Title: Quantum foundations in the light of quantum gravity (Part 1A)

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Abstract:

Quantum gravity in the light of quantum foundations

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August 07

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Issues:

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   a) The measurement/reality problem in cosmology

The measurement or reality problem

We do not observe quantum states. We do not see ourselves as a vector or matrix in a very large complex linear space.

We observe particles which have positions and trajectories
We observe waves with frequencies and wavelengths.

How do we get from the quantum state description to what we observe?

or

What is the relationship between the quantum state description and physical reality?

Quantum theory requires a division of the world into

system + environment

The quantum states refer to the system. We, plus our experimental apparatuses and clocks are in the environment.

Von Neumann's rule 1: When we do not make a measurement the system evolves unitarily

Von Neumann rule 2: When we do make a measurement of an observable O represented by an operator **O,** if the system is in state |T> we see the eigenvalue O_I with probability $|\langle O_I|T\rangle|^2$

What is a measurement? Why is it distinguished?

Can we extend this to a closed system like the universe where there is only a system and no environment?

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ANSWERS/INTERPRETATIONS,

assume that the formalism is correct

Bohr, this is what we must do because physics is an extension of ordinary langauge we use to describe our interactions with nature.

Can't be applied to the whole universe by definition.

What is a measurement? Why is it distinguished?

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Everett, physical reality is just the quantum state, what is predicted are just correlations. The different outcomes live in "different branches of the universe"

This fails because of the preferred basis problem-there are an infinite number of bases to use to define the branches

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Decoherent histories: a fancy version of this applied to histories and not states

Fails because there are many sets of decoherent histories and most are not semiclassical. Leads to a radical version of many realities

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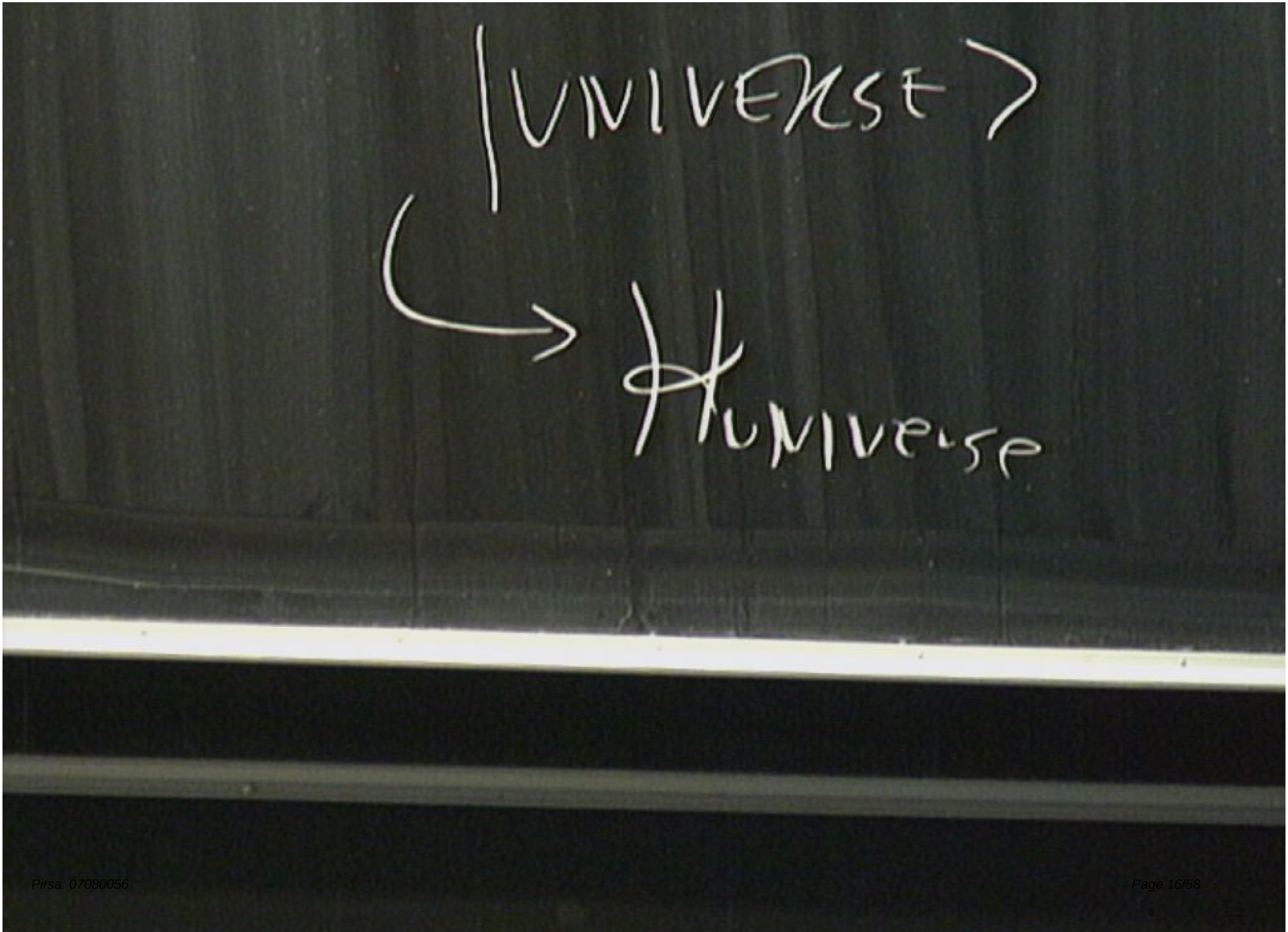
Decoherence: let the environment decohere/select the preferred basis. This is a real physical effect.

But it requires an environment and hence cannot solve the reality/measurement problem for the universe as a whole.

My conclusions:

After many years of trying, no interpretation of quantum mechanics extends convincingly to a closed system that contains its observers.

Unless this changes, a new cosmological theory is needed that will reduce to quantum mechanics for small subsystems, where we have acceptable interpretations as well as good experimental evidence.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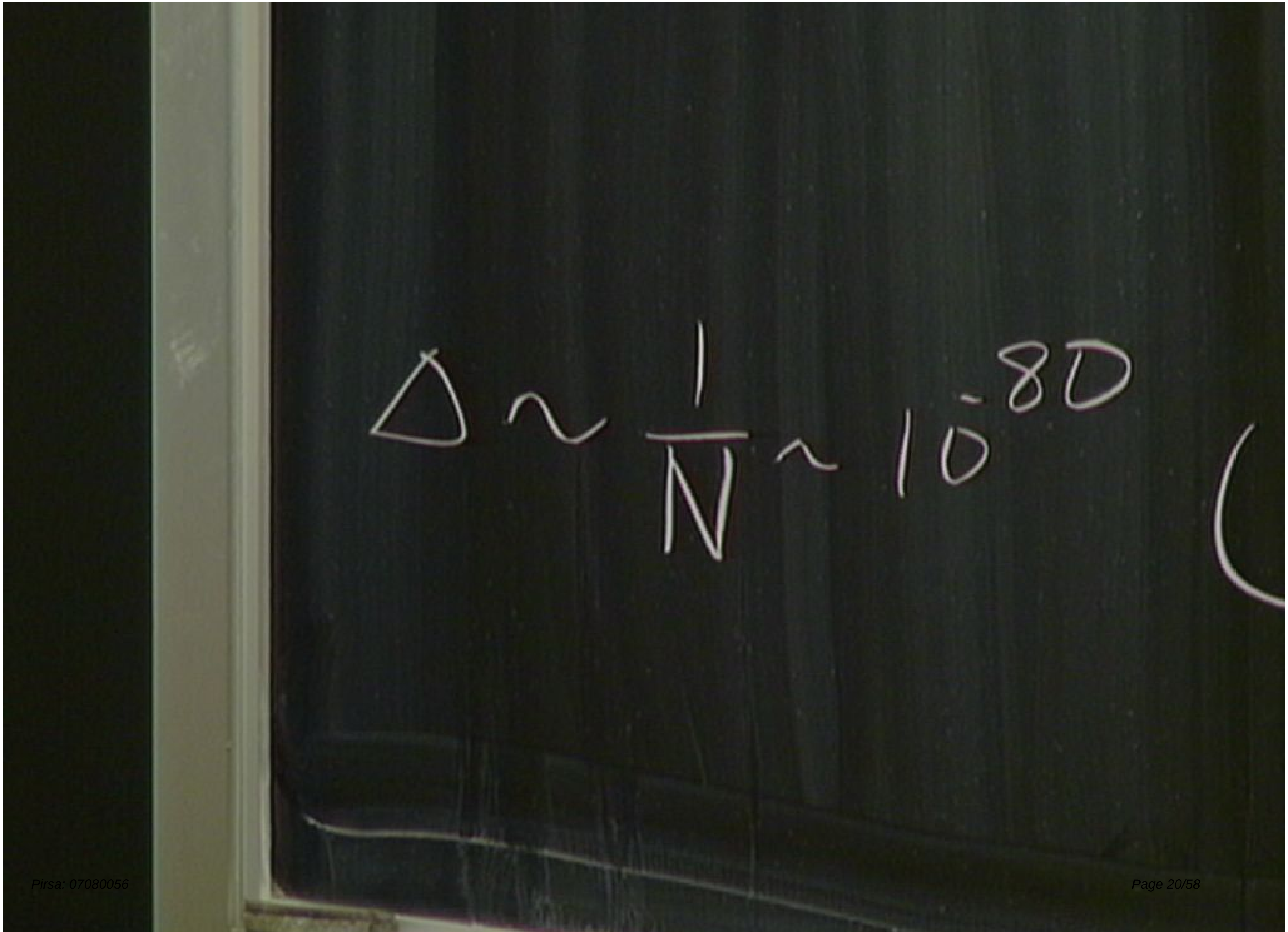
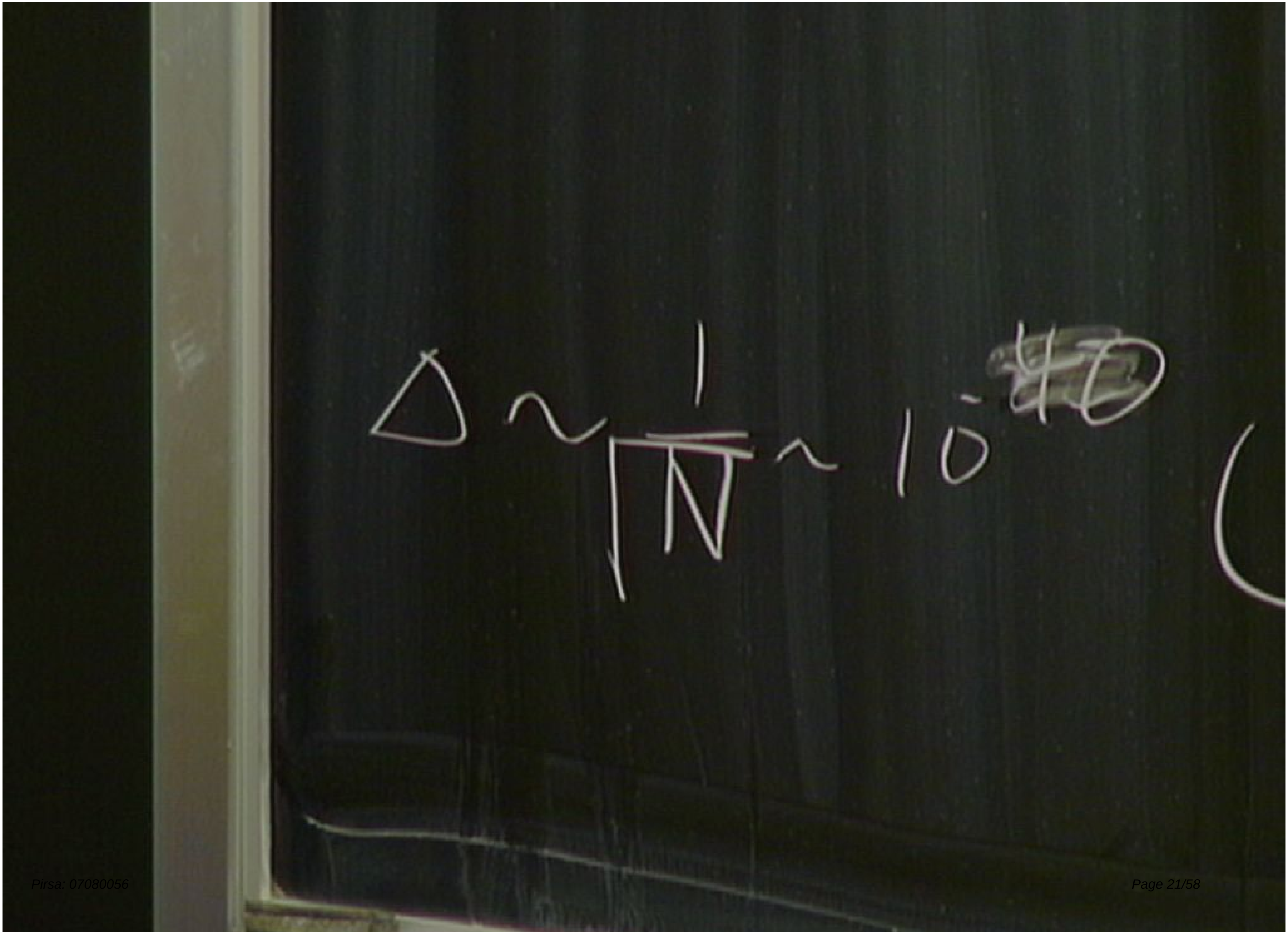
How do we find this new theory?

