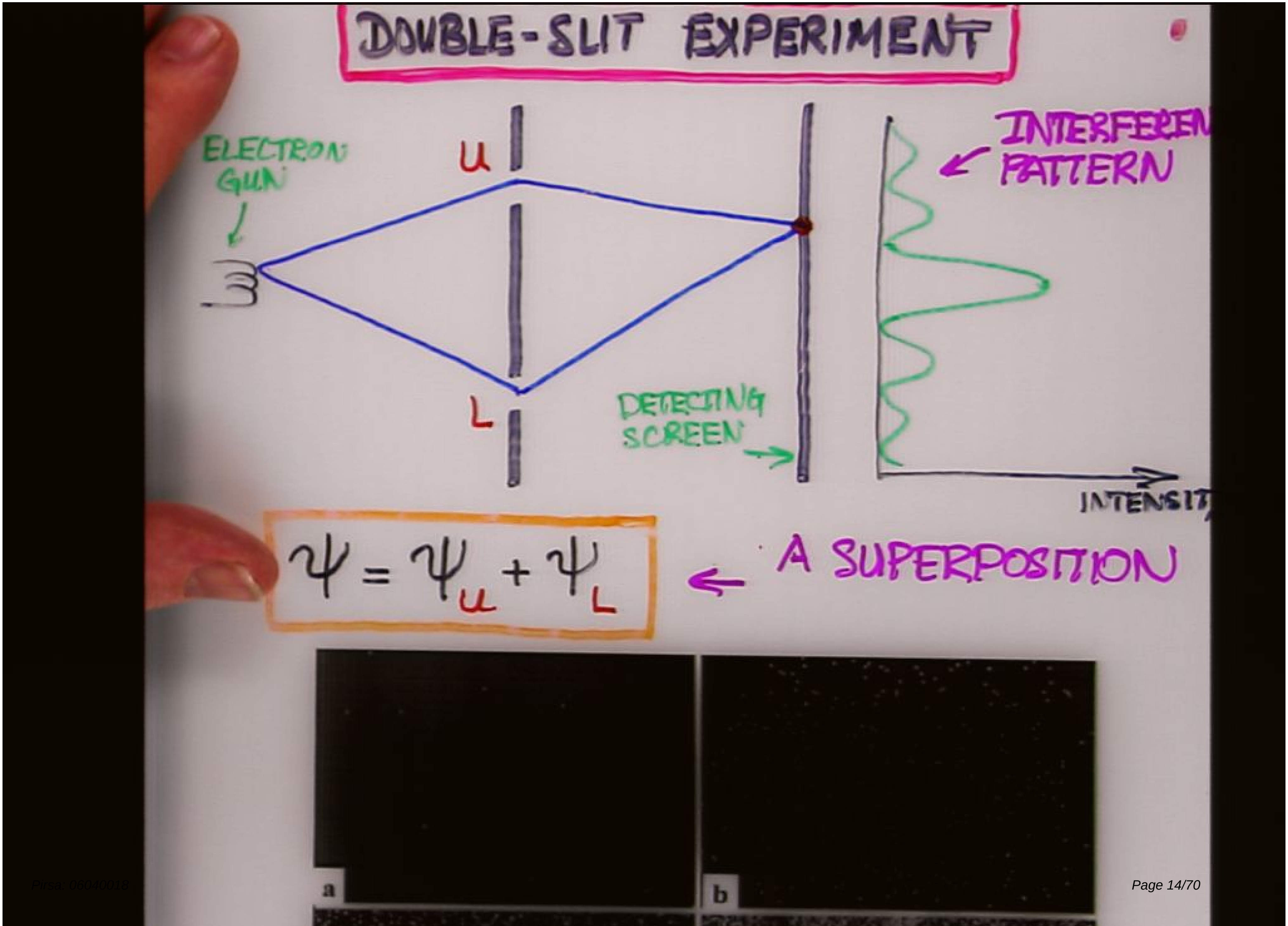
3. DESPITE THIS, AFTER [illegible]
THERE IS NO [illegible]
TO QM THAT [illegible]
THE REST [illegible]
RELATIVITY [illegible]


GUN
PATTERN
L
DETECTING SCREEN
INTENSIT
$\psi = \psi_u + \psi_L$
A SUPERPOSITION
a
b


DOUBLE-SLIT EXPERIMENT
ELECTRON GUN
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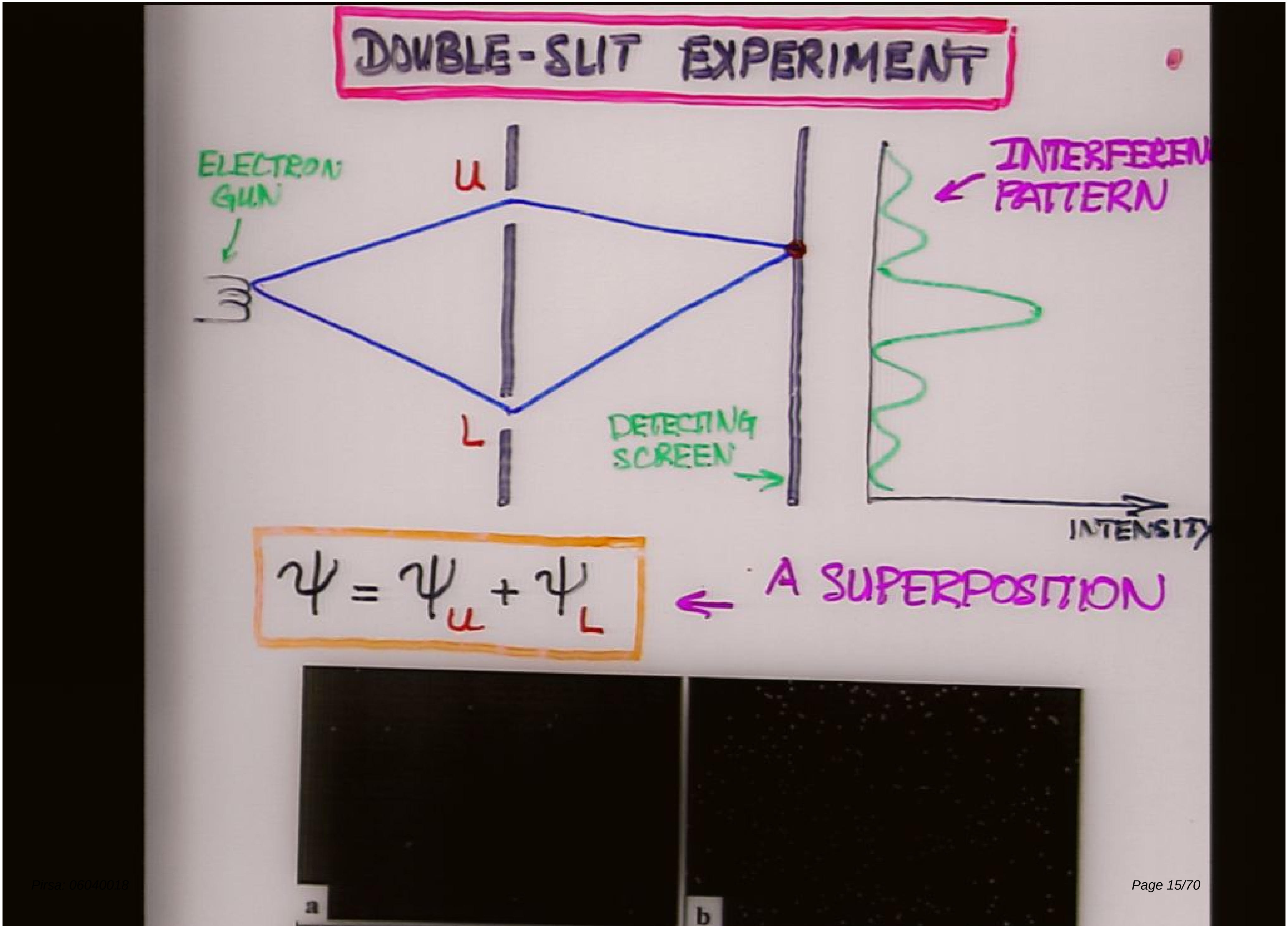
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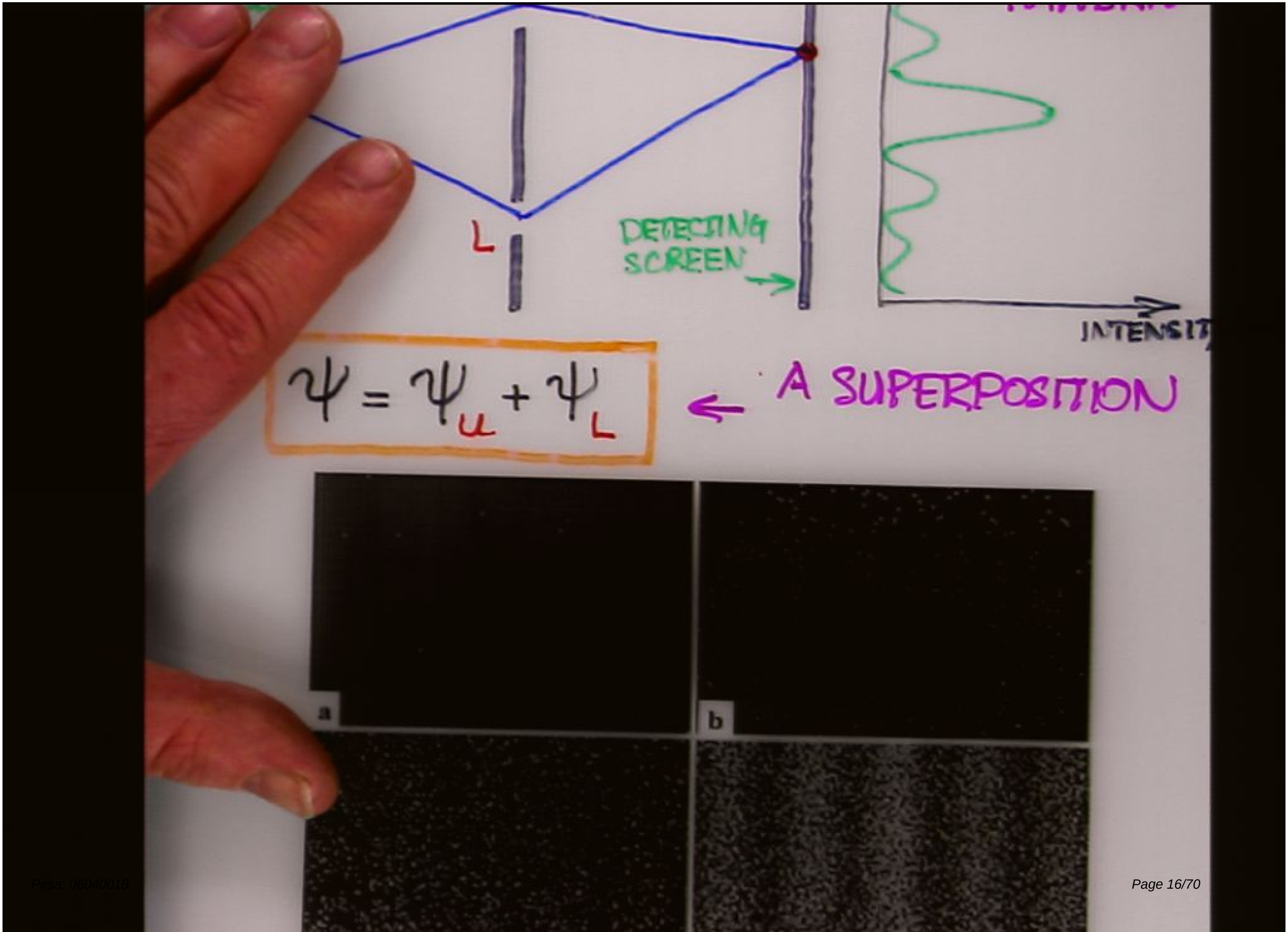
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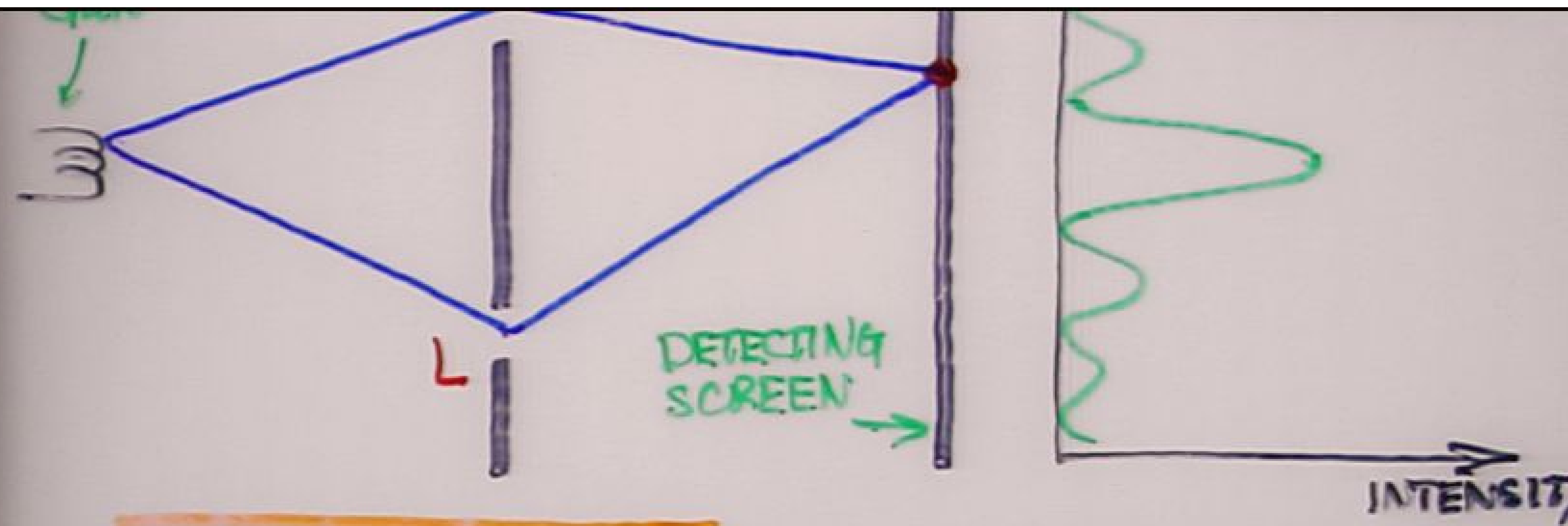
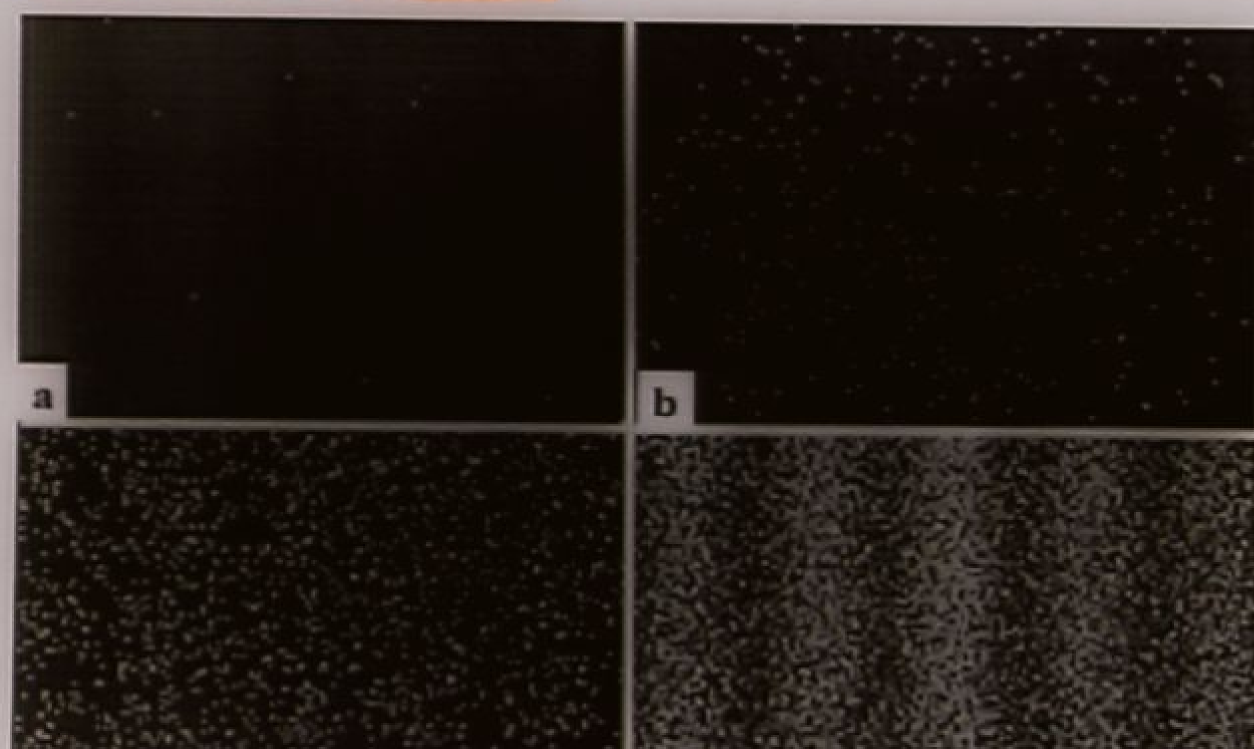
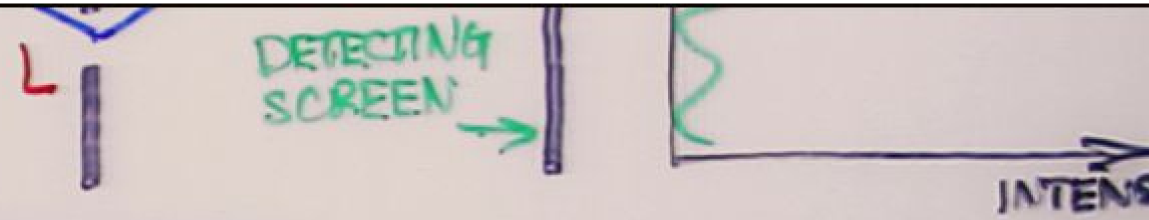


