Title: Quantum cosmology from first principles: second thoughts

Speakers: Lee Smolin

Series: Colloquium

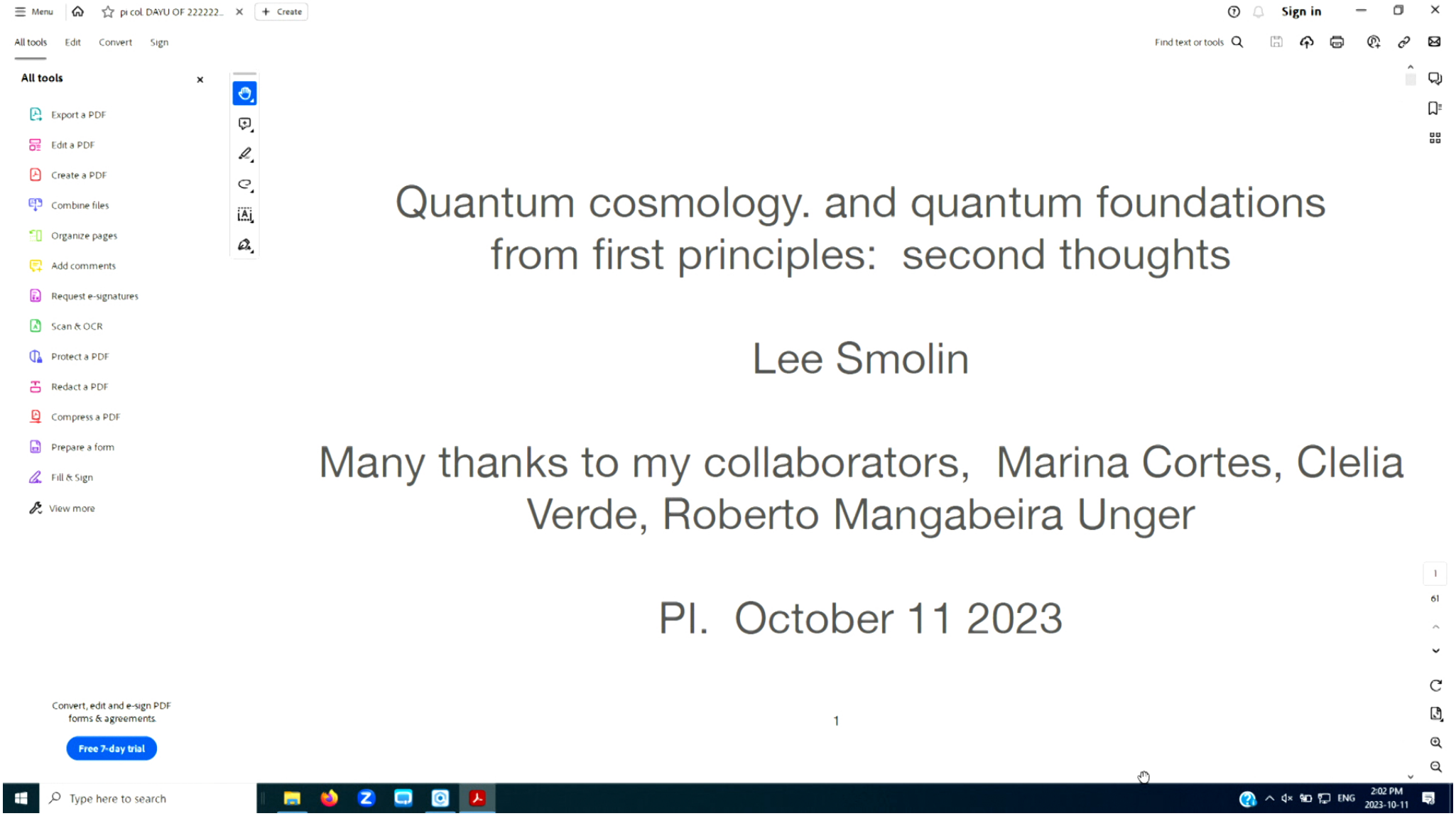
Date: October 11, 2023 - 2:00 PM

URL: https://pirsa.org/23100057

Abstract: I argue that the answer is yes, by reviewing the history and current status of such a theory. Since 1982, I have been developing a series of such theories, beginning in 1982 with an N --> infinity limit of 2+1 dimensional matrix model (the IAS model), through another N --> infinity, T --> 0 limit of a BFSS model. During this time our work was complemented by Adler's Trace model and others.