Where should we expect to see the first corrections?


$\Delta \sim \frac{1}{N} \sim 10^{-80}$


$\Delta \sim \frac{1}{\sqrt{N}} \sim 10^{-40}$

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   b) What is probability without an external time?

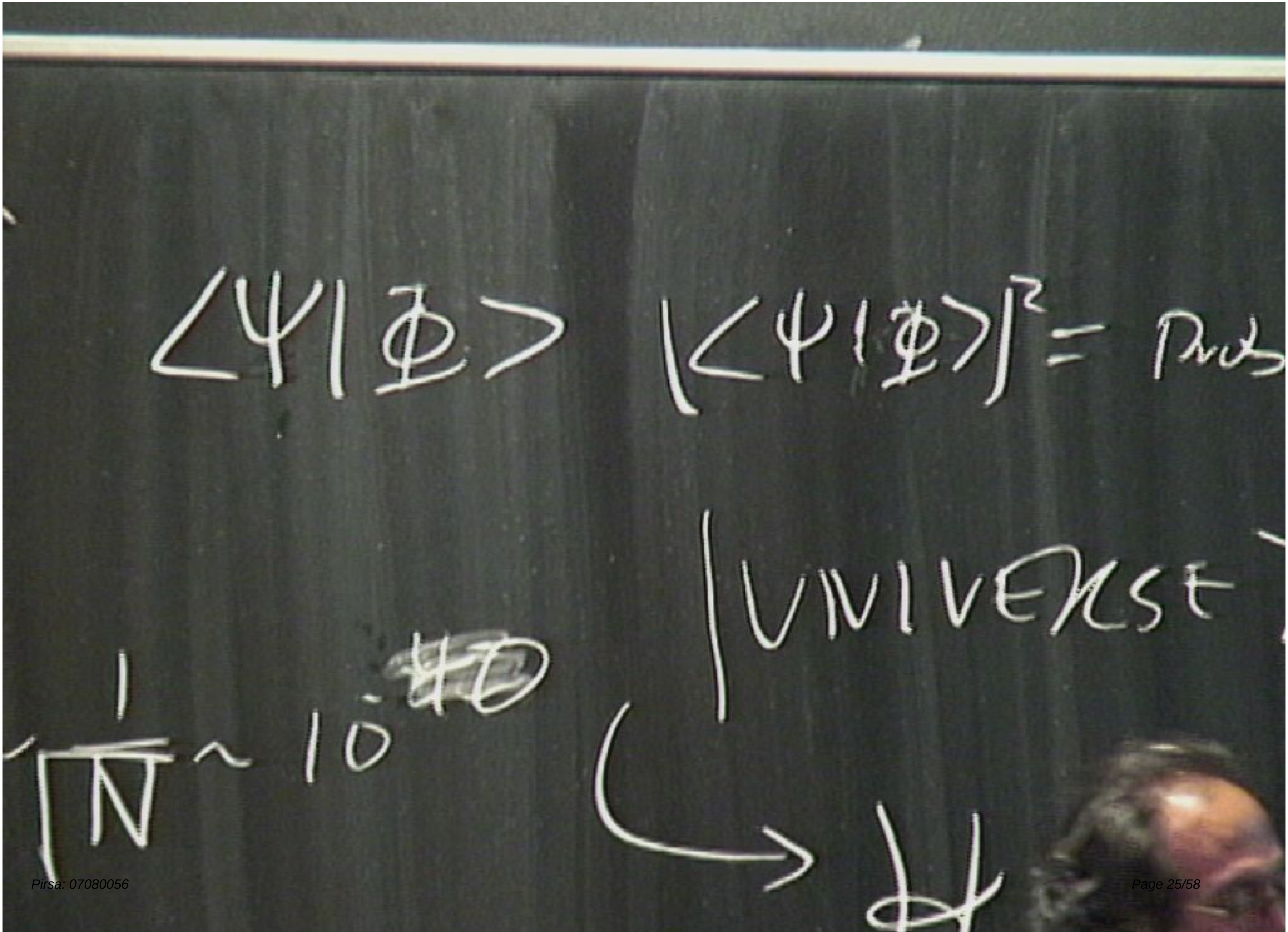
What is probability without an external time?

The inner product <A|B> distinguishes which operators are hermitian or unitary.

Unitary evolution conserves probability with respect to a clock outside the system