$$\psi = \psi_u + \psi_L$$ ← A SUPERPOSITION





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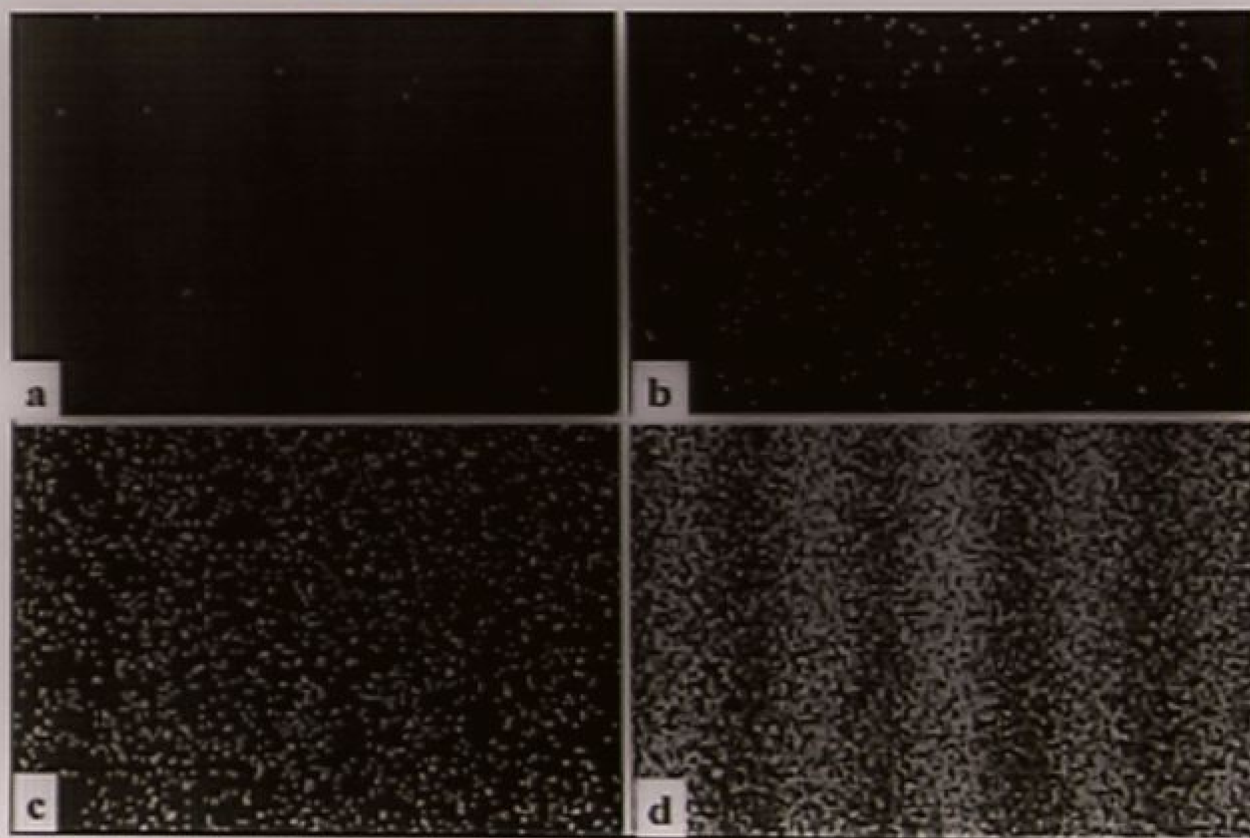
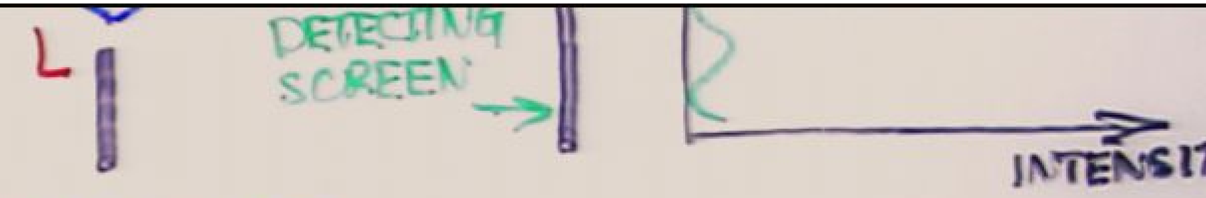


TONOMURA, ET. AL. ('89)