Beginning in 2012, Cortes and I developed a different approach to an relational quantum cosmology by adding intrinsic energy momentum to Sorkin et al's causal set models. The addition of energy- momentum as intrinsic variables opens up a new mechanism for the emergence of space, and spacetime, plus interacting relativistic particles. Note that the warm phase is purely algebraic, you need no prior existence of any space to get other dimensions to emerge. In 2021 I discovered how to derive quantum non-relativistic many body theory from what has since been called the Causal Theory of Views. Finally in papers since we report progress on the construction of special and general relativistic Causal Theory of Views.

Zoom link: https://pitp.zoom.us/j/95891848248?pwd=TUpWK2RWbU9GTGxZS1lMeS81QWp1dz09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Quantum cosmology. and quantum foundations from first principles: second thoughts
Lee Smolin
Many thanks to my collaborators, Marina Cortes, Clelia Verde, Roberto Mangabeira Unger
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What if the realists are right...
And QM is wrong in the end?
So some Nonlocal hidden variables theory is right!!

Do there exist now some promising directions to make non-local hidden variable theories?

YES: N —> infty limits of certain matrix models..

LS 1983, and on, Adler, Markopoulou, ...

Key Idea: eigenvalues are beables
MATRIX elements are flluctuations, scale as T and Match T and 1/N as T—>. 0

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Main Idea:

Eigenvalues are beables —> observables
Matrix elements are flluctuations,
scale w T and 1/N as T—> 0

Space goes away, emerges at leading order in 1/N

Matrix elements are hidden, non-local variables.

Corrections to QM computed as next order
In 1/N: N~ 10^{80}.
Might be testable cosmologicaly

Joined by Adler's Trace Dynamics —> QFT

—works for certain limit of KKLT/BFSS/M theory action. (LS)

meets LQG: matrices are agacency matrices of spin-networks with non-local links

2010. Meets causal sets which become Energetic causal sets. Marina Cortes (2012…)

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Leibnizian relationalism:

The universe contains everything that is the case,
There is nothing outside or apart from it.

The universe contains a large number of subsets. The intersection of the past with a subset defines a past neighboughood.

The neighbourhoods of every event are unique. Each are one of an an infinite number of neighbourhoods.

The universe has many small subsystems, which satisfy the rules of finite products ,
unions and intersections of intuitionalistic logic. (Heyting Algebras. Markopopulou)

An observer produces “propositions”; these are relatively stable records that
are consonant with intuitionalistic logic.

Relative to an observation, a proposition can be definite or indefinite

“Definite” means that it responds the same way to the same conditions.

This implies evolution is deterministic.

“Indefinite” means the system does not respond the same way to the same conditions.

This gives us causal; but un-deterministic evolution

The basic Ontology is that of Energetic Causal Sets: time is real, space is emergent
(MARKOPOULOU)

No fundamental objects (beables).
Fundamental actions (happenables), are events,

Causal relations, between events, mark transfer of energy and momentum from causally earlier events to causally later events.

Time is the process which continually brings into being novel events. By doing so they transform what were a moment ago future, and thus, potential, events into, first present, then past, events

The *views of an events is what that event* knows of its causal past by the information passed to it from its backwards light cone.

Emergent properties are then those properties left behind as the future disappears and are thus left only in the present records of the past, now present events:

space, time, space-time
particles and their dynamics in spacetime
quantum states and dynamics in spacetime

How energetic causal sets evolve:

- Any given observer is always in the present.
  - "***The time is always now!!!!!***"
- Relative to a particular event or observer-moment, the other events fall into three classes: present, past, or future.
- In each moment, N present events are chosen from the set of present events their "children."
- .These produce a new present event, by a rule called **THE RULE.**
- These present events increase each of their number of children by one. We say that the N events **cause** the new event. The gives the set of events a partial order.

No present event can have more than M children. When it does, it becomes a Past event.