$$i\,d/dt\,|\Psi\rangle = H\,|\Psi\rangle$$

t is a clock outside the quantum system.unitarity implies the probabilities for the different possible outcomes for any time t, measured by that external clock add up to unity.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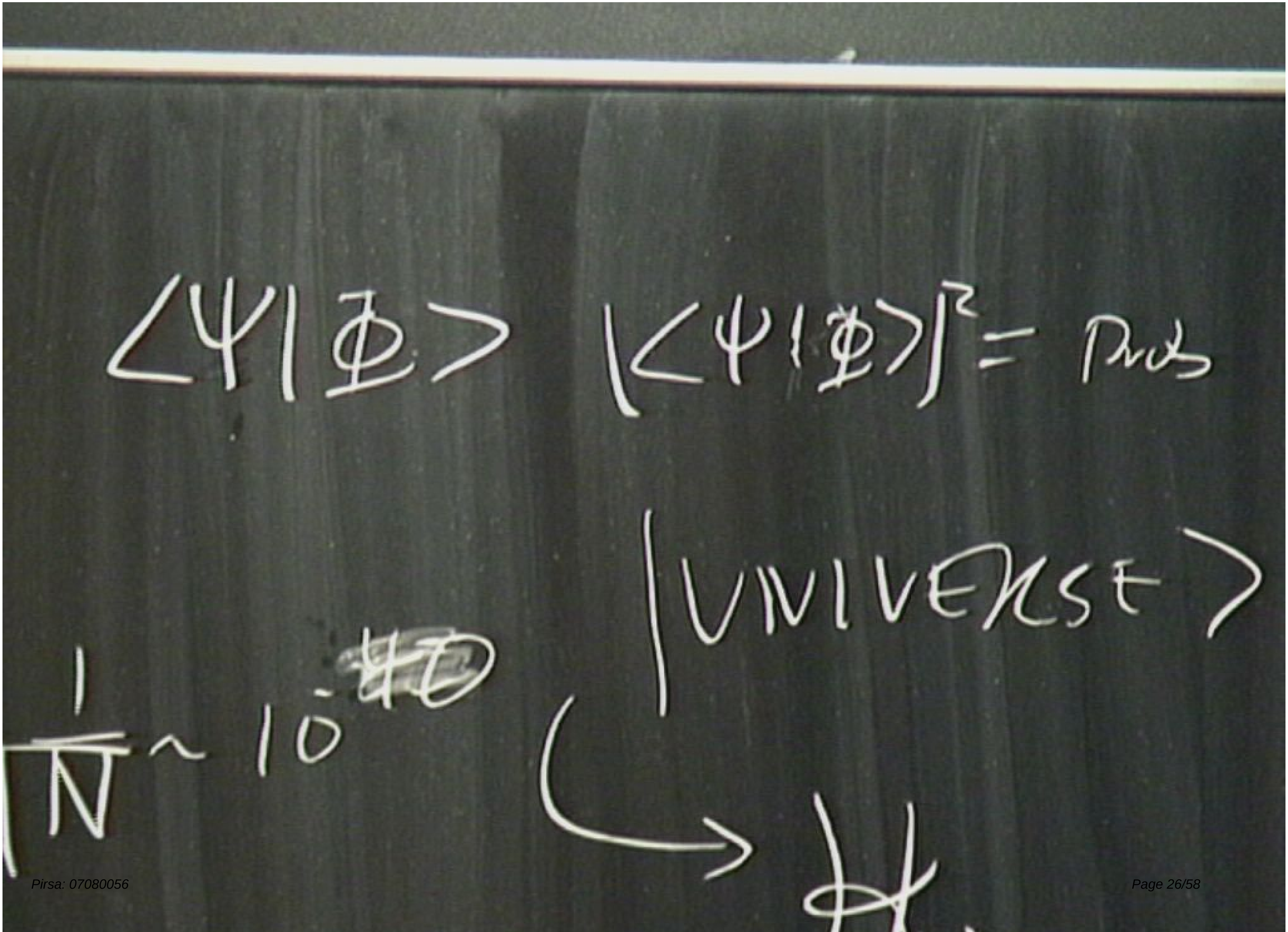
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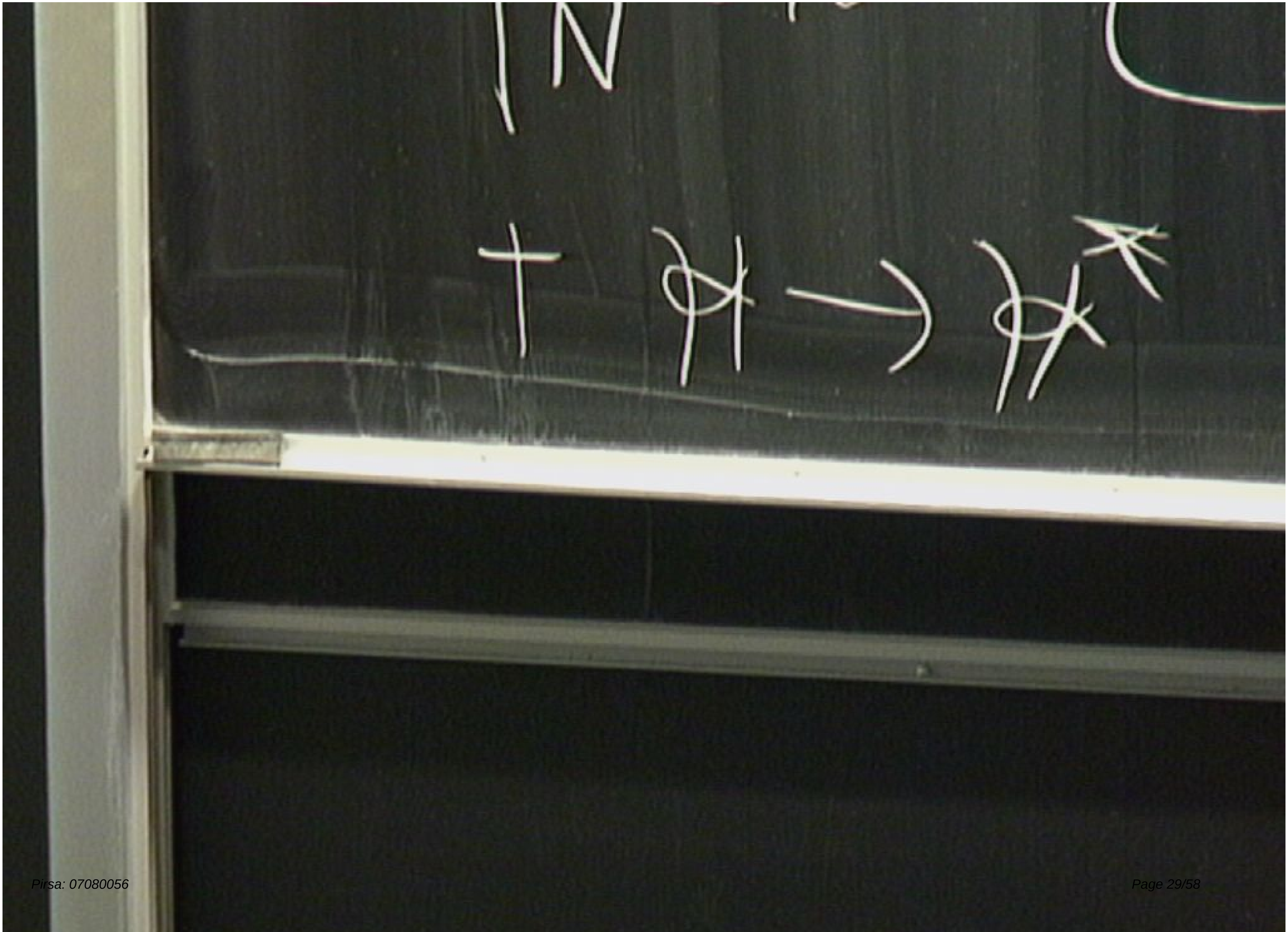
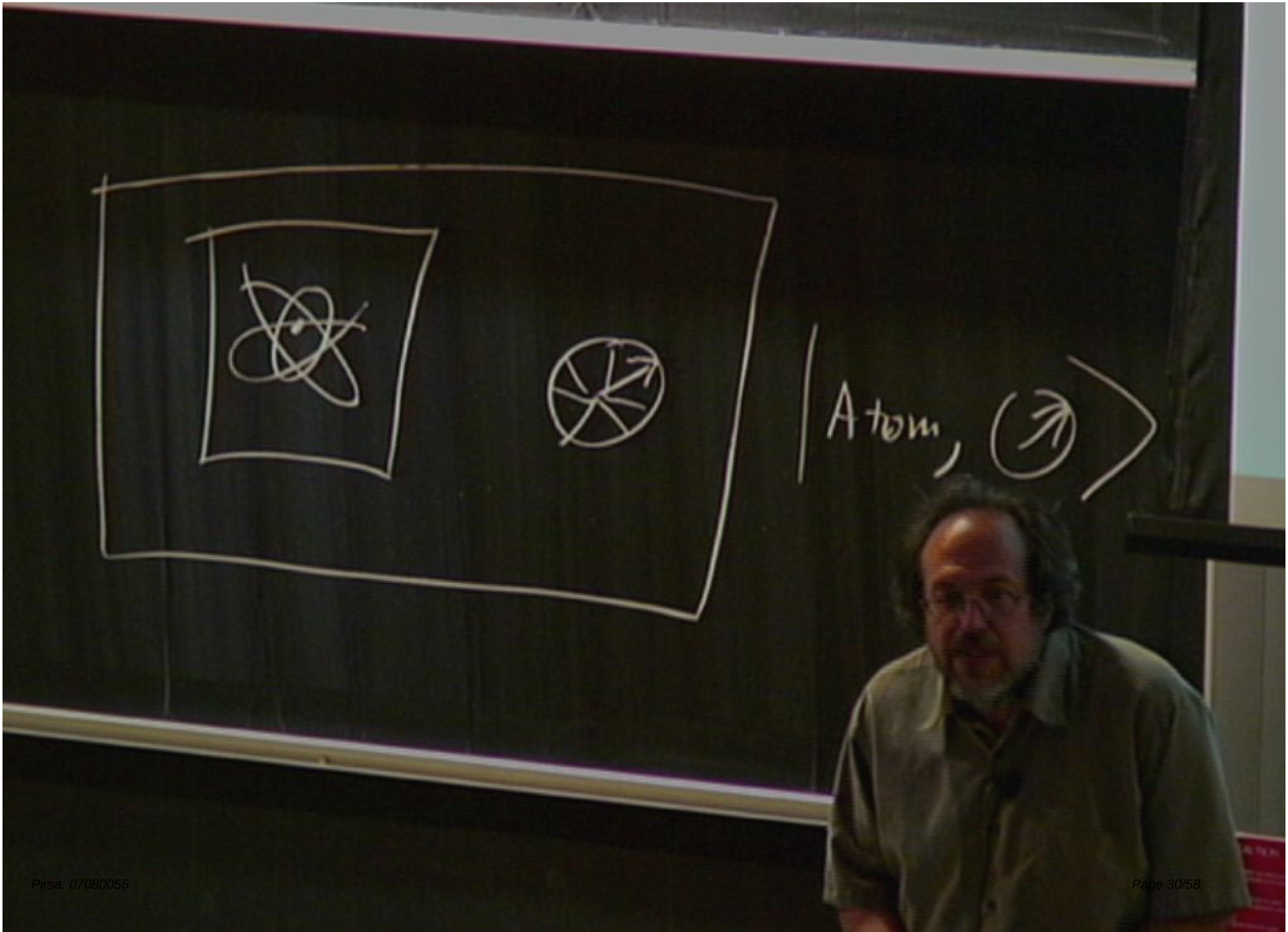

+ H → H*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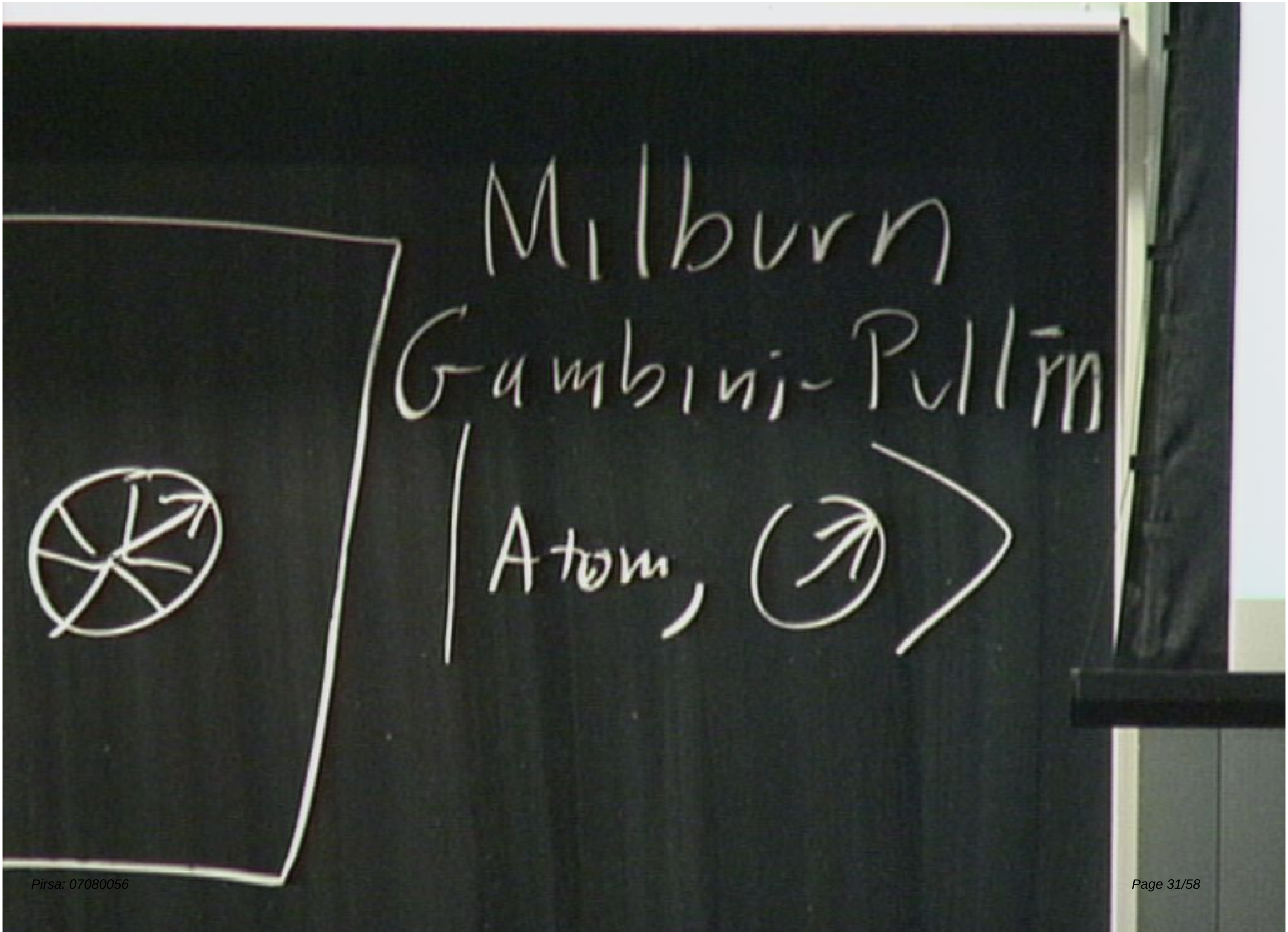
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How are dynamics and probability defined when there is no external clock?