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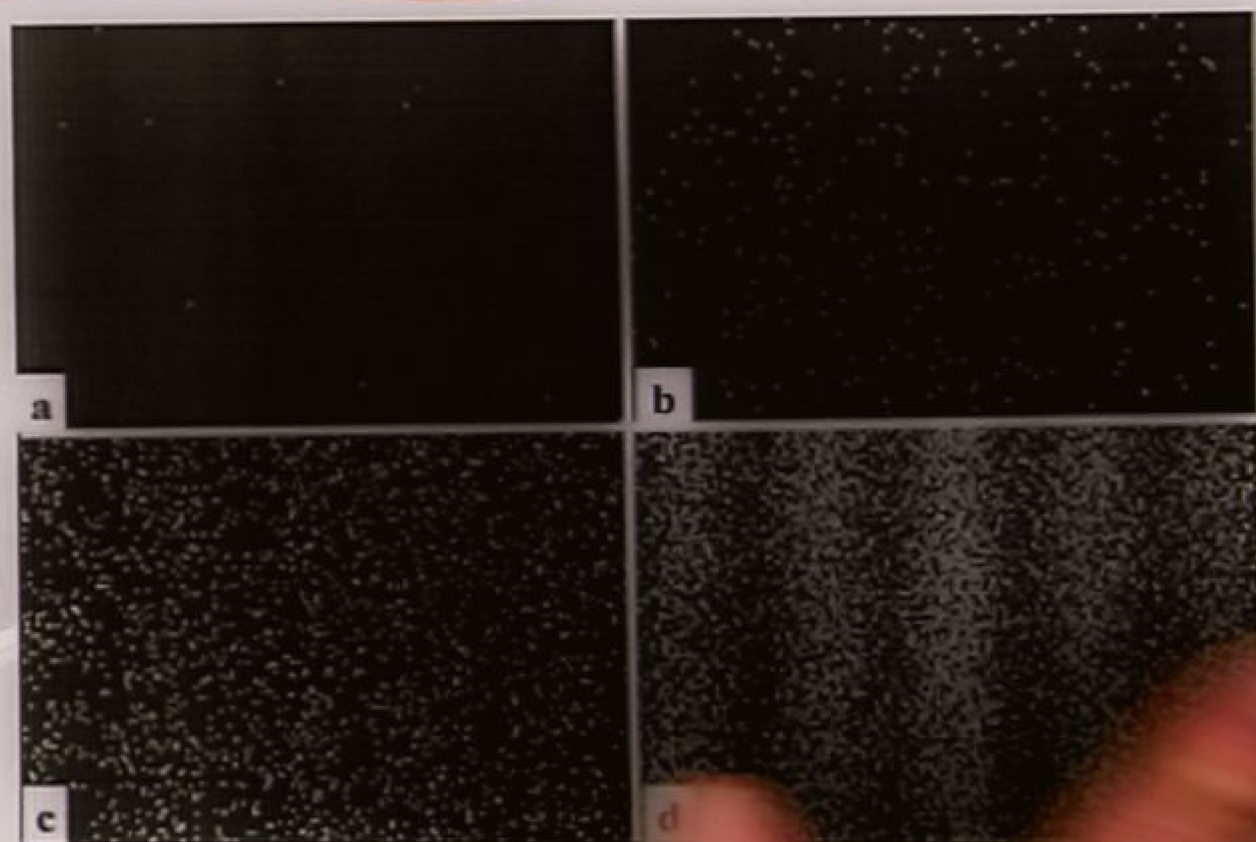

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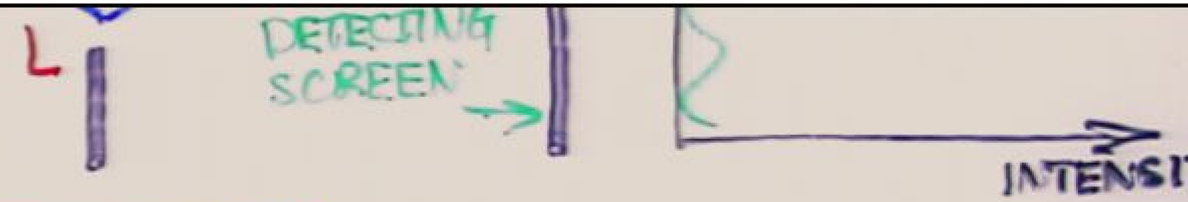

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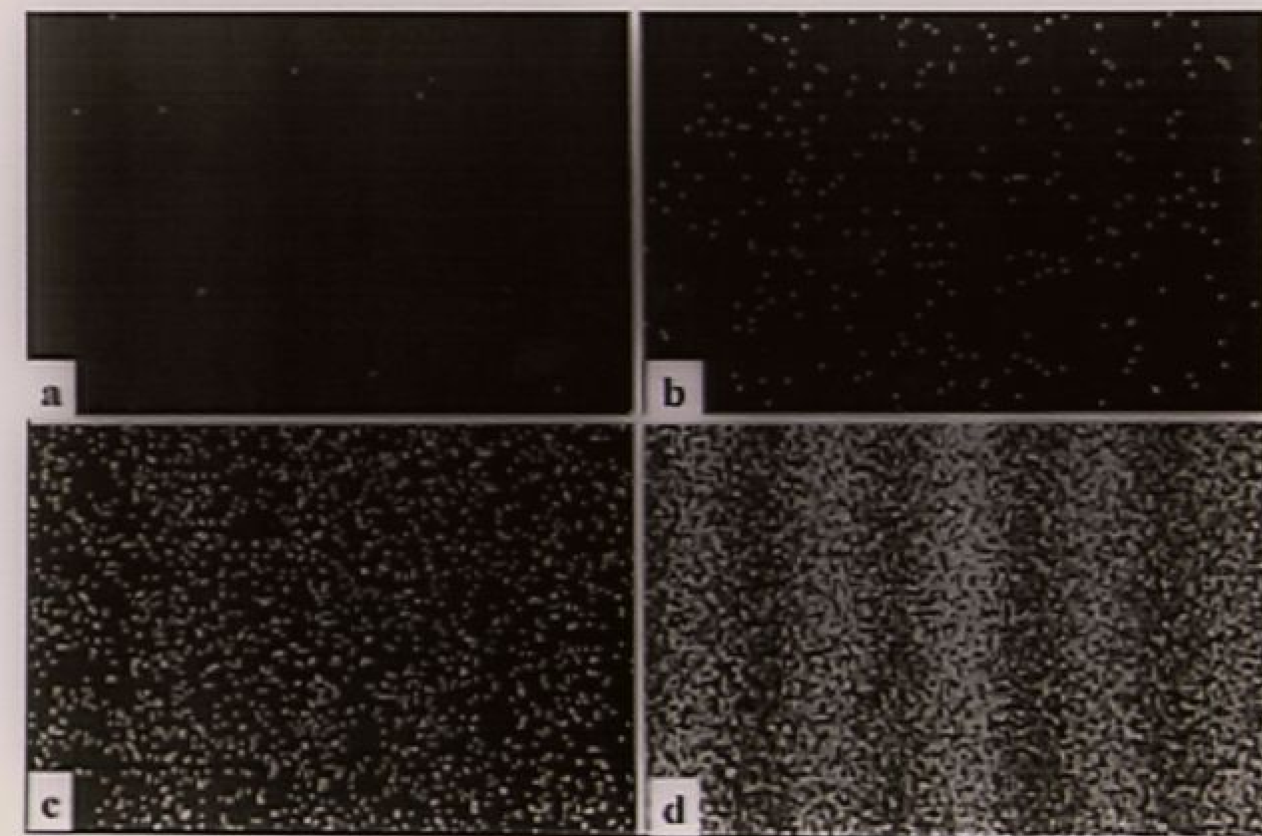

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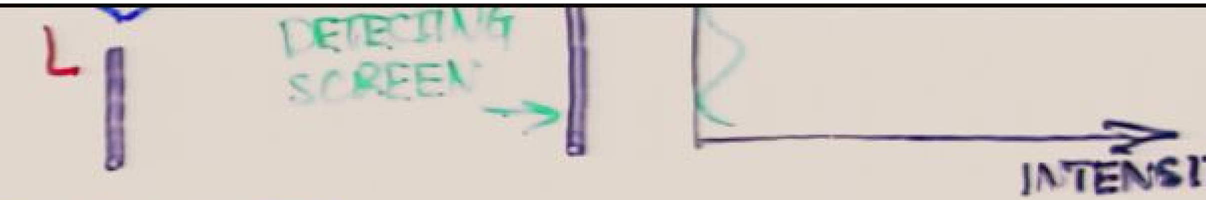

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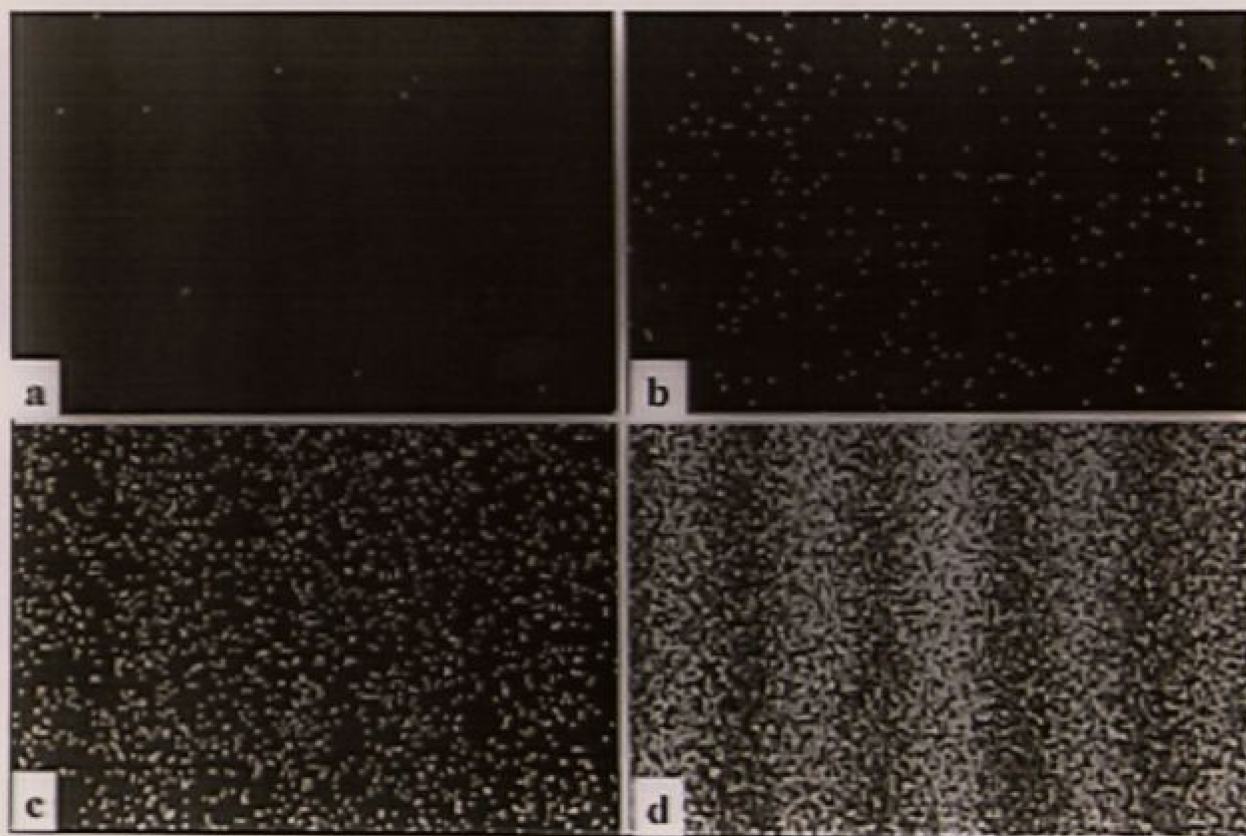

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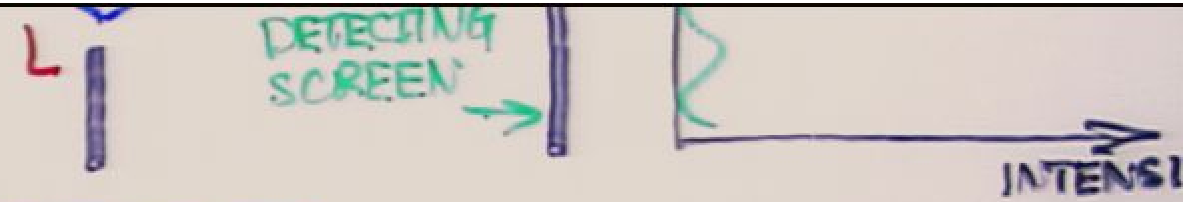