- A past event can have no more influence on the future. In this sense, past events do not exist
- A present event is one that has been created in a prior move, but has less than its quota of M children

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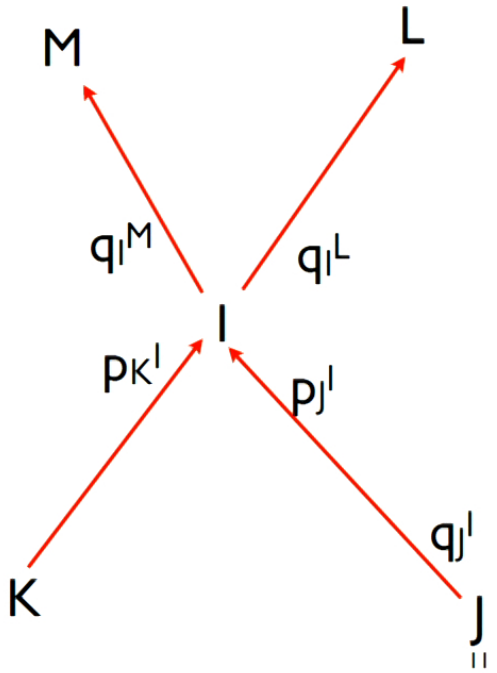
Energetic causal sets:

Each link, connecting E_I to one of its parents, E_J, has two momenta, an incoming momenta $p_J{}^I$ and an outgoing momentum $q_I{}^J$.

The total momenta of an event $$P_a^I = \sum_J p_{aI}^J$$



SUMMARY: **Dual Causal Views Ontology**:

Fundamental (beables): (equivalent)

Views
Time as the process which continually brings into being novel views, from present views.

Distances. —> Differences: D(I,J)

Implies—> Events and their causal relations
Energy and momentum and other conserved quantities

Emergent:

space-time
particles and their dynamics in spacetime
quantum states and dynamics in spacetime

The universe is made up of nothing but partial views of itself!

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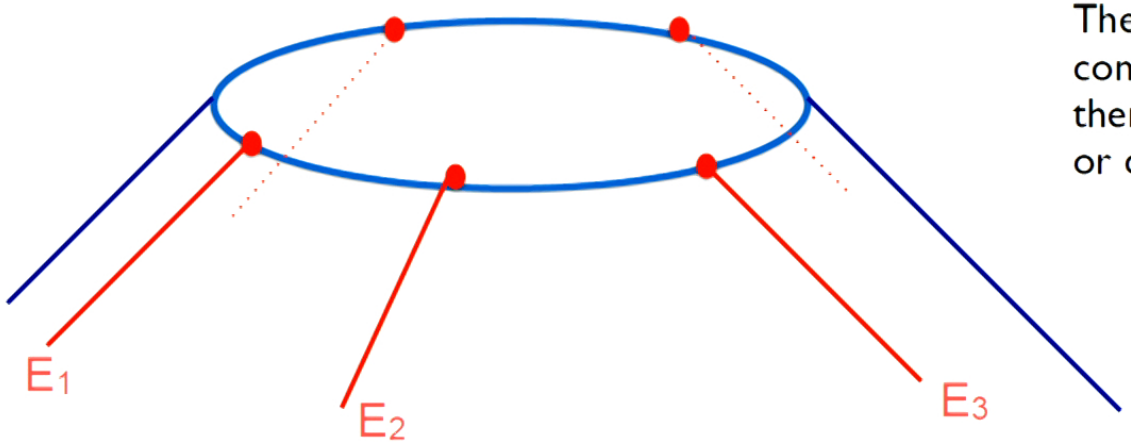
Views as punctured two spheres: *the sky!*

The view of an event is a collection of null or timeline energy momentum vectors, representing incoming information about the past. $\{ p_a{}^J , p_a{}^K , \dots \}$.

We can represent the directional information as points on an S^2, with labels which are the energy.



There are also views of composite events, as when there is entanglement or coherent states.

NEXT STEPS

We add a highly non-local interaction, which acts to extremise the diversity of the set of views.

As there is fundamentally no space, the potential energy cannot depend on distances on space, or spatial derivatives.

Instead, the potential energy is a function of the differences amongst the views. We choose it to be U = - Variety

~~"Systems more likely to interact if they are nearby in spacetime".~~ → "Systems more likely to interact if they have similar views of their causal pasts;"

Views interact strongly with similar views around the universe. This creates a tightly coupled ensemble with similar statistical distributions. We construct quantum states from these ensembles.

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We derive quantum mechanics in the non-relativistic approx. in which we neglect differences in the frames of an event.