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The fact that there is no external time means that $|\Psi\rangle$ cannot depend on t. This implies that

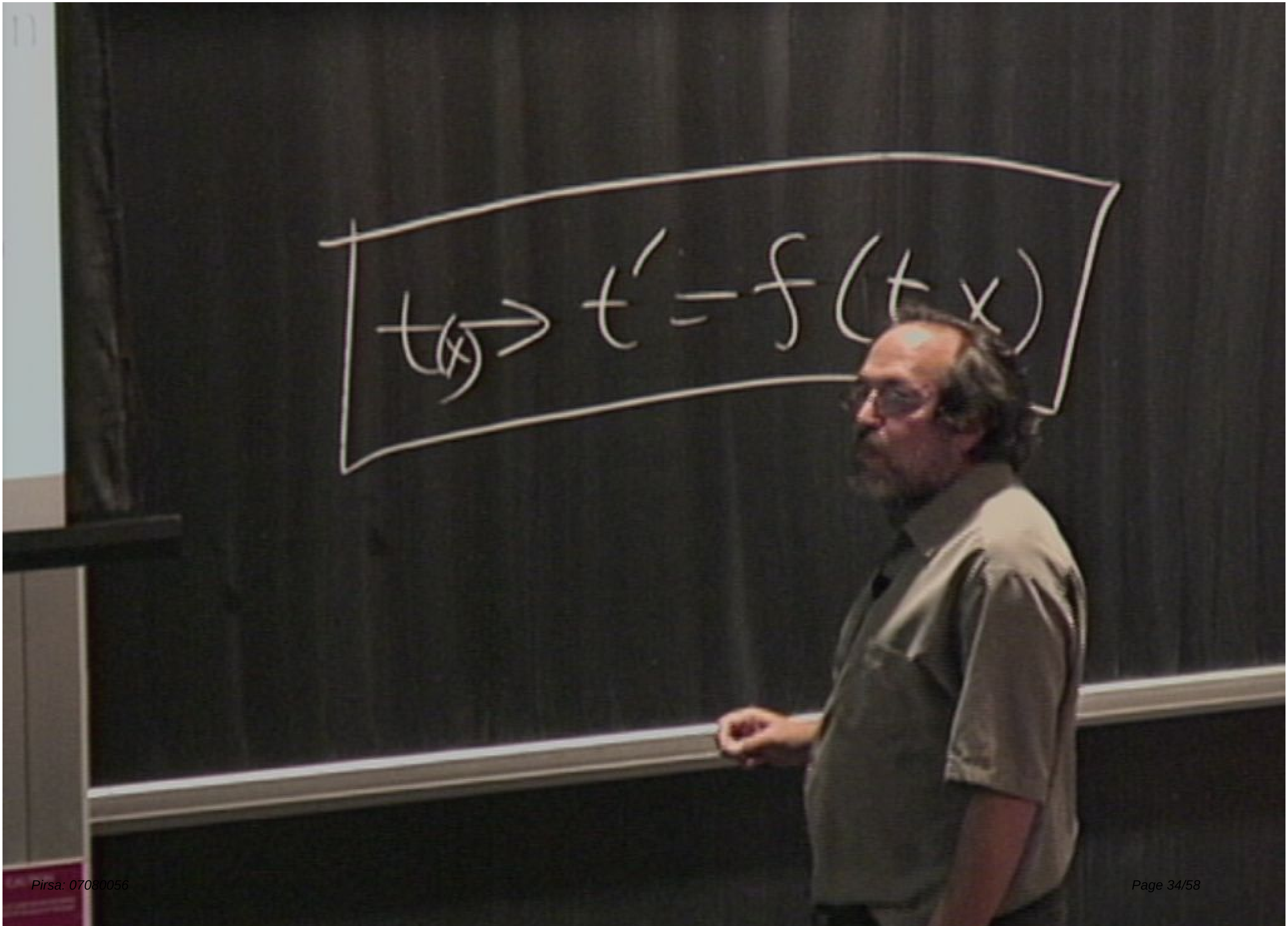
$$i\,d/dt\,|\Psi\rangle = 0 \quad \Rightarrow \quad H\,|\Psi\rangle = 0$$

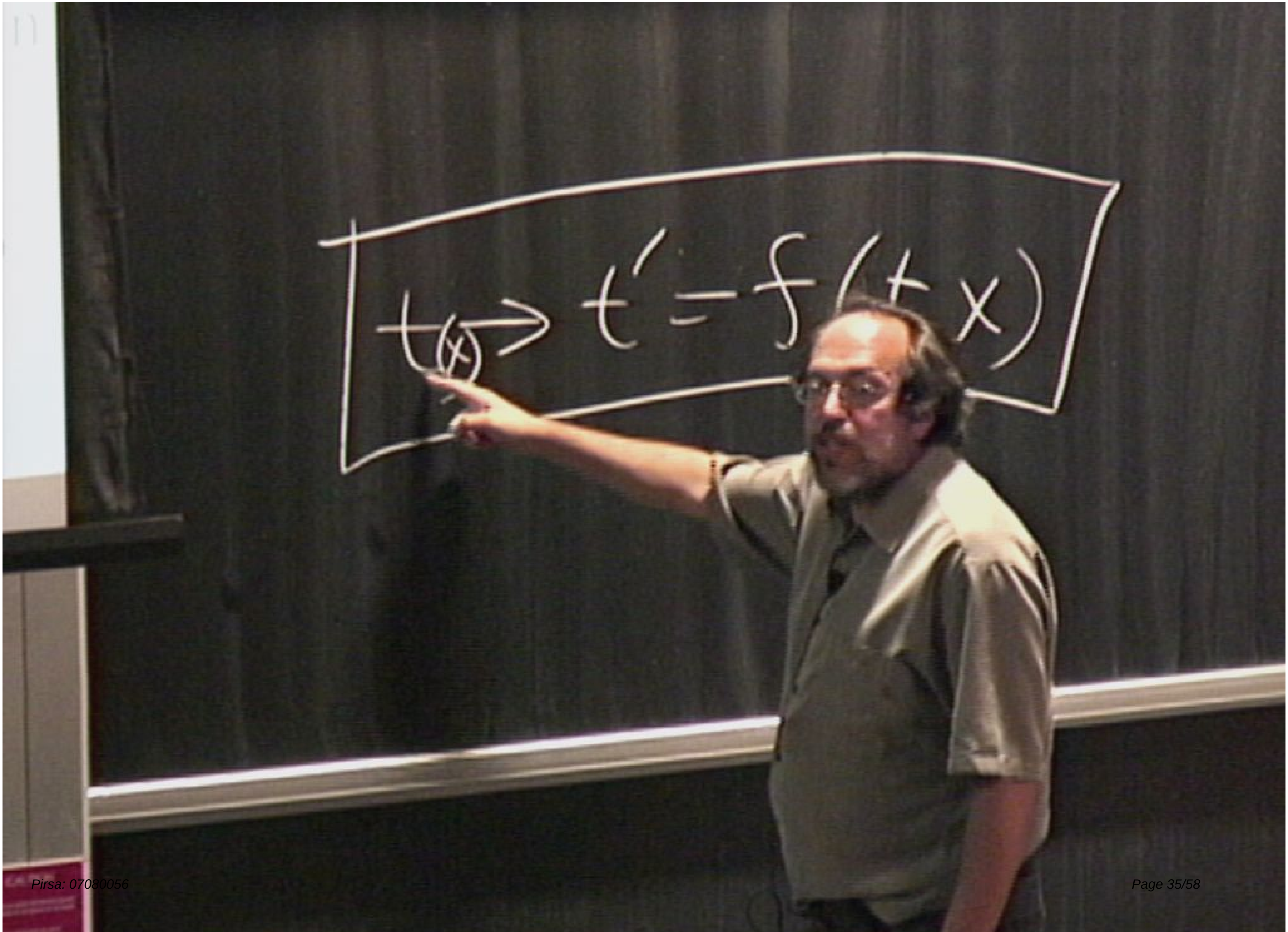
This is the *Hamiltonian constraint equation*.

We know some solutions to it for quantum general relativity.

But we are not sure how to interpret them, because there is no time coordinate.   And we are not sure what probabilities mean or how to define the inner product.