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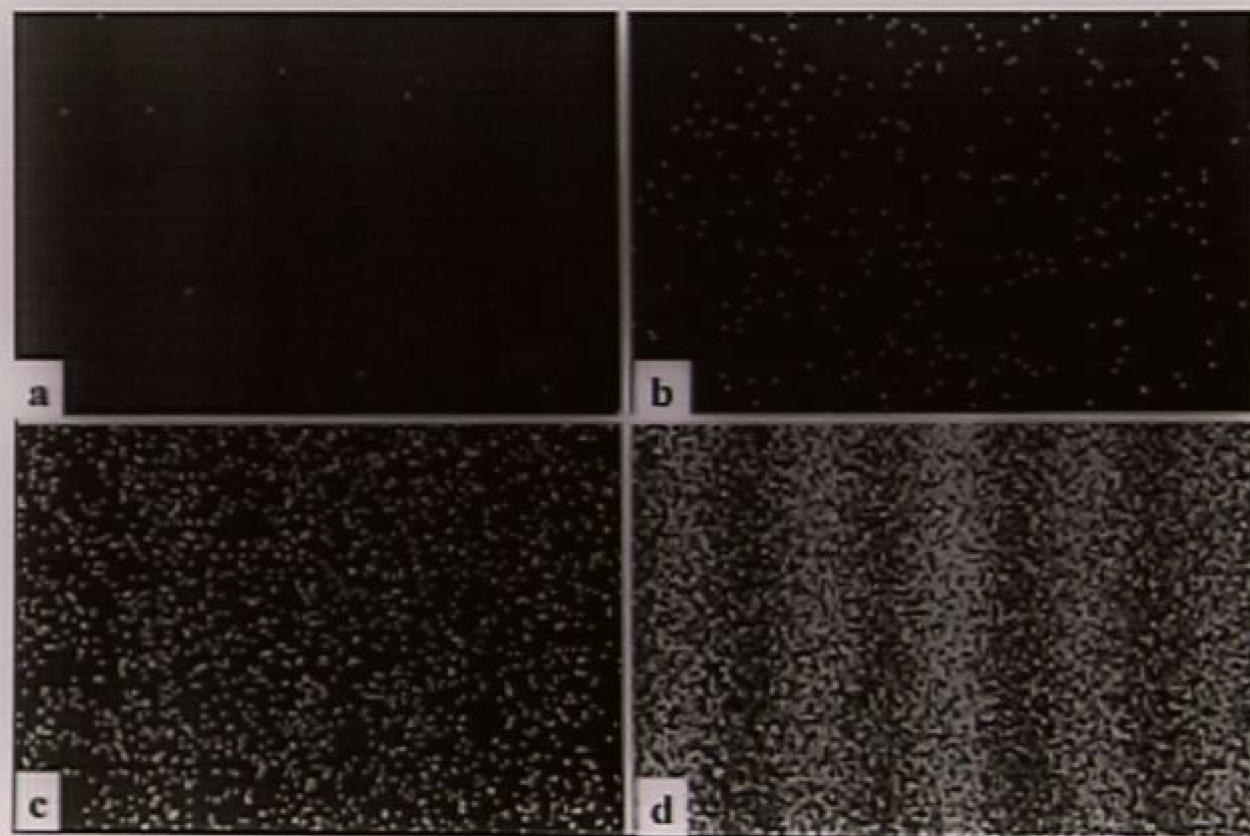
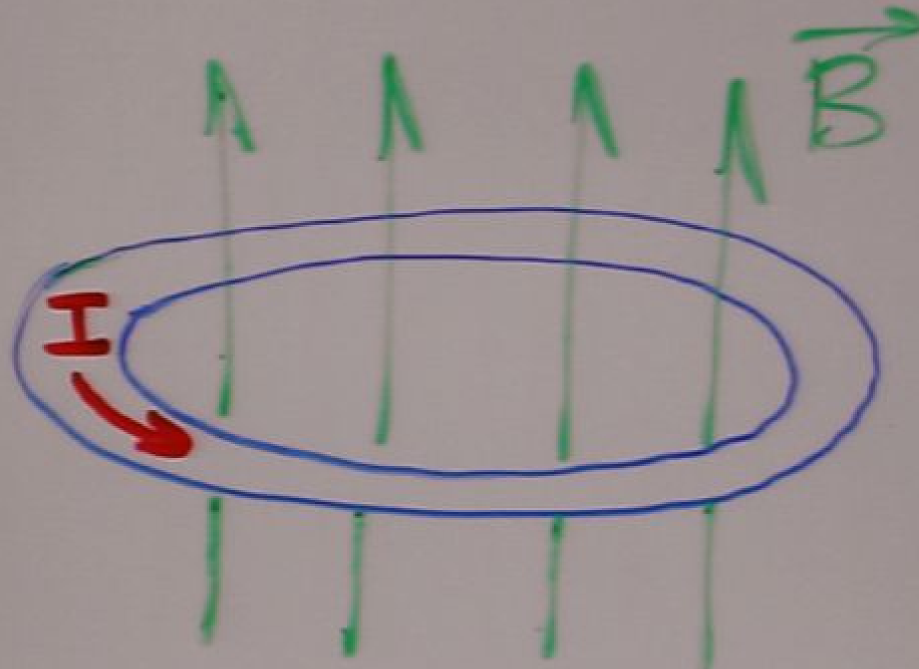


TONOMURA, ET. AL. ('89)

"QUANTUM SUPERPOSITION OF DISTINCT MACROSCOPIC STATES"

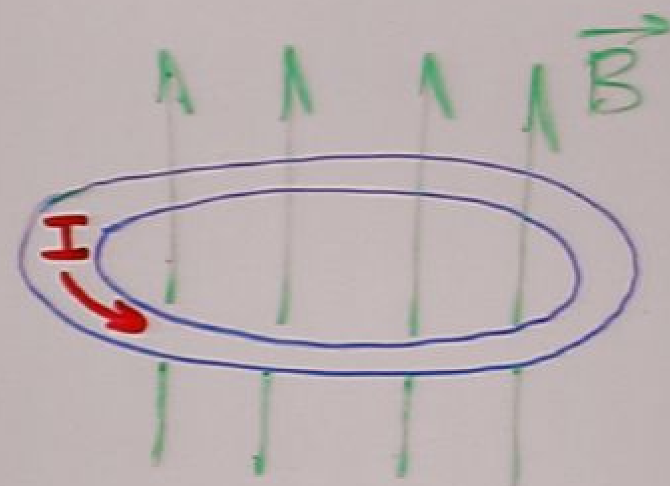
FRIEDMAN, et. al. NATURE 406, 43 (2

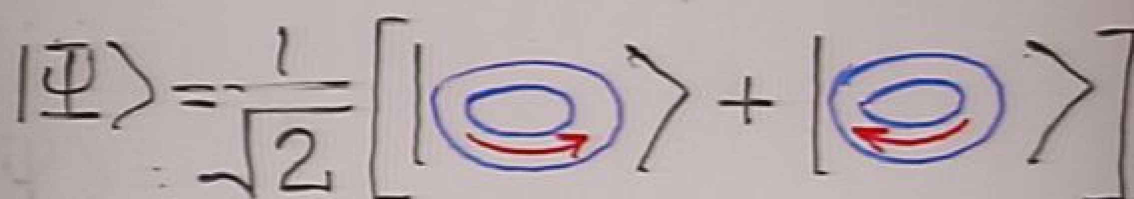


EXPERIMENT

"QUANTUM SUPERPOSITION OF DISTINCT MACROSCOPIC STATES"

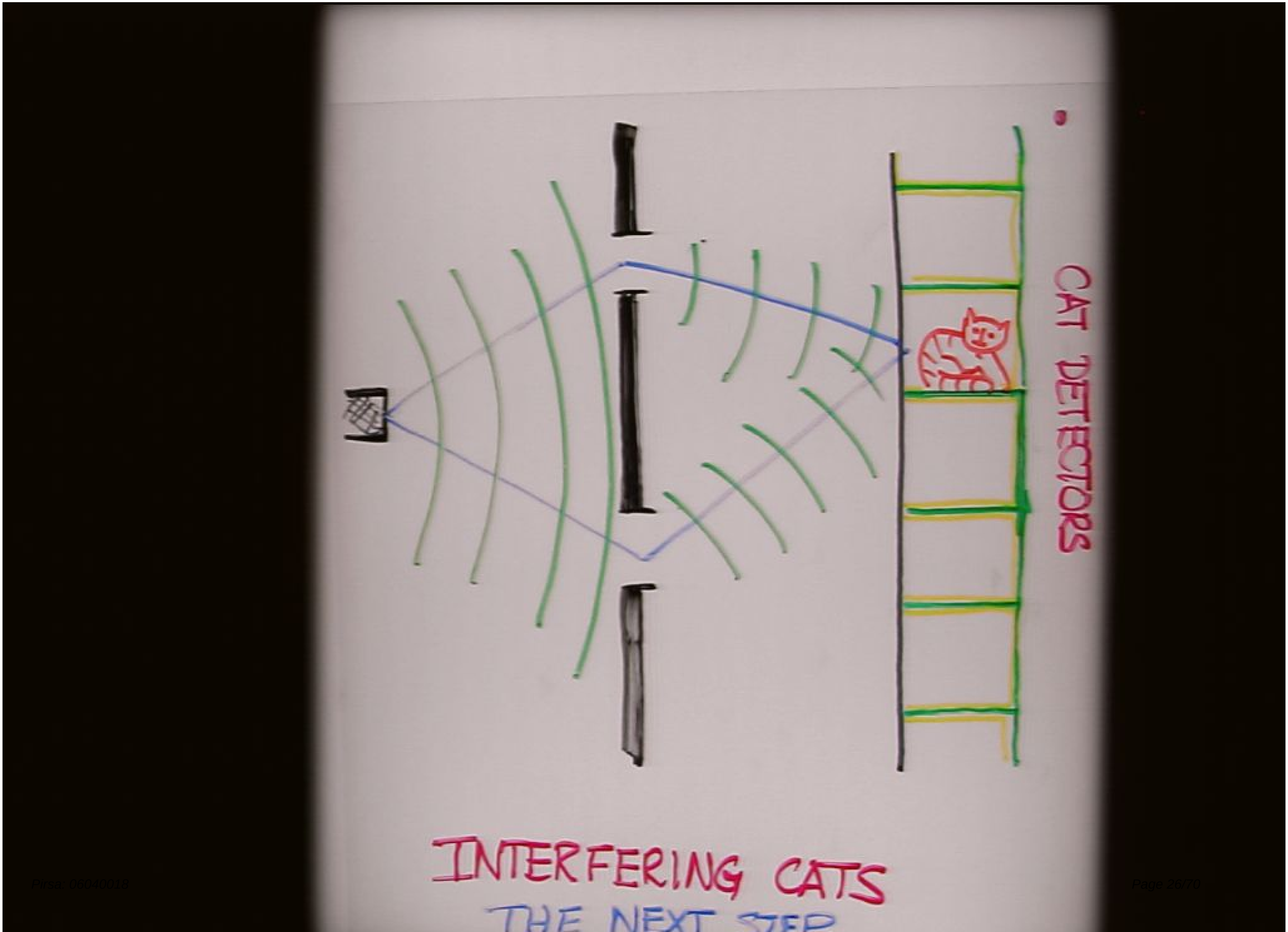
FRIEDMAN, et. al. NATURE 406, 43 (2000)





TWO STATES DIFFER BY

$10^{10}\mu_B$


CAT DETECTORS
INTERFERING CATS
THE NEXT STEP

THE DUTY OF A RAPPORTEUR

- BOHMIAN MECHANICS (BOHM, et.al.)
- FUNDAMENTAL NOISE (GRW, PEARLE...)
- DETERMINISM BENEATH QUANTUM MECHANICS ('t HOOFT)
- NON-COMMUTING DETERMINISM (ADLER)
- QUANTUM GRAVITY DECAY OF SUPERPOSITIONS (PENROSE)

WE WILL INVESTIGATE HOW FAR WE CAN GO WITH QUANTUM MECHANICS FROM NOW ON.

QUANTUM MECHANICS INCORPORATES ASSUMPTIONS ABOUT SPACE & TIME

$$i \frac{\partial \Psi}{\partial t} = H \Psi$$

TIME

$$\Psi \rightarrow \frac{P\Psi}{\|P\Psi\|}$$

AT THE TIME OF A MEASUREMENT

(TWO LAWS OF EVOLUTION)

QUANTUM MECHANICS
INCORPORATES ASSUMPTIONS
ABOUT SPACE & TIME

$$i \frac{\partial \Psi}{\partial t} = H\Psi$$

TIME

$$\Psi \rightarrow \frac{P\Psi}{\|P\Psi\|}$$

AT THE TIME
OF A MEASUREMENT

(TWO LAWS OF EVOLUTION)

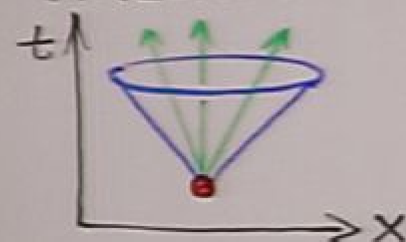
A BRIEF HISTORY OF SPACETIME I

1686 NEWTONIAN

SPACE + ONE ABSOLUTE TIME.