We define e ensembles, a set, S, of events such that

$$\mathcal{D}_{IJ} < \epsilon, \qquad \forall I, J \in \mathcal{S}$$

We posit that the quantum state describes this ***real ensemble*** of similar systems. The variety potential gives a non-local interaction which resists similarity. This is the explanation of quantum phenomena.

We introduce a probability distribution on this ensemble, r.

$$< \mathcal{O} >= \frac{1}{N} \sum_{K \in \mathcal{S}} \mathcal{O}_K = \int d^d w \rho(w) \mathcal{O}(w)$$

The variety turns into the integral of Bohm's quantum potential.

$$\mathcal{V} = \frac{1}{4} \int dw ds \ \rho \ (\frac{1}{\rho} \partial_i \rho)^2$$

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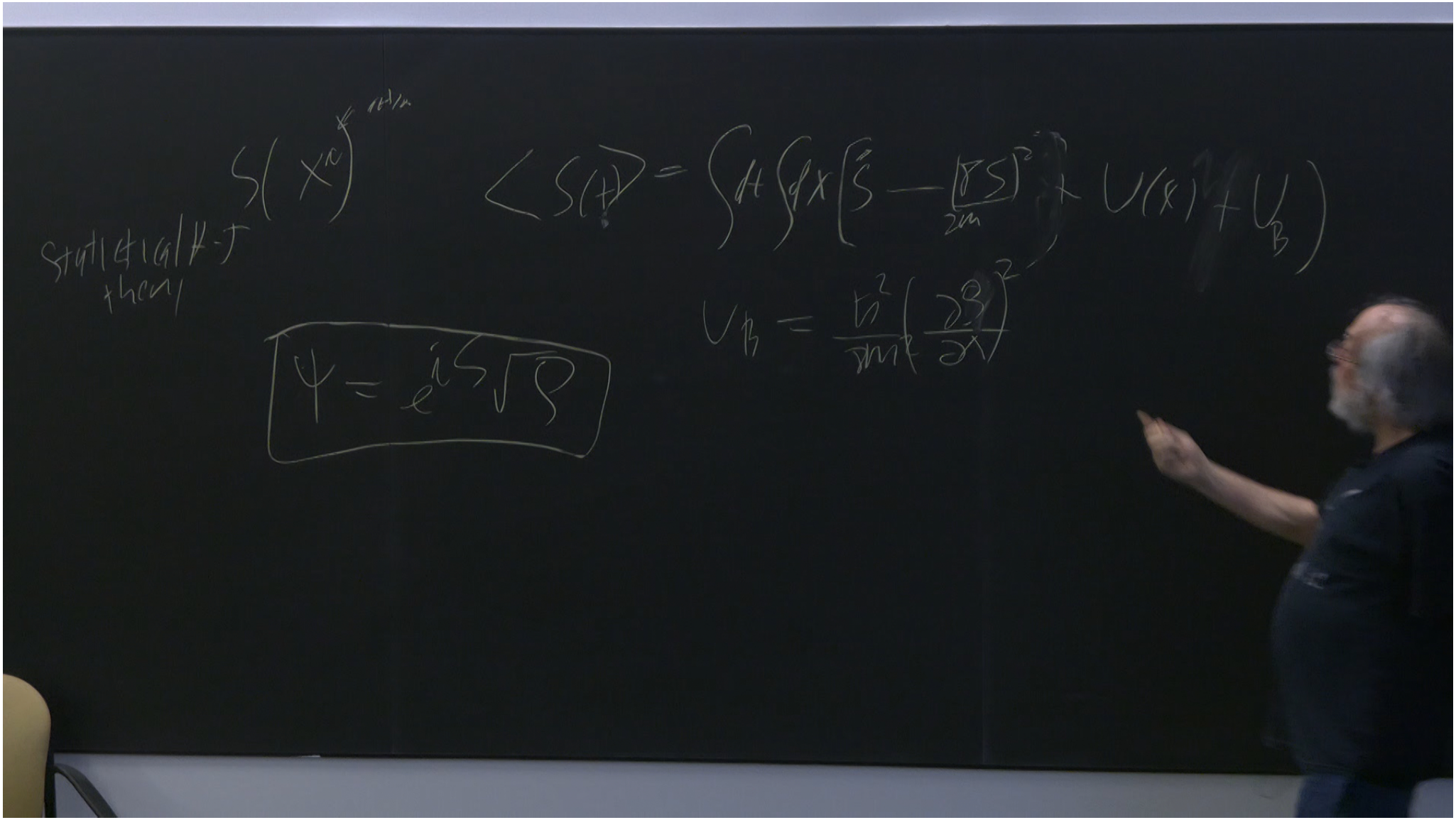
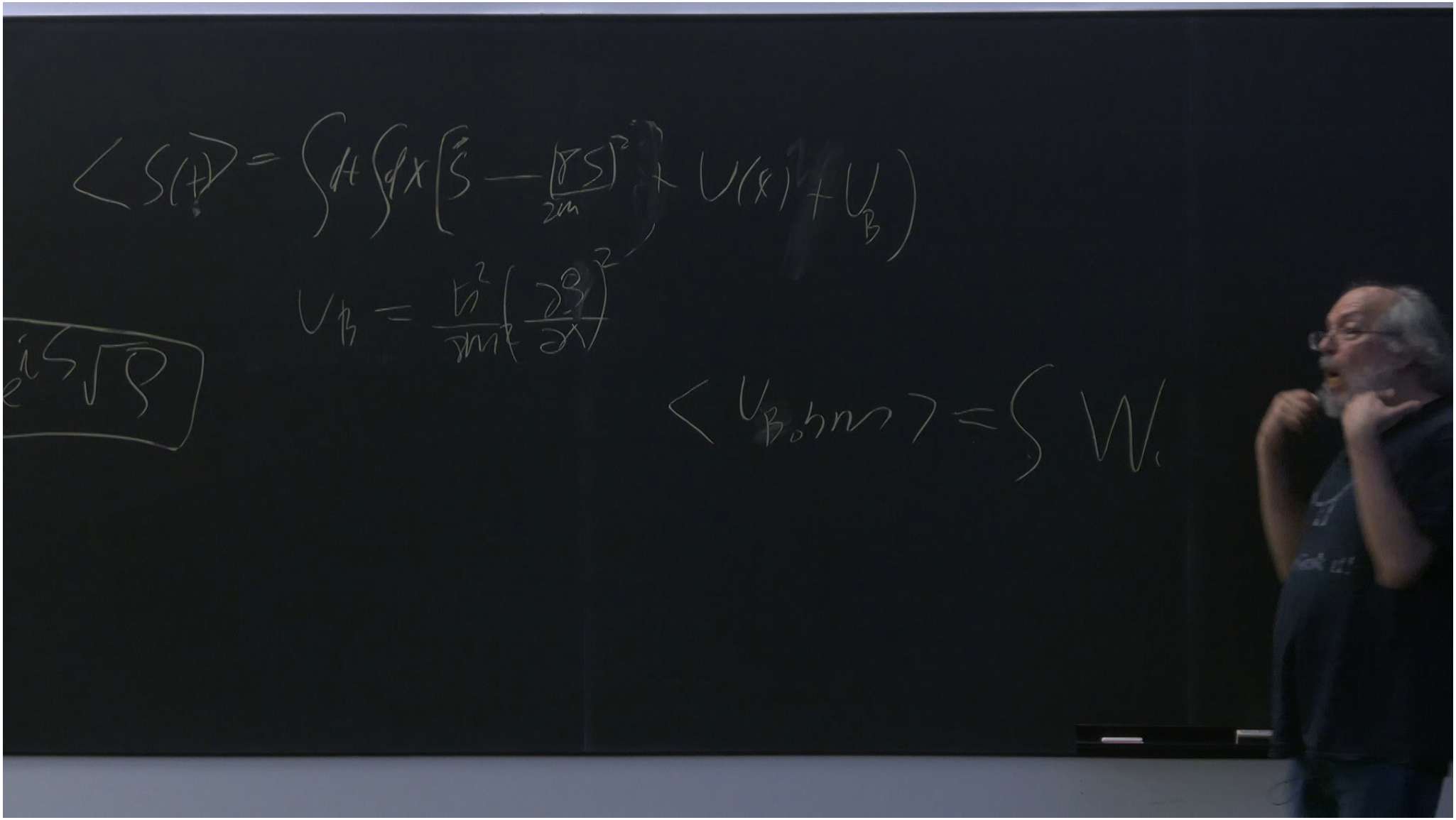