There are proposals for how to answer these questions, but so far none has been shown to work for real theories.


t(x) → t′ = f(t x)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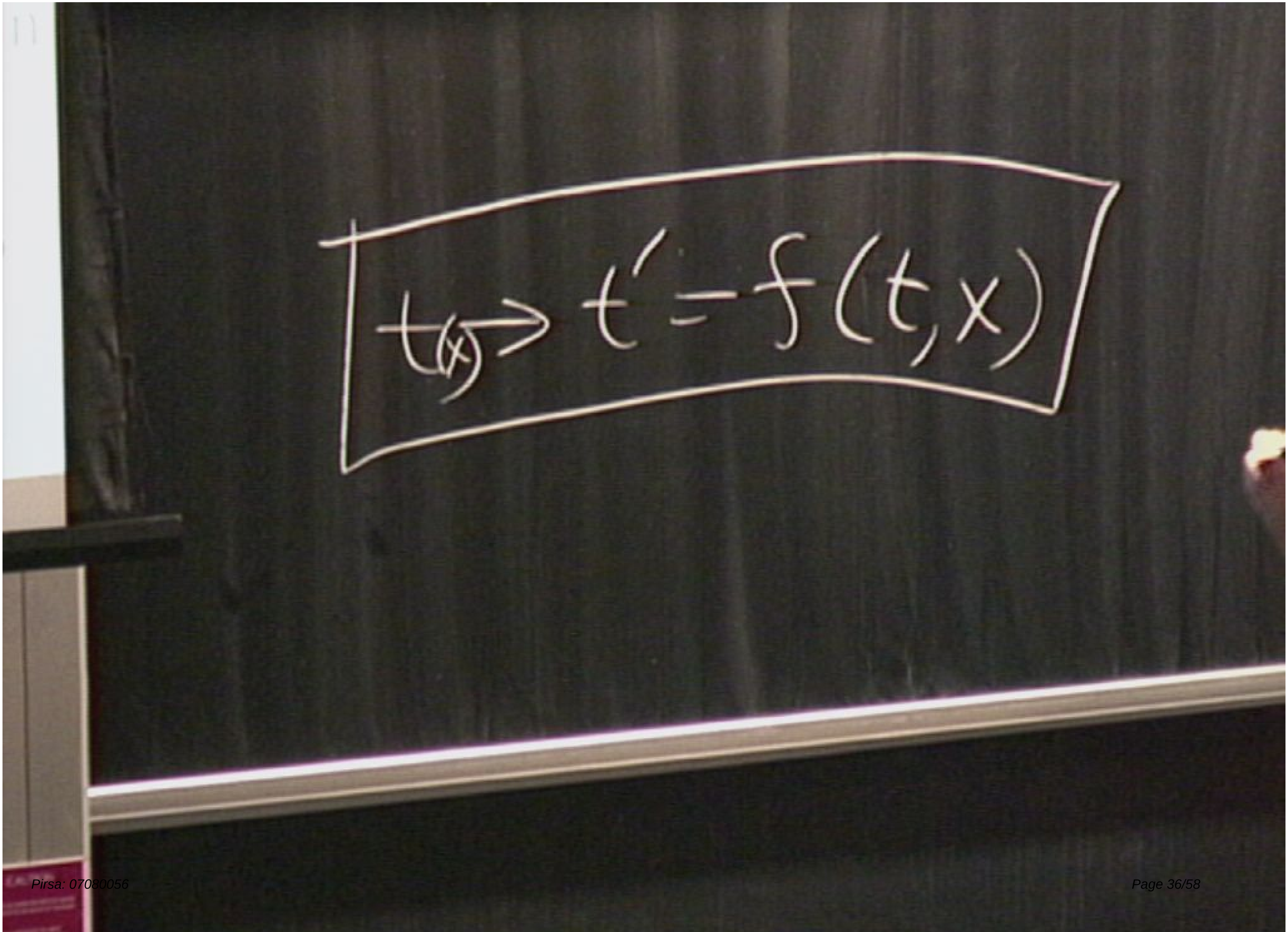
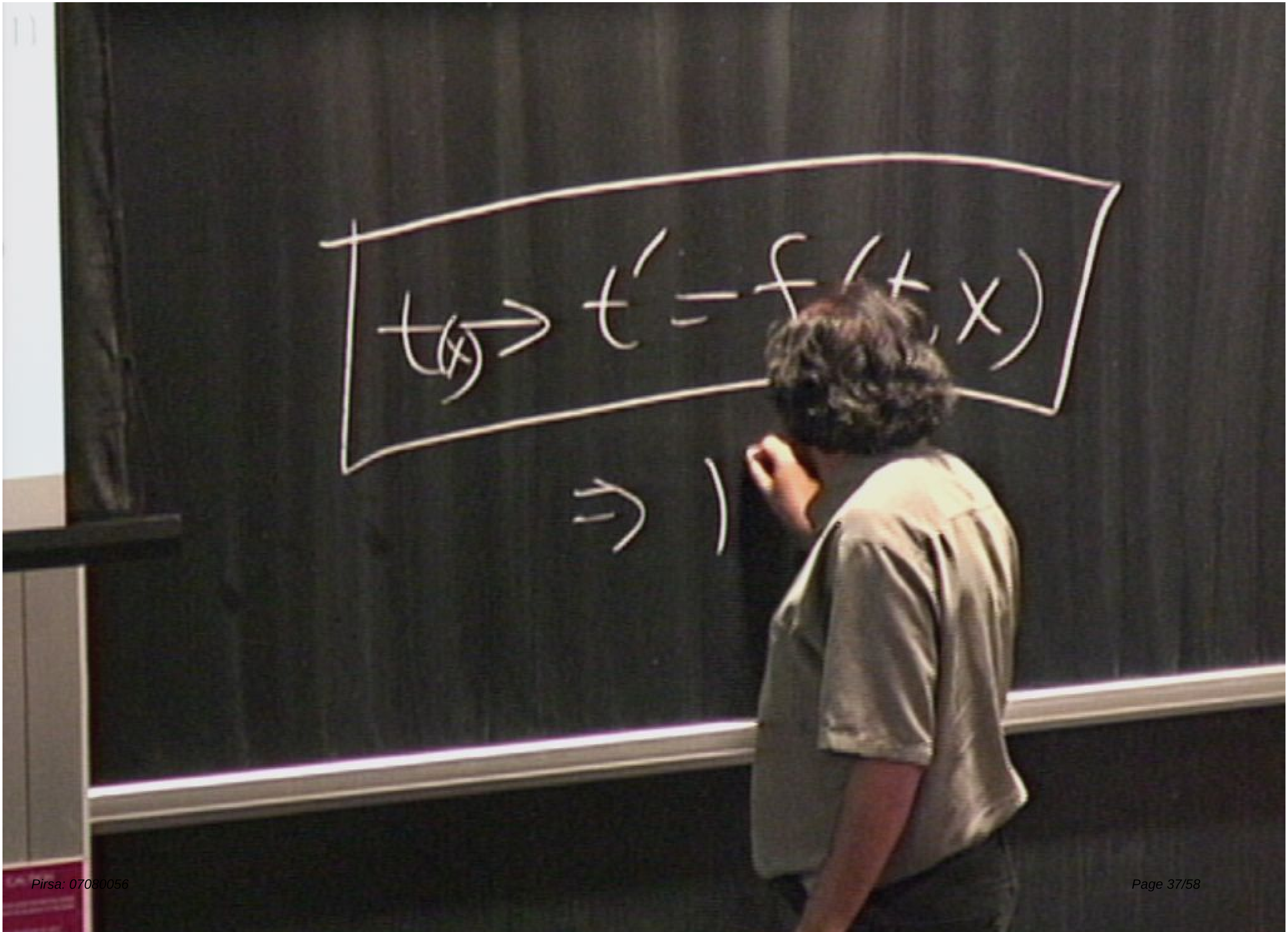