1905 SPECIAL RELATIVITY

MANY TIMELIKE DIRECTIONS

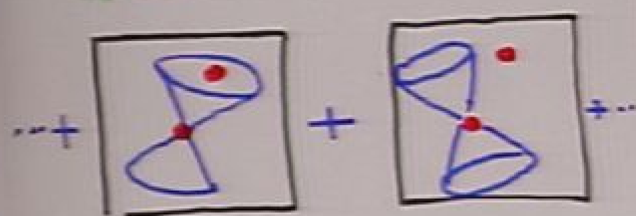


1915 GENERAL RELATIVITY

BRIEF HISTORY OF SPACETIME II

~1955 QUANTUM GRAVITY

SPACETIME GEOMETRY NOT FIXED BUT FLUCTUATING. QUANTUM MECHANICALLY



~1974 +·· STRING THEORY M-THEORY, Q.T. GEOM, ···

SPACETIME NOT A BASIC VARIABLE.

A BRIEF HISTORY OF SPACETIME I

1686 NEWTONIAN

SPACE + ONE ABSOLUTE TIME, t

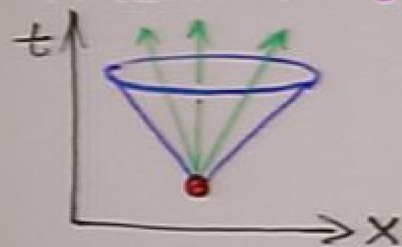
NON-RELATIVISTIC QM

$$i\frac{\partial \Psi}{\partial t} = H\Psi$$

$$\Psi \to \frac{P\Psi}{\|P\Psi\|} \text{ at } t$$

1905 SPECIAL RELATIVITY

MANY TIMELIKE DIRECTIONS t



RELATIVISTIC QM

PICK ANY t $\quad i\frac{\partial \Psi}{\partial t} = H\Psi$

RESULTS ARE UNITARILY EQUIVALENT TO ANY OTHER CHOICE

1915 GENERAL RELATIVITY

QFTCST

PICK A FOLIATING FAMILY OF SPACELIKE SURFACES

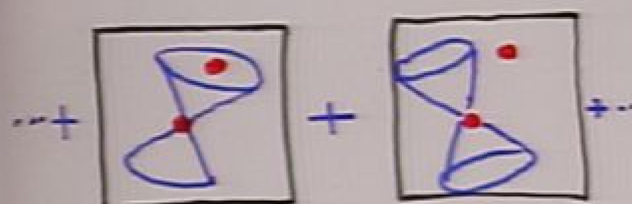
$$i\frac{\partial \Psi}{\partial t} = H\Psi$$

NOT GENERALLY UNITARILY EQUIVALENT TO OTHER CHOICES.

BRIEF HISTORY OF SPACETIME II

~1955 QUANTUM GRAVITY

SPACETIME GEOMETRY NOT FIXED BUT FLUCTUATING. QUANTUM MECHANICALLY



PROBLEM OF TIME

~1974 +.. STRING THEORY M-THEORY, Q.T. GEOM., ...

SPACETIME NOT A BASIC VARIABLE.

?

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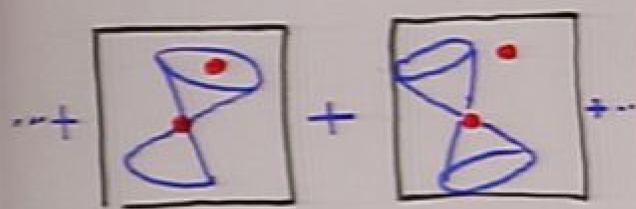


PROBLEM OF TIME

~1974 +·· STRING THEORY M-THEORY, Q.T. GEOM., ···

SPACETIME NOT A BASIC VARIABLE.

?

USUAL QUANTUM MECHANICS MUST BE GENERALIZED TO APPLY TO COSMOLOGY.

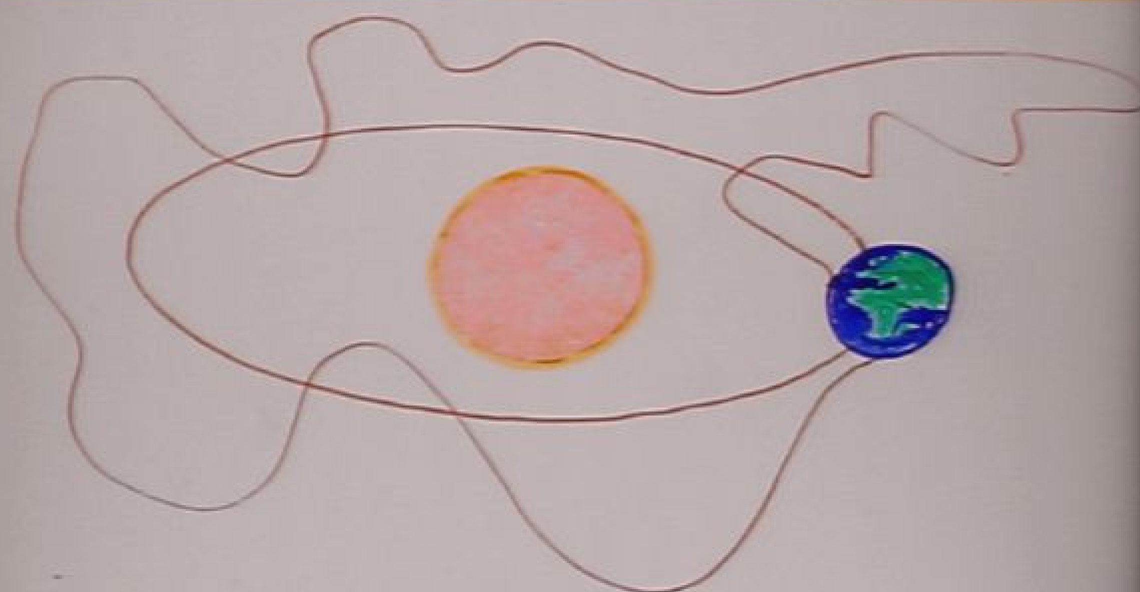
THE USUAL FORMULATIONS ASSUME AS FUNDAMENTAL:

- MEASUREMENTS
- OBSERVERS
- THE CLASSICAL REALM

BUT: THE EARLY UNIVERSE HAS NONE OF THESE.

THE GENERALIZATION NEEDED FOR SPACETIME IS CONNECTED TO THAT NEEDED FOR COSMOLOGY.

THE MOST GENERAL OBJECTIVE OF
A QUANTUM THEORY OF A CLOSED SYSTEM
IS THE PREDICTION OF THE PROBABILITIES
OF COARSE GRAINED ALTERNATIVE
TIME HISTORIES OF THE SYSTEM.



NOT EVERY SET OF ALTERNATIVE HISTORIES CAN BE ASSIGNED PROBABILITIES

PROBABILITIES CANNOT BE ASSIGNED TO THE ALTERNATIVE HISTORIES:

(1) ELECTRON GOES THROUGH u TO y.

(2) ELECTRON GOES THROUGH L TO y.

BECAUSE THE PROBABILITY SUM RULE

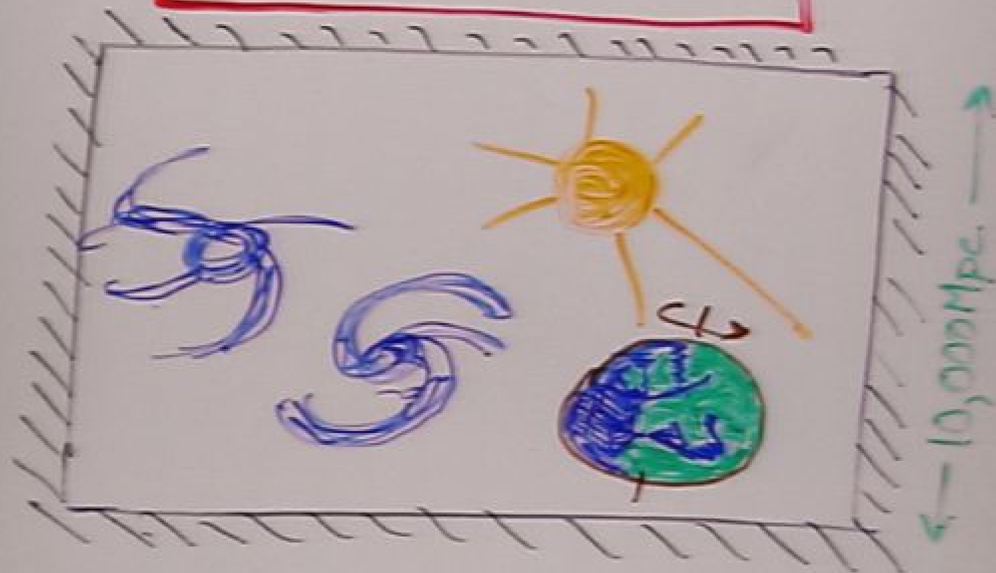
$$p(y) \neq p_u(y) + p_L(y)$$

WOULD NOT BE SATISFIED AS A CONSEQUENCE OF INTERFERENCE

$$|\psi_L(y) + \psi_u(y)|^2 \neq |\psi_u(y)|^2 + |\psi_L(y)|^2$$

A RULE IS NEEDED TO DETERMINE WHICH SETS OF HISTORIES CAN BE ASSIGNED PROBABILITIES AND WHICH CANNOT.

MODEL UNIVERSES IN A BOX



NEGLECT QUANTUM GRAVITY

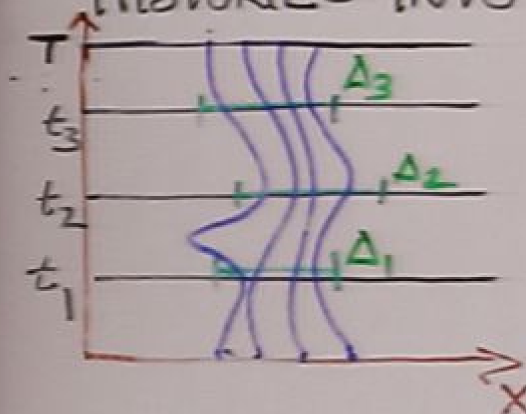
USUAL APPARATUS OF HILBERT SPACE, STATES, SCHRÖDINGER EQUATION, ... CAN BE APPLIED.