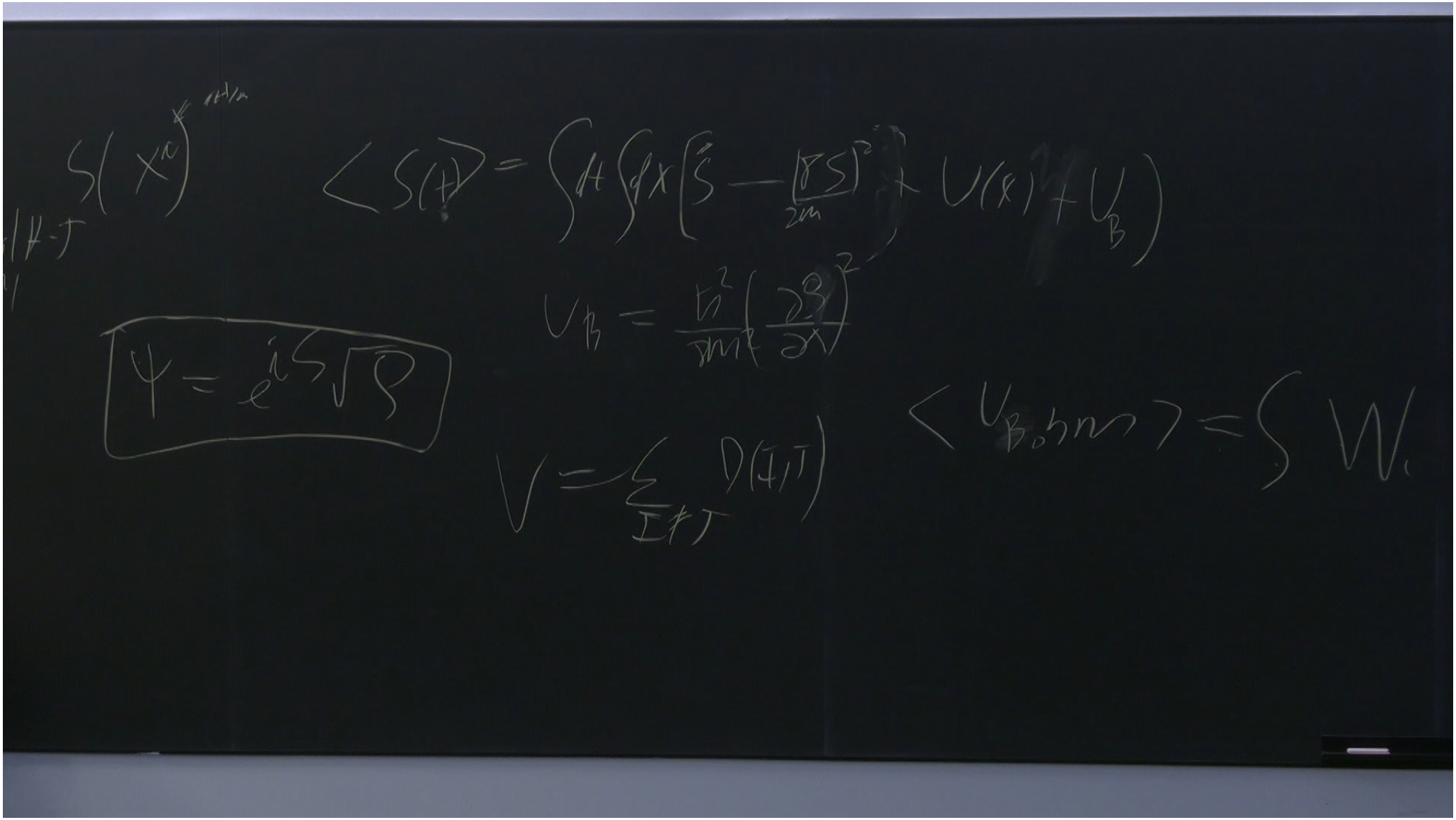
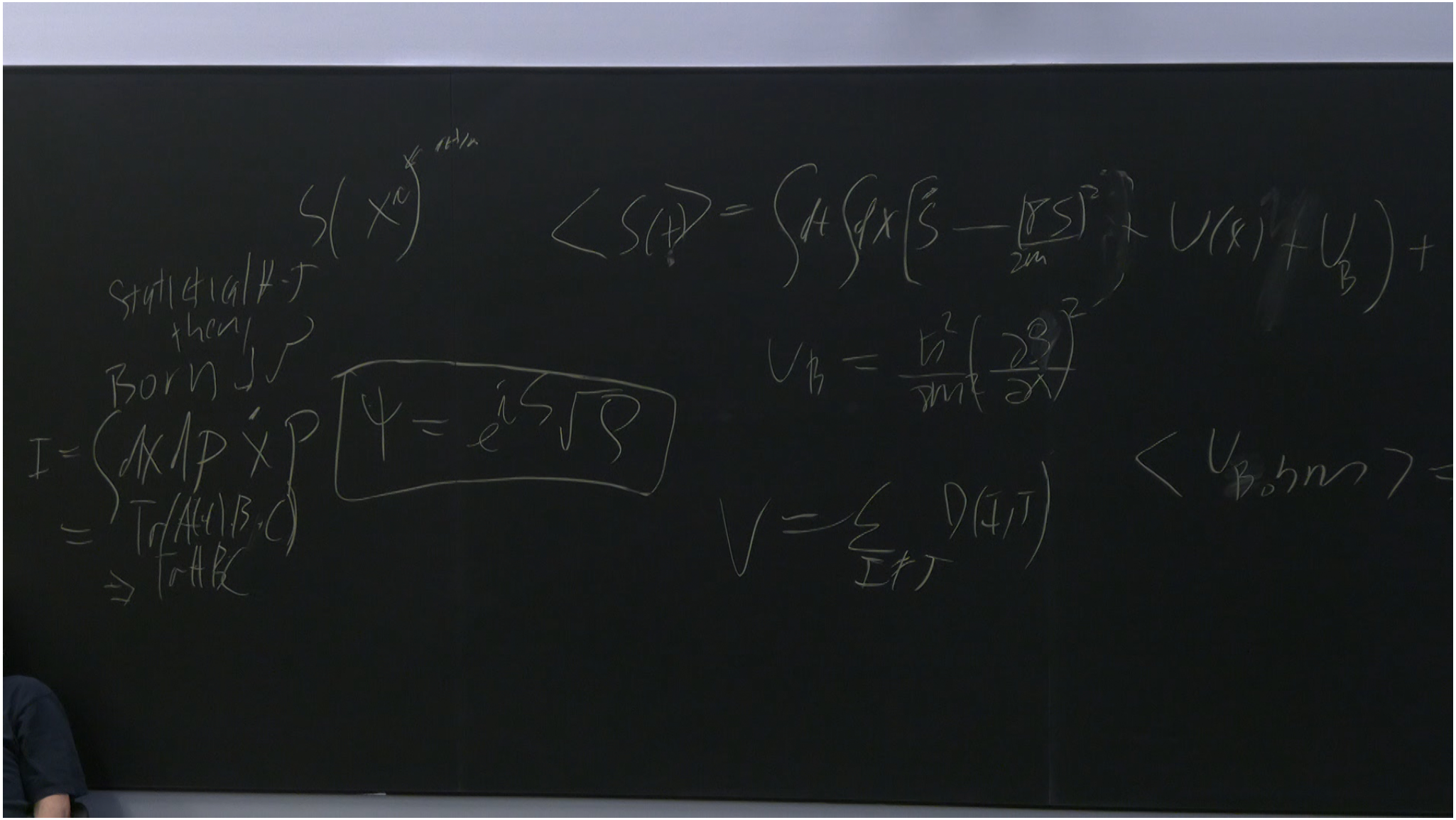

$S(x^\alpha)$
$\langle S(t) \rangle = \int dt \int dx \left[\dot{S} - \frac{(\nabla S)^2}{2m} + U(x) + U_B \right]$
$U_B = \frac{\hbar^2}{2m} \left(\frac{\partial \beta}{\partial x} \right)^2$
$\psi = e^{iS/\hbar} \sqrt{\rho}$


$\langle S(t) \rangle = \int dt \int dx \left(\mathcal{L} - \frac{(\partial S)^2}{2m} + U(x) + U_B \right)$
$U_B = \frac{\hbar^2}{8m} \left(\frac{\partial \rho}{\partial x} \right)^2$
$\langle U_{B,3m} \rangle = \int W$


$\Psi = e^{iS/\hbar}\sqrt{\rho}$
$V = \sum_{I \neq J} D(I,J)$
$\langle U_{B,hm} \rangle = \sum W_i$


Statistical H-J
then
Born
$\Psi = e^{iS/\hbar}$
$U_B = \frac{\hbar^2}{2m} \frac{\partial^2}{\partial x^2}$
$V = \sum_{I \neq J} D(I,J)$