$t(x) \Rightarrow t' = f(t,x)$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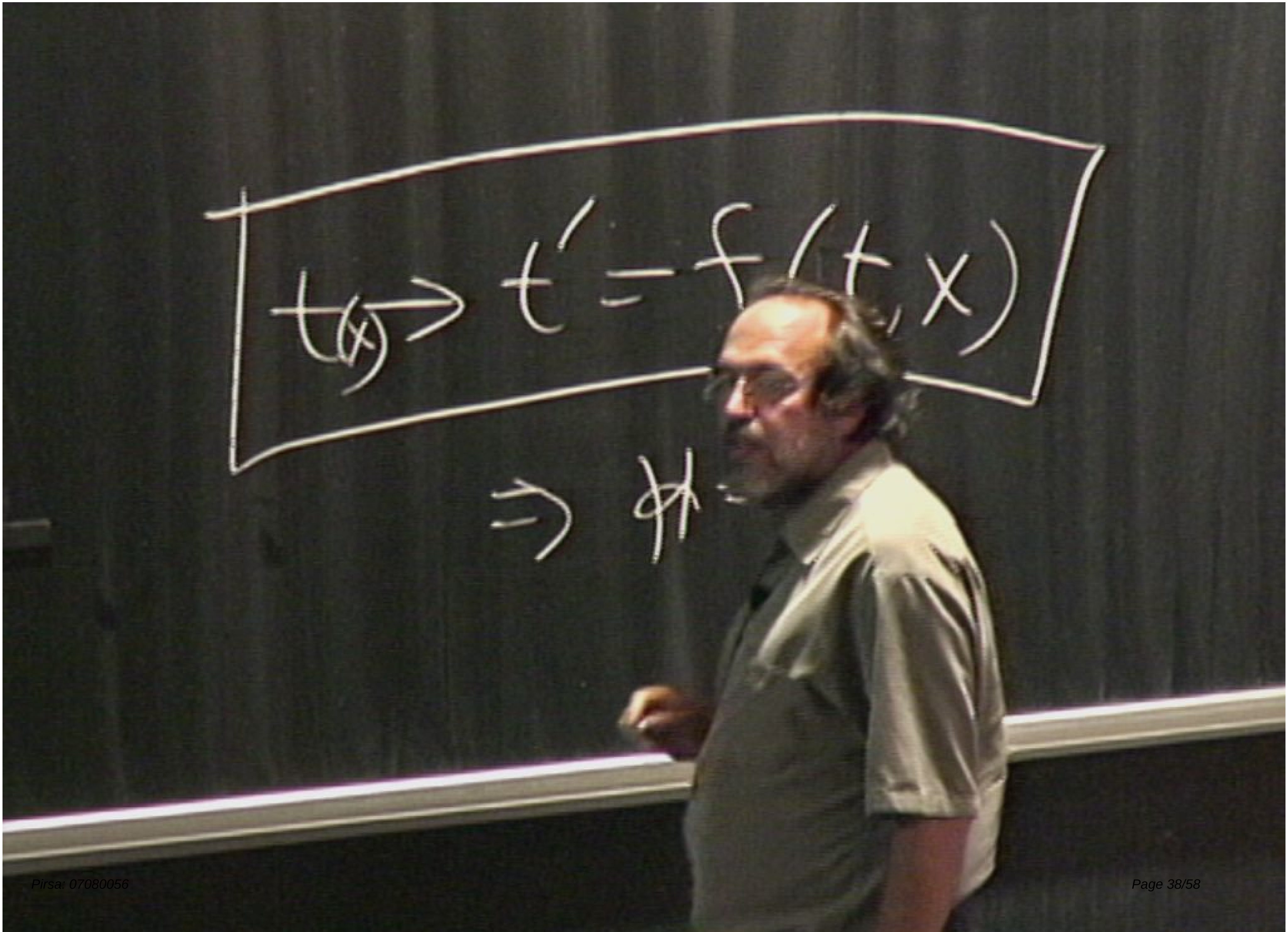
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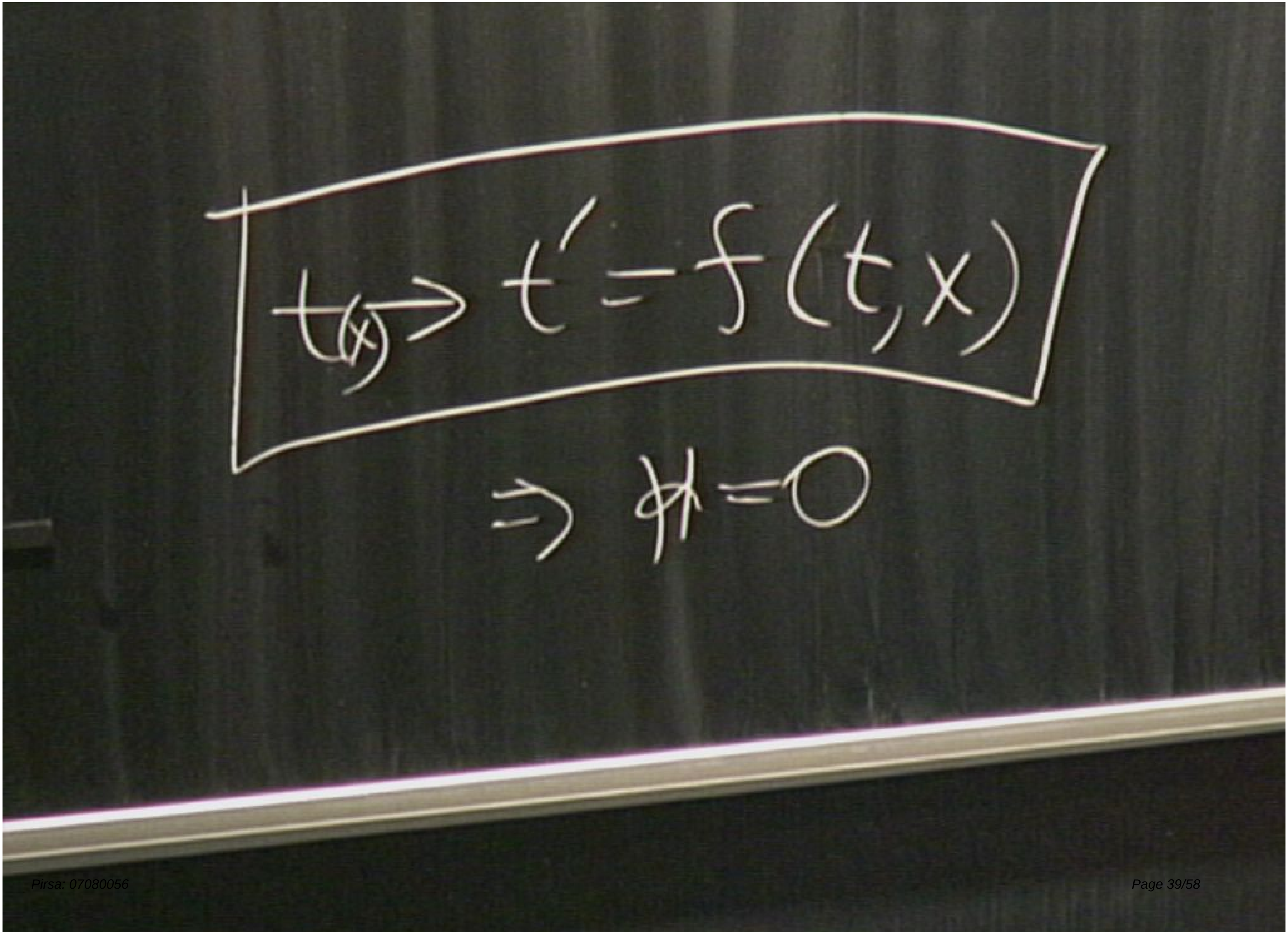
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