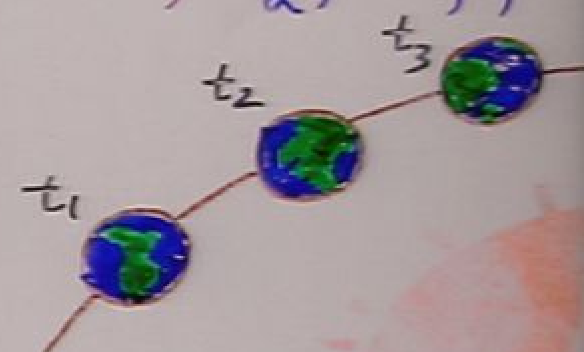
WHAT'S ASSUMED

- DYNAMICS H
- STATE $|\Psi\rangle$

II SETS OF ALTERNATIVE COARSE-GRAINED HISTORIES

- PARTITIONS OF FINE-GRAINED HISTORIES INTO CLASSES, C_α, $\alpha = 1, 2, \cdots$





- BRANCH STATE VECTORS FOR EACH HISTORY

$$|\Psi_\alpha\rangle = C_\alpha|\Psi\rangle = \sum_{\text{PATHS} \in C_\alpha} \exp\left(i\,S[x(t)]/\hbar\right)|\Psi\rangle$$

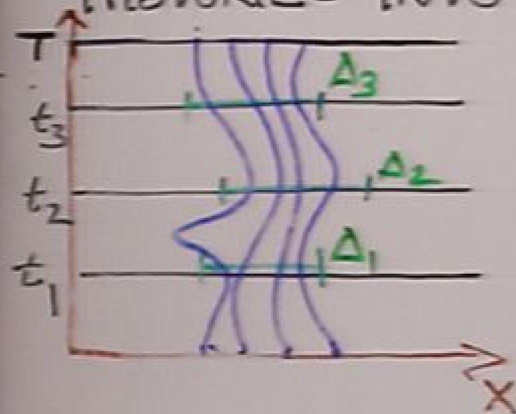
SUM OVER PATHS IN C_α — ACTION

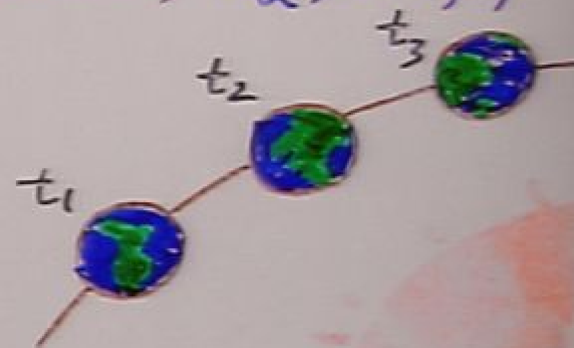
FEYNMAN

- HEISENBERG PICT

$$|\Psi_\alpha\rangle = e^{-iHT} P_{\Delta_3}(t_3) P_{\Delta_2}(t_2) P_{\Delta_1}(t_1)|\Psi\rangle$$

- PARTITIONS OF FINE-GRAINED HISTORIES INTO CLASSES, C_α, $\alpha = 1, 2, \cdots$





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SUM OVER PATHS IN C_α — ACTION

FEYNMAN

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$$|\Psi_\alpha\rangle = e^{-iHT} P_{\Delta_3}(t_3) P_{\Delta_2}(t_2) P_{\Delta_1}(t_1) |\Psi\rangle$$

III MEASURE OF INTERFERENCE BETWEEN COARSE-GRAINED HISTORIES

- INITIAL STATE $|\Psi\rangle$
- BRANCH STATE VECTORS FOR EACH HISTORY

$$|\Psi_\alpha\rangle = C_\alpha |\Psi\rangle$$

- DECOHERENCE FUNCTIONAL

$$D(\alpha', \alpha) = \langle \Psi_{\alpha'} | \Psi_\alpha \rangle$$

- A SET OF HISTORIES DECOHERES WHEN

$$D(\alpha', \alpha) \approx 0, \quad \alpha' \neq \alpha$$

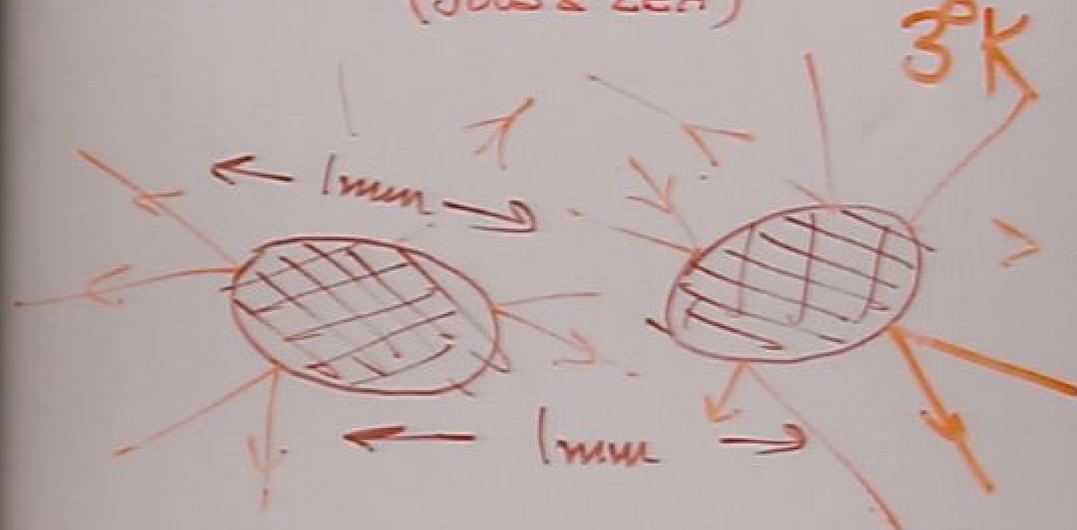
i.e. $|\Psi_\alpha\rangle \perp |\Psi_{\alpha'}\rangle$

- DECOHERENCE ENSURES THE CONSISTENCY OF PROBABILITIES

$$p_\alpha = \| C_\alpha |\Psi\rangle \|^2$$

DECOHERENCE IS WIDESPREAD

(JOOS & ZEH)



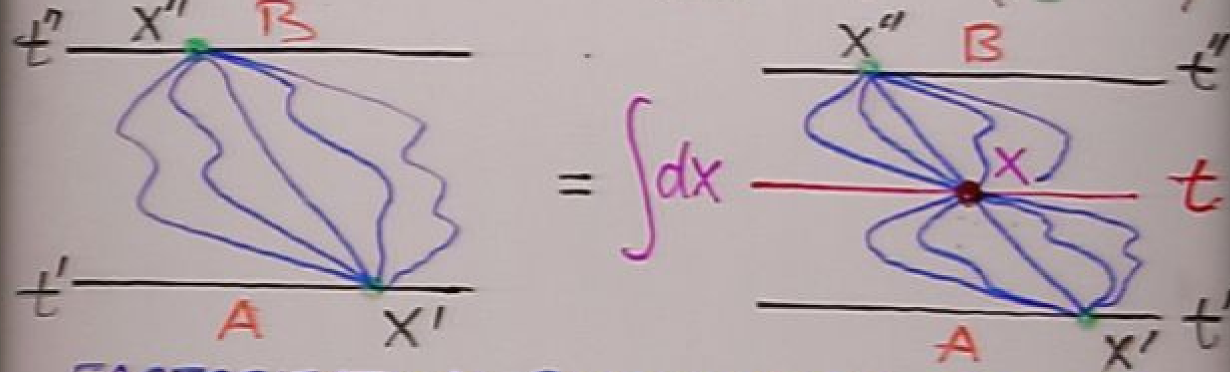
(DECOHERENCE TIMESCALE) $\sim 10^{-9}$ sec

SPACETIME QM

THIS FORMULATION OF QM IN TERMS OF PATH INTEGRALS IS 4-DIMENSIONAL BUT CAN BE CONNECTED TO A FORMULATION IN TERMS OF STATES ON A SPACELIKE SURFACE AND THEIR UNITARY EVOLUTION.

CONNECTION WITH USUAL QUANTUM MECHANICS
UNITARY EVOLUTION

TRANSITION AMPLITUDE : $(\phi_A \text{ at } t') \rightarrow (\phi_B \text{ at } t'')$



FACTORIZATION GIVES INNER PRODUCT;

$$\langle B t'' | A t' \rangle = \int dx \, \langle B t'' | x t \rangle \langle x t | A t' \rangle$$

$$= \int dx \; \psi_B^*(x,t) \, \psi_A(x,t)$$

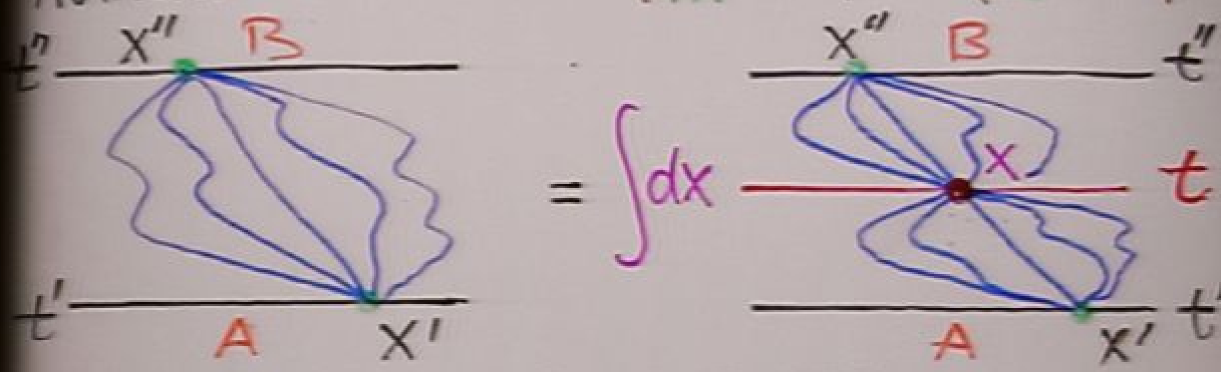
EVOLVING STATE DEFINED BY SOH.

$$\boxed{\psi_A(x,t) \equiv \int \delta x \, e^{iS[x(t)]} \phi_A(x_0)}$$

THIS SATISFIES SCHRÖDINGER EQN

$$\boxed{i \frac{\partial \psi_A(x,t)}{\partial t} = H \psi_A(x,t)}$$

TRANSITION AMPLITUDE : $(\phi_A \text{ at } t') \rightarrow (\phi_B \text{ at } t'')$



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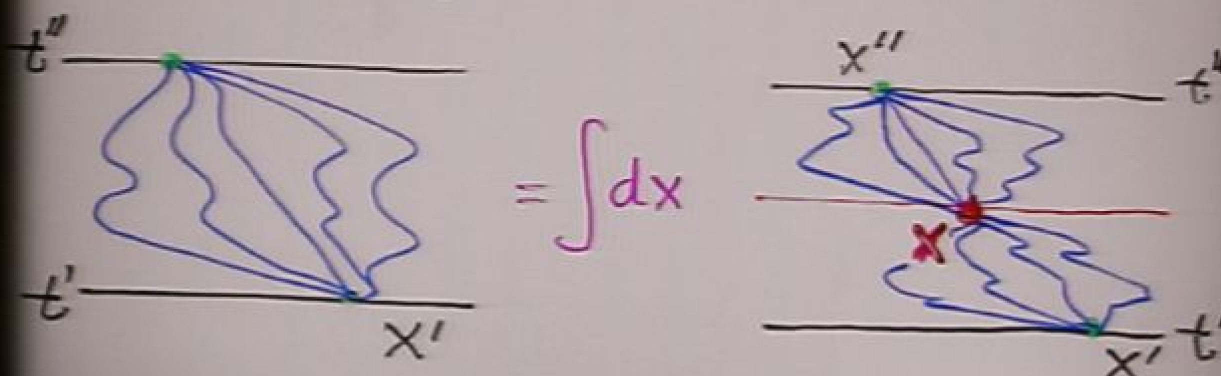
THIS SATISFIES SCHRÖDINGER EQN

$$i \frac{\partial \psi_A(x,t)}{\partial t} = H \psi_A(x,t)$$

EQUIVALENCE OF SUM OVER HISTORIES AND USUAL QUANTUM MECHANICS REQUIRES

- A FIXED SPACETIME GEOMETRY
- FOLIABLE BY A FAMILY OF SPACELIKE SURFACES THROUGH WHICH A STATE CAN EVOLVE.
- HISTORIES SINGLE VALUED IN THE TIME LABELING THESE SURFACES. (FIELDS OK)
- ALTERNATIVES AT MOMENTS OF TIME.



* THE MAIN POINT. *

THE USUAL QUANTUM MECHANICS OF STATES EVOLVING THROUGH SPACELIKE SURFACES NEEDS TO BE GENERALIZED TO APPLY WHEN

- SPACETIME IS NOT FIXED
- NOT FOLIABLE BY SPACELIKE SURFACES.
- HISTORIES ARE NOT SINGLE VALUED
- ALTERNATIVES NOT AT MOMENTS OF TIME.

FEYNMAN'S 4D SUM OVER HISTORIES QUANTUM MECHANICS SUPPLIES ONE KIND OF GENERALIZATION.

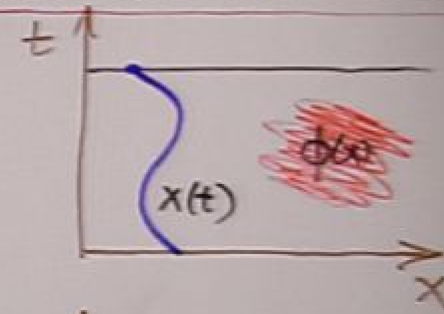
GENERALIZED QUANTUM THEORY

GELL-MANN, ISHAM, LINDEN, HALLIWELL, ...