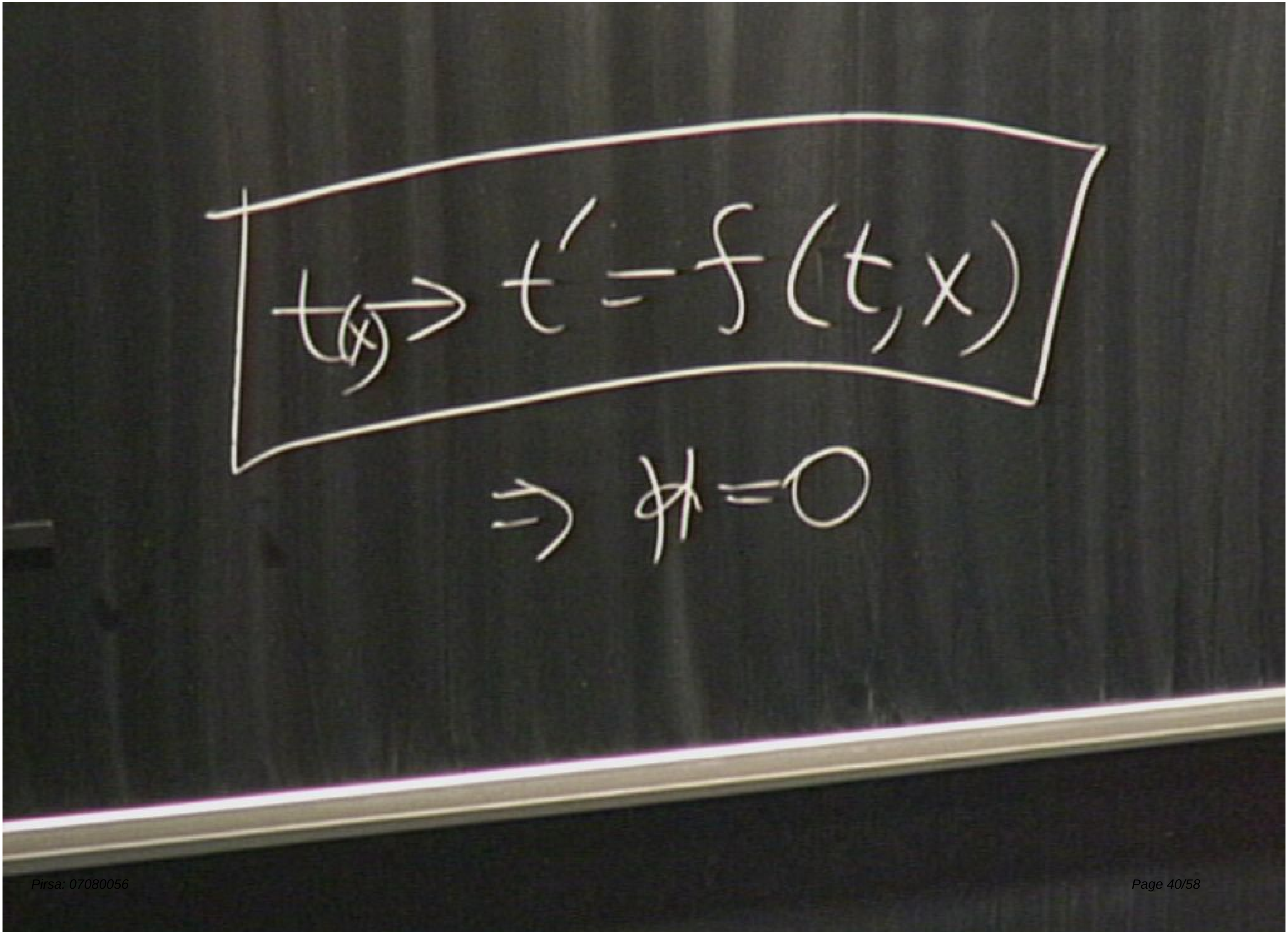
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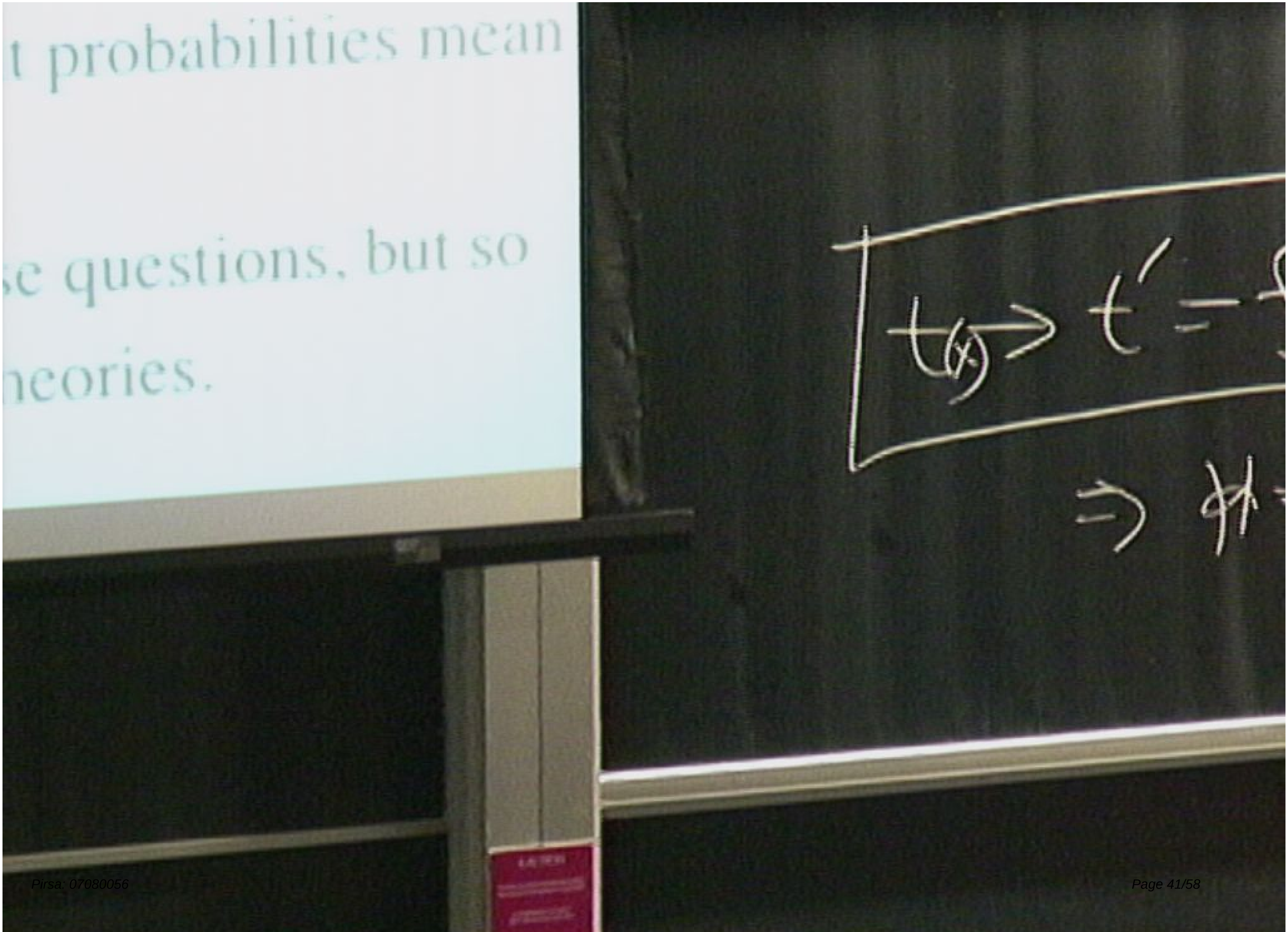
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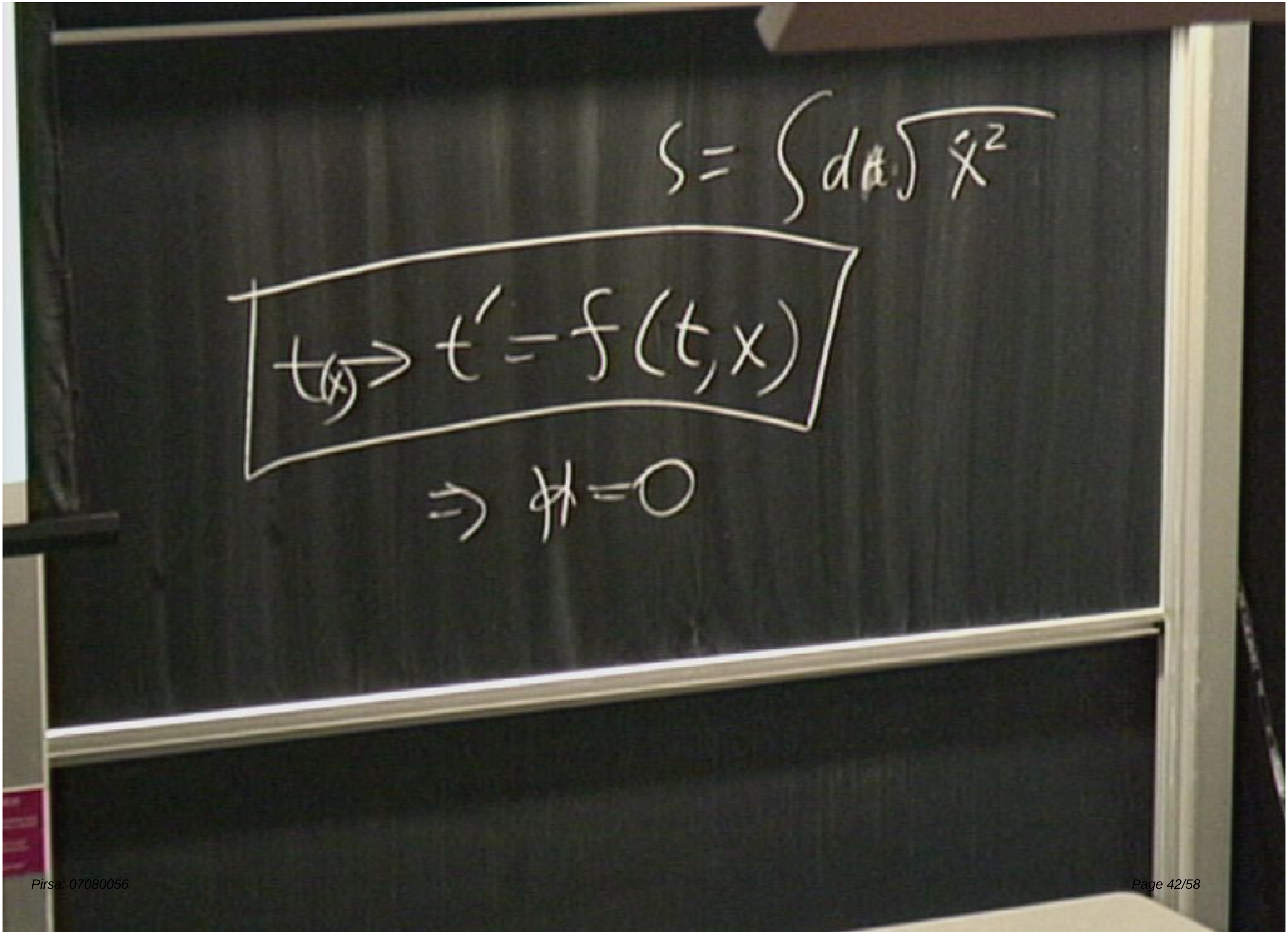
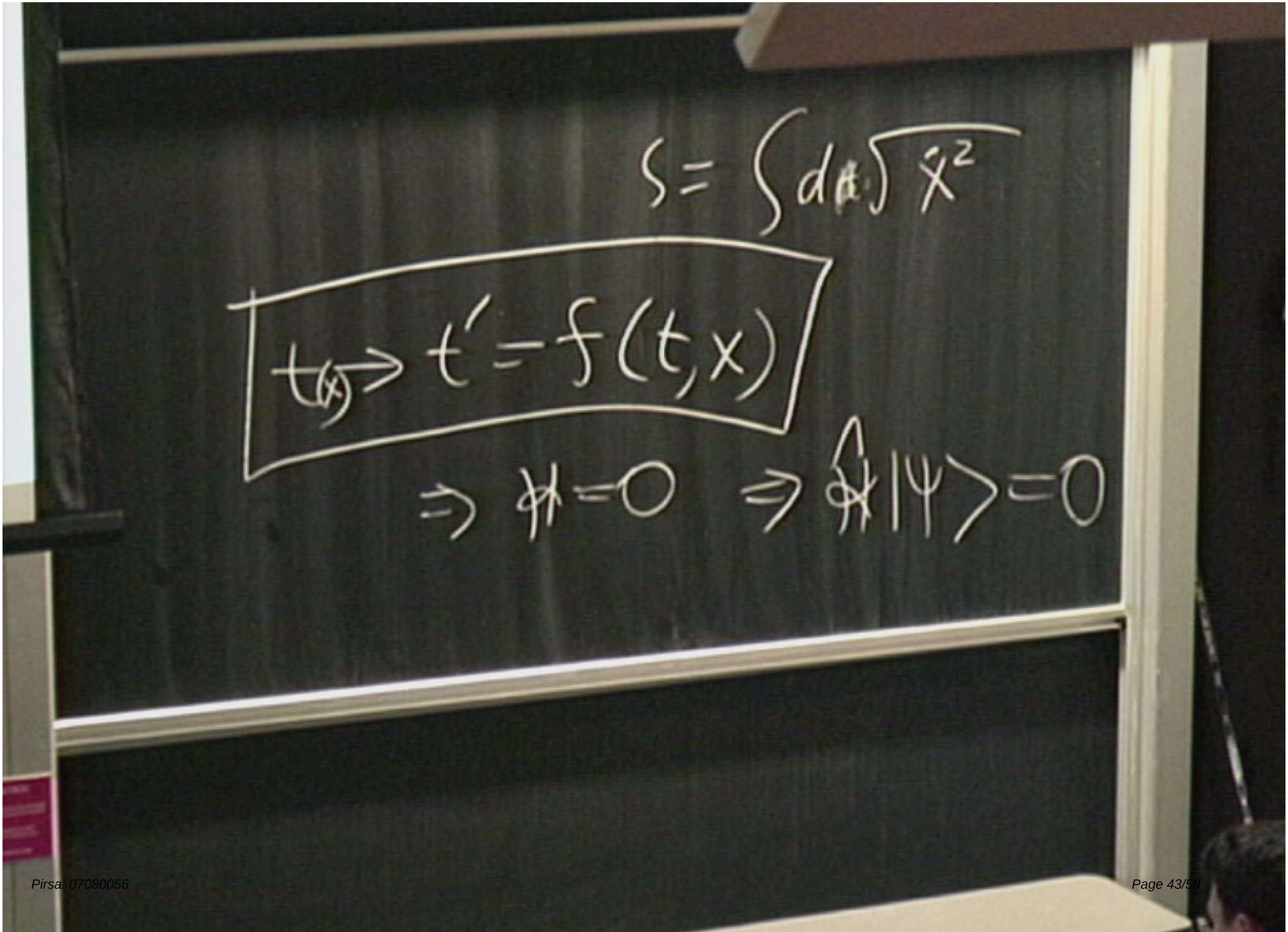

$S = \int dt \sqrt{\dot{x}^2}$
$t(x) \rightarrow t' = f(t,x)$
$\Rightarrow \mathcal{H} = 0$


S = ∫ d(t) √ ẋ²
t(x) ⇒ t′ = f(t,x)
⇒ H = 0 ⇒ H |ψ> = 0

My conclusion:

This is more evidence it may not be right just to extend the quantum formalism to the whole universe.

Could the linear dynamics of quantum theory hold only in the approximation in which the subsystem is much smaller than the universe as a whole?

There is no other case in physics where linearity is exact. Every other linear equation turns out to be an approximation to a non-linear equation.
Why should the Schroedinger equation be different.

But then where should we expect to see the first non-linear corrections to quantum dynamics?

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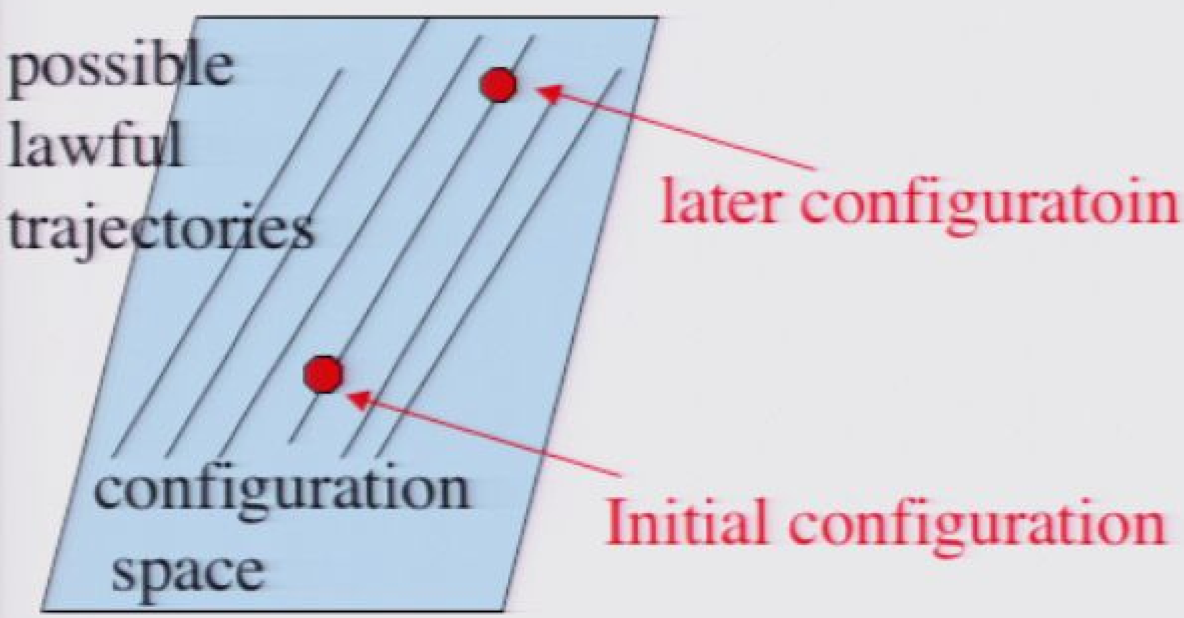
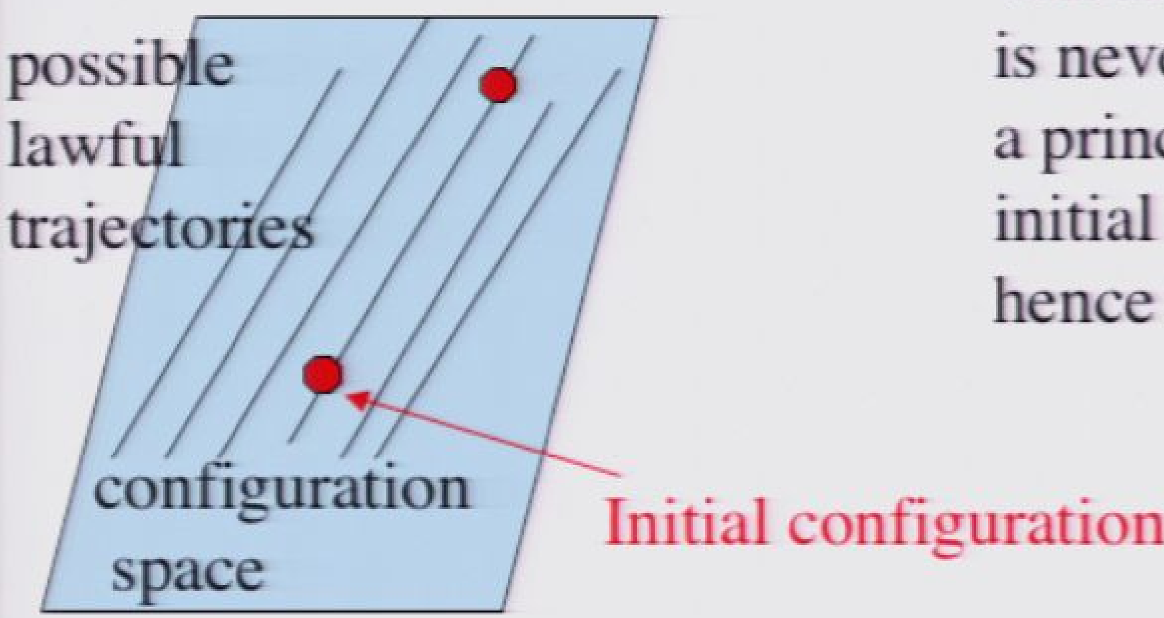
Newtonian schema for dynamical theories



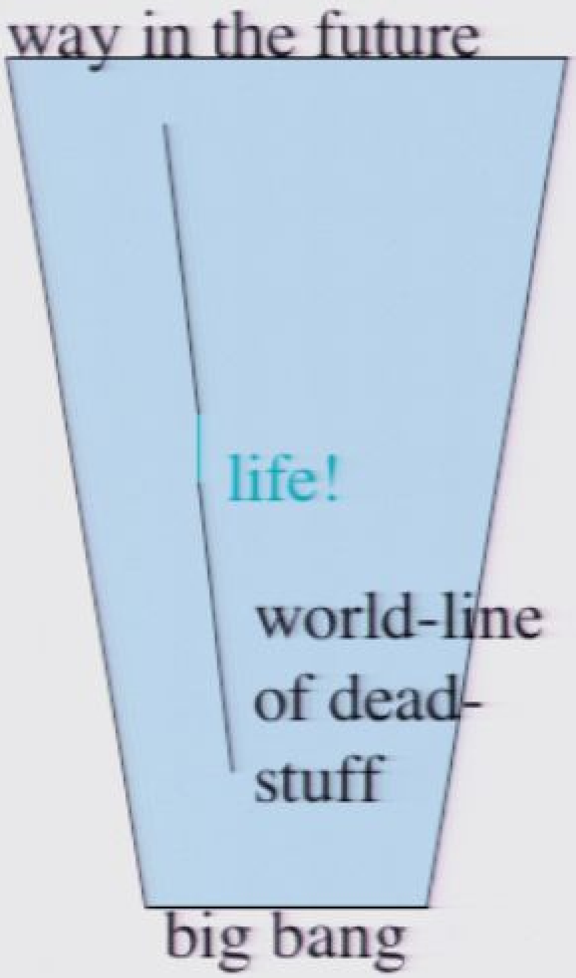
This is also quantum theory only the state space is a complex linear space and the trajectories are given by unitary time evolution.

The separation of laws and initial conditions makes sense for subsystems which come in many instances. The laws code what is common, the initial conditions what distinguishes the different instances.

What is the meaning of a configuration or state space for the whole universe, almost all of which is never realized? Should there be a principle that picks out the actual initial condition of the universe and hence its actual trajectory?



Beware of the fallacy of physicist as God, looking at the universe from outside space and time.



The whole point of cosmology is that there is nothing outside the universe and no point of view or observation of the universe from outside of it.

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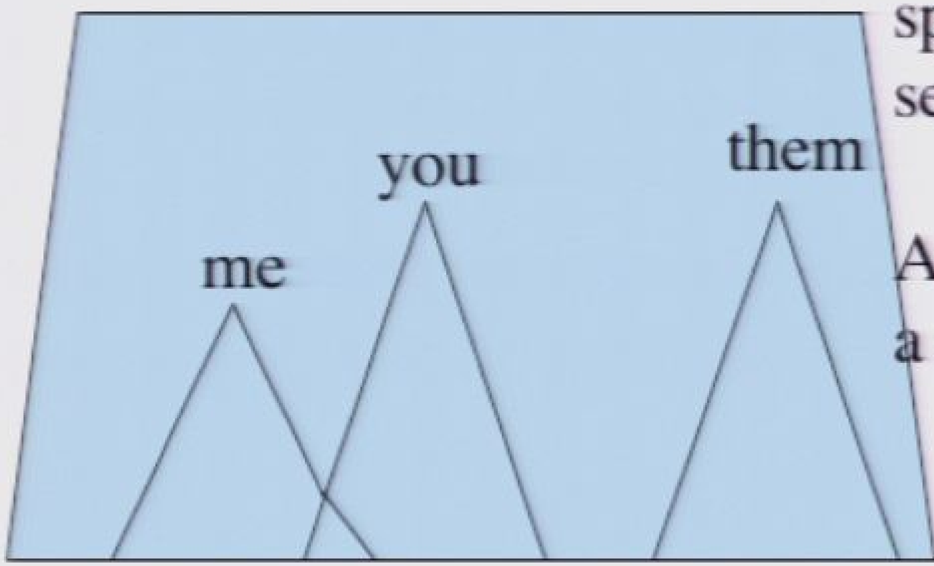
The “quantum state of the universe” does not correspond to anything that a real observer can measure, because by causality (no info faster than the speed of light) any real observer sees only a small part of the universe.



And each observer can only measure a small fraction of the observables.

Why use a formalism, whose basic elements: the quantum state and the algebra of observables, are not observable?

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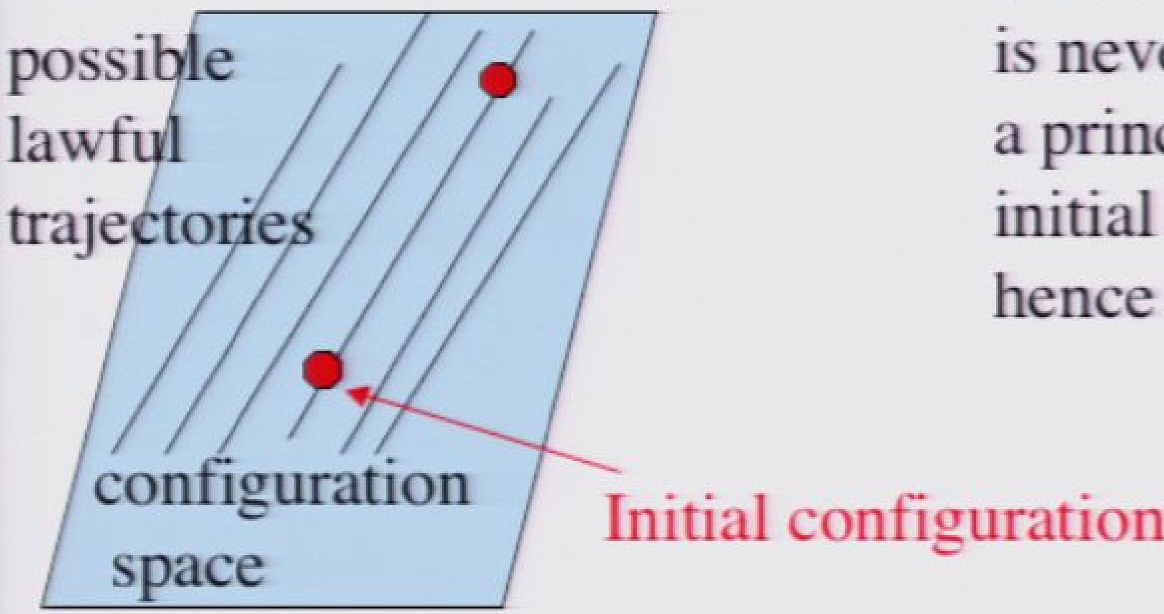

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