ELEMENTS OF GENERALIZED QUANTUM THEORY

1) FINE GRAINED HISTORIES

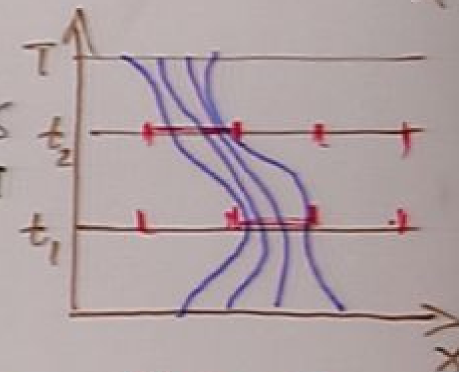
THE MOST REFINED POSSIBLE DESCRIPTION OF THE SYSTEM



2) COARSE GRAININGS

THE ALLOWED PARTITIONS OF A FINE GRAINED SET INTO CLASSES

C_α, $\alpha = 1, 2, 3, \ldots$



3) DECOHERENCE FUNCTIONAL $D(\alpha, \alpha')$

MEASURES INTERFERENCE BETWEEN MEMBERS OF A COARSE GRAINED SET

REQUIREMENTS

- i) HERMITICITY: $D(\alpha, \alpha') = D(\alpha', \alpha)^*$
- ii) POSITIVITY: $D(\alpha, \alpha) \geq 0$
- iii) NORMALIZATION: $\sum_{\alpha' \alpha} D(\alpha', \alpha) = 1$
- iv) SUPERPOSITION: $D(\bar{\alpha}', \bar{\alpha}) = \sum_{\substack{\alpha \in \bar{\alpha} \\ \alpha' \in \bar{\alpha}'}} D(\alpha', \alpha)$

  WHERE $\{C_{\bar{\alpha}}\}$ IS ANY COARSE GRAINING OF $\{C_\alpha\}$

ISHAM, SORKIN, GELL-MANN + others.

GENERALIZED QUANTUM THEORY (CONT'D)

- A DECOHERENCE CONDITION THAT DETERMINES WHICH SETS OF ALTERNATIVE COARSE-GRAINED HISTORIES MAY BE ASSIGNED PROBABILITIES.

e.g. **MEDIUM DECOHERENCE**

$$D(\alpha', \alpha) = 0 \quad , \quad \alpha' \neq \alpha$$

- CONSISTENT PROBABILITIES ARE A CONSEQUENCE OF DECOHERENCE

THE PROBABILITY OF AN INDIVIDUAL HISTORY α IS

$$p(\alpha) = D(\alpha, \alpha)$$

DECOHERENCE + REQUIREMENTS ON D IMPLY

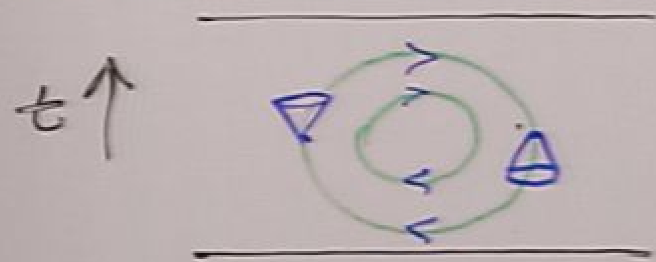
$$0 \leq p(\alpha) \leq 1$$

$$p(\bar{\alpha}) = \sum_{\alpha \in \bar{\alpha}} p(\alpha)$$

← THE MOST GENERAL PROBABILITY SUM RULE (CONSISTENCY)

FOR ANY COARSE-GRAINING $\{C_{\bar{\alpha}}\}$ OF $\{C_\alpha\}$

GENERALIZED QUANTUM MECHANICS ON SPACETIMES WITH CTC's



- NO FOLIATING FAMILY OF SPACELIKE SURFACES TO DEFINE THE EVOLUTION OF A STATE.

BUT: SPACETIME APPROACH O.K.

- HISTORIES: FIELDS $\phi(x)$
- ALTERNATIVES: PARTITIONS OF FIELDS INTO CLASSES, c_α
- BRANCH STATE VECTORS

$$|\Psi_\alpha\rangle = \int_{c_\alpha} \delta\phi \, e^{iS[\phi]} |\Psi_0\rangle$$

OK

FRIEDMAN, SIMON, PAPASTAMATIOU

KEY IDEA OF
GENERALIZED QUANTUM THEORY
APPLIED TO SPACETIME GEOMETRY

HISTORIES DO NOT HAVE TO REPRESENT EVOLUTION IN SPACETIME,

BUT CAN REPRESENT EVOLUTION OF SPACETIME.

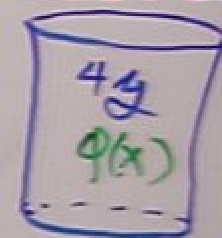
HISTORIES CAN BE FOUR-DIMENSIONAL SPACETIME GEOMETRIES

GENERALIZED QUANTUM MECHANICS OF SPACETIME GEOMETRY

(1) FINE-GRAINED HISTORIES

4-GEOMETRIES ${}^4g$

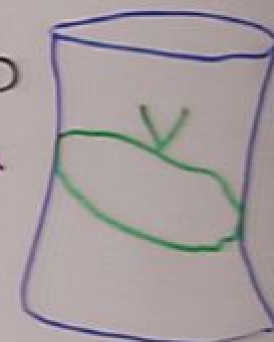
4-FIELD CONFIG. $\varphi(x)$



(2) COARSE-GRAINED HISTORIES

= PARTITIONS OF FINE-GRAINED HISTORIES INTO CLASSES. c_α

EX: BY WHETHER THE ${}^4g$ HAS A SPACELIKE SURFACE WITH VOLUME $> V_0$ OR NOT.



(3) DECOHERENCE MEASURE

BRANCHES FOR EACH C.G. HIST c_α

$$|\Psi_\alpha\rangle = \sum_{({}^4g,\varphi)\in c_\alpha} \exp\left[iS[{}^4g,\varphi]\right] |\Psi\rangle$$

↖ INITIAL COND OF U.

$$D(\alpha',\alpha) = \text{"}\langle\Psi_{\alpha'}|\Psi_\alpha\rangle\text{"}$$

A FULLY FOUR-DIMENSIONAL QUANTUM MECHANICS OF SPACETIME.

NO EQUIVALENT FORMULATION IN TERMS OF

- STATES ON SPACELIKE SURFACES
- SCHRÖDINGER EQN
- ⋮

STATES RECOVERED APPROXIMATELY WHEN GEOMETRY BEHAVES CLASSICALLY

- FOR CERTAIN COARSE GRAININGS AND INITIAL CONDITIONS

$$|\Psi_\alpha\rangle = \sum_{({}^4g,\varphi)\in c_\alpha} e^{iS[{}^4g,\varphi]}|\Psi\rangle$$

$$\approx \sum_{\varphi\in c_\alpha} e^{iS[{}^4g,\varphi]}|\Psi\rangle$$

SEMICLASSICAL GEOMETRY

THEN: THEORY EQUIVALENT TO FIELD THEORY IN FIXED ${}^4g$

CAUSAL STRUCTURE
TIME
STATES ON SPACELIKE SURFS
SCHRÖDINGER EQN.

APPROXIMATELY

IN THIS WAY, FAMILIAR
HAMILTONIAN QUANTUM MECHANICS
WITH ITS PREFERRED TIME(S)
EMERGES AS AN APPROXIMATION
IN THE LATE UNIVERSE,
APPROPRIATE TO THOSE INITIAL CONDITIONS
WHICH IMPLY CLASSICAL SPACETIME THERE,
IN A MORE GENERAL
SUM-OVER-HISTORIES FORMULATION
OF QUANTUM COSMOLOGY
FREE FROM THE PROBLEM OF TIME.

NO SPACETIME

QM CAN STILL BE APPLIED, IF WE HAVE:

- COMPLETELY FINE-GRAINED DESCRIPTIONS (DON'T CALL THEM 'HISTORIES')
- COARSE-GRAINING
- A MEASURE OF INTERFERENCE (D) BETWEEN ALTERNATIVES CONSISTENT WITH THE SUPERPOSITION PRINCIPLE.

GENERALIZED QUANTUM THEORY NEEDS NEITHER SPACE NOR TIME.

EMERGENCE

$$D^{fund}(\alpha',\alpha) \approx D^{eff}(\alpha',\alpha)$$

APPROXIMATE EQUALITY ONLY FOR A LIMITED CLASS OF COARSE GRAININGS AND SPECIFIC HISTORIES HERE, DESCRIBING THE (EMERGENT) PHENOMENA ASSUMED HERE

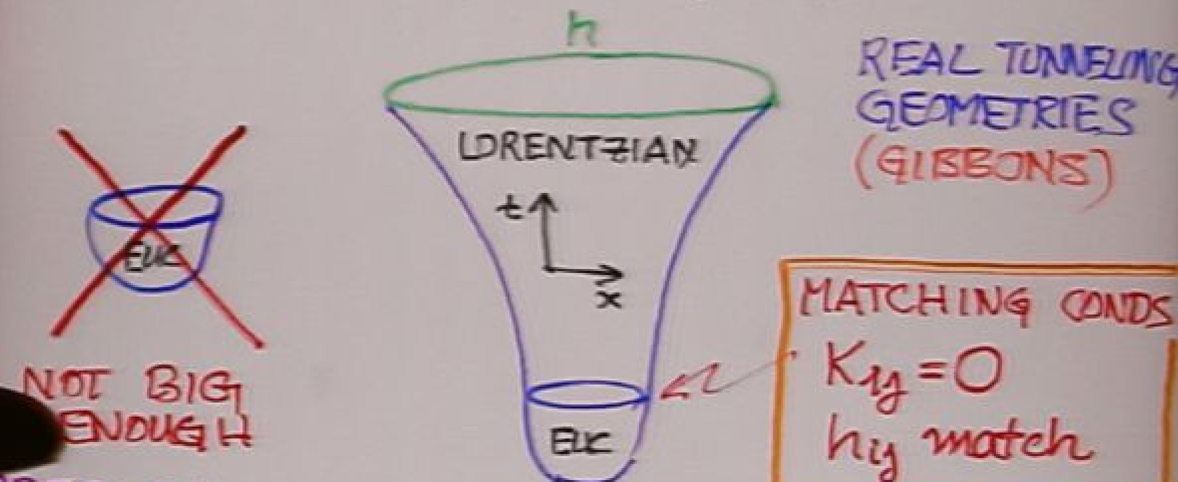
- EFFECTIVE FIELD THEORIES
- THE QUASICLASSICAL REALM
- MEASUREMENT, STATES ON SPACELIKE SURFACES
- CHEMISTRY, GEOLOGY, HUMAN HISTORY

CLASSICAL SPACETIME EMERGENT FROM NO-BOUNDARY WAVU

$$\Psi[h] = \int \delta g \, e^{-I[g,\Lambda]/\hbar} \approx A\cos(S[h]/\hbar)$$

"NO-BOUNDARY" — $\Lambda > 0$ — SEMICLASSICALY

ASK FOR THE SEMICLASSICAL GEOMETRIES ENDING IN A LARGE $(R \geq \Lambda^{1/2})$ SYMMETRIC 3-GEOMETRY h.



PREDICT:

LORENTZIAN NOT EUC. SPACETIME

1 TIME (TWO WOULDN'T MATCH)

CLASSICAL SPACETIME EMERGENT FROM NO-BOUNDARY WAVU

$$\Psi[h] = \int \delta g \, e^{-I[g,\Lambda]/\hbar} \approx A\cos(S[h]/\hbar)$$

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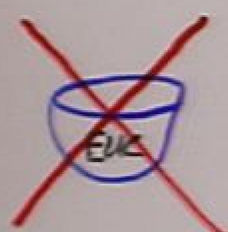
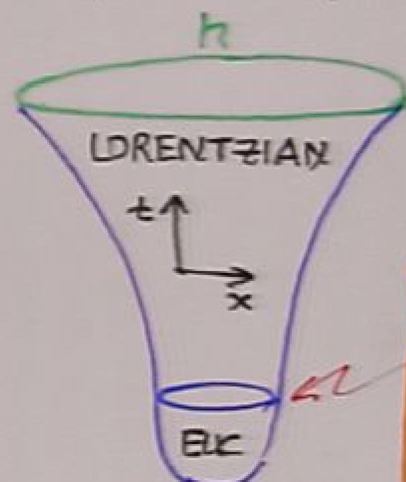


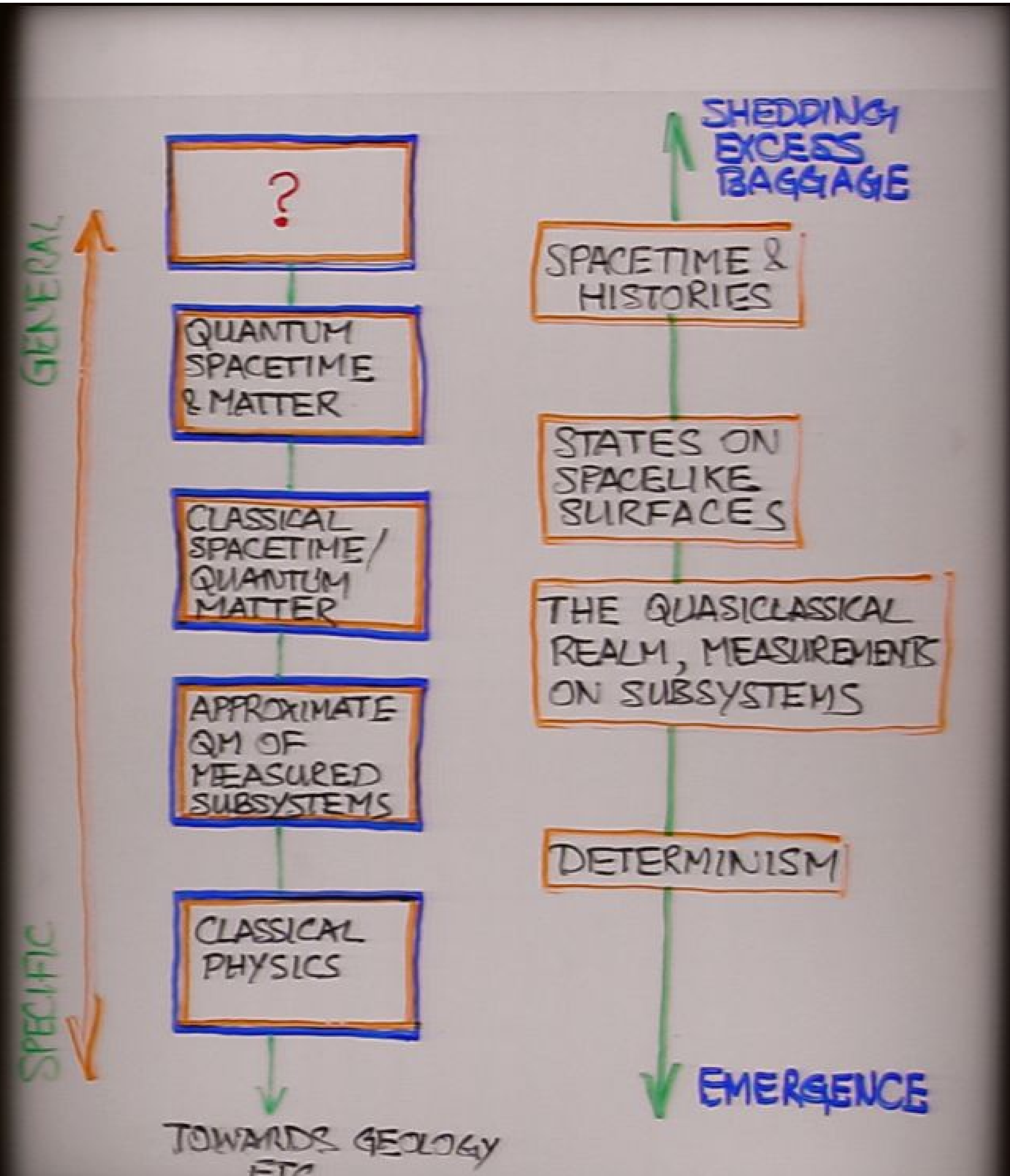


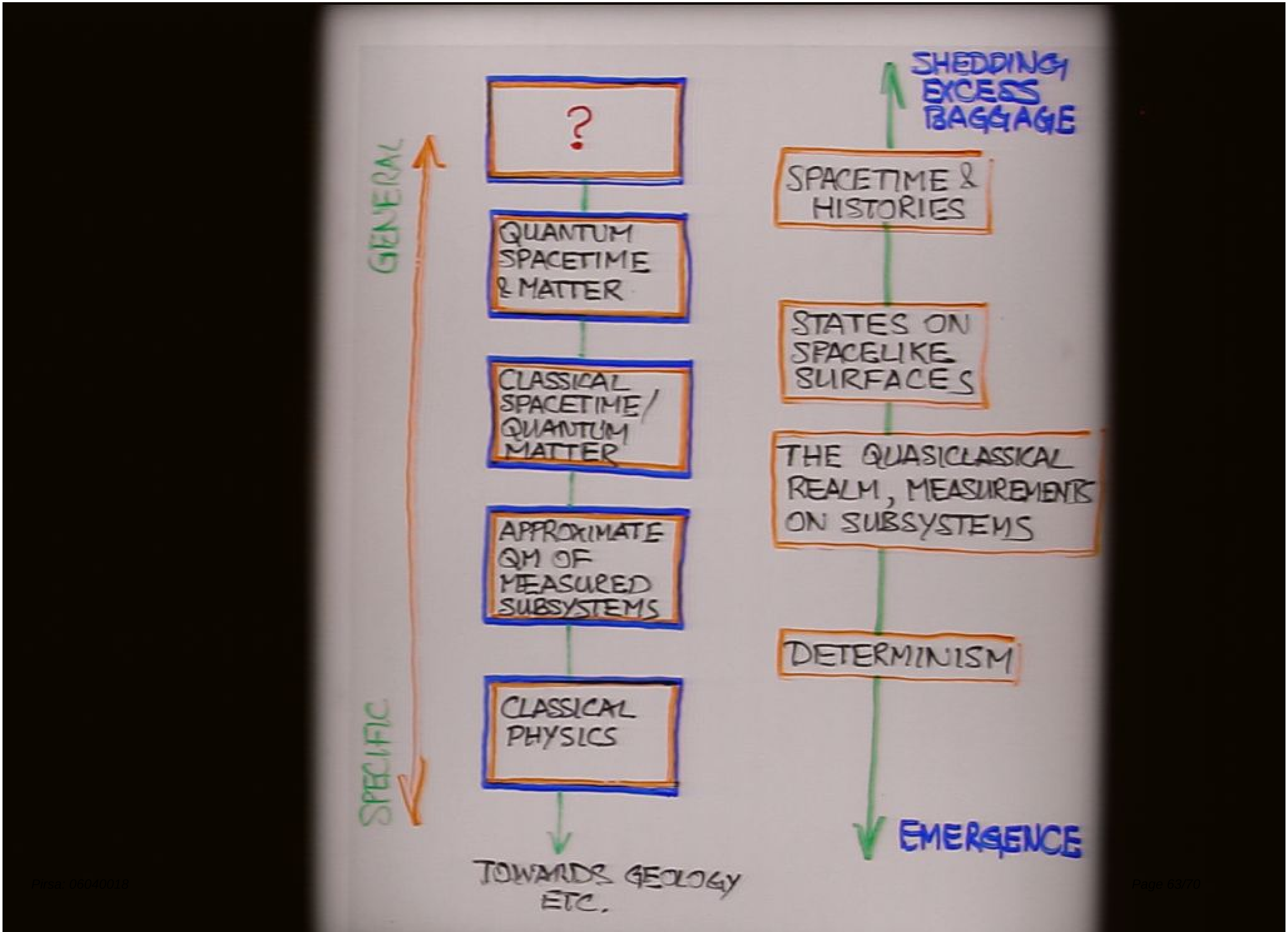
REAL TUNNELING GEOMETRIES (GIBBONS)

MATCHING CONDS
$K_{ij} = 0$
h_{ij} match

PREDICT:

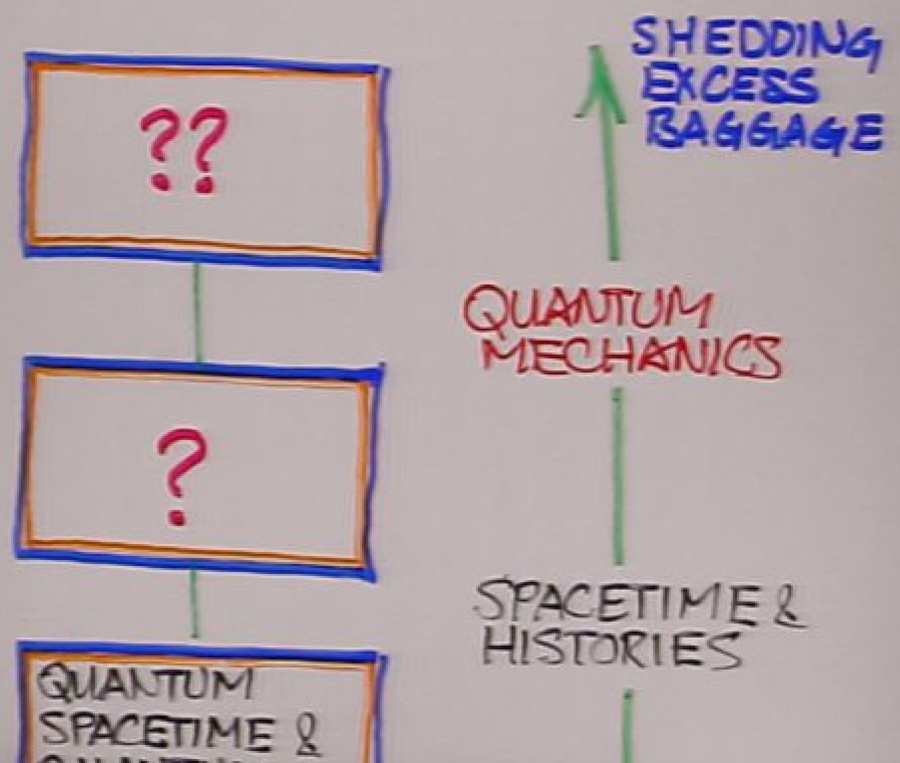
LORENTZIAN NOT EUC. SPACETIME
1 TIME (TWO WOULDN'T MATCH.)


GENERAL
SPECIFIC
?
QUANTUM SPACETIME & MATTER
CLASSICAL SPACETIME/ QUANTUM MATTER
APPROXIMATE QM OF MEASURED SUBSYSTEMS
CLASSICAL PHYSICS
TOWARDS GEOLOGY
SHEDDING EXCESS BAGGAGE
SPACETIME & HISTORIES
STATES ON SPACELIKE SURFACES
THE QUASICLASSICAL REALM, MEASUREMENTS ON SUBSYSTEMS
DETERMINISM
EMERGENCE


?
QUANTUM SPACETIME & MATTER
CLASSICAL SPACETIME/ QUANTUM MATTER
APPROXIMATE QM OF MEASURED SUBSYSTEMS
CLASSICAL PHYSICS
TOWARDS GEOLOGY ETC.
GENERAL
SPECIFIC
SHEDDING EXCESS BAGGAGE
SPACETIME & HISTORIES
STATES ON SPACELIKE SURFACES
THE QUASICLASSICAL REALM, MEASUREMENTS ON SUBSYSTEMS
DETERMINISM
EMERGENCE

WHY QUANTUM MECHANICS?

- COMPLEMENTARITY: WHAT IS ITS ORIGIN WHEN APPLIED TO THE UNIVERSE, WHICH IS NEVER MEASURED?
- SUPERPOSITION: WHAT IS ITS ROLE WHEN THERE IS ONLY ONE STATE?



THE QUESTION:

DOES QUANTUM MECHANICS APPLY TO SPACETIME?

THE ANSWER:

YES BUT THE USUAL TEXTBOOK FORMULATION MUST BE GENERALIZED TO DO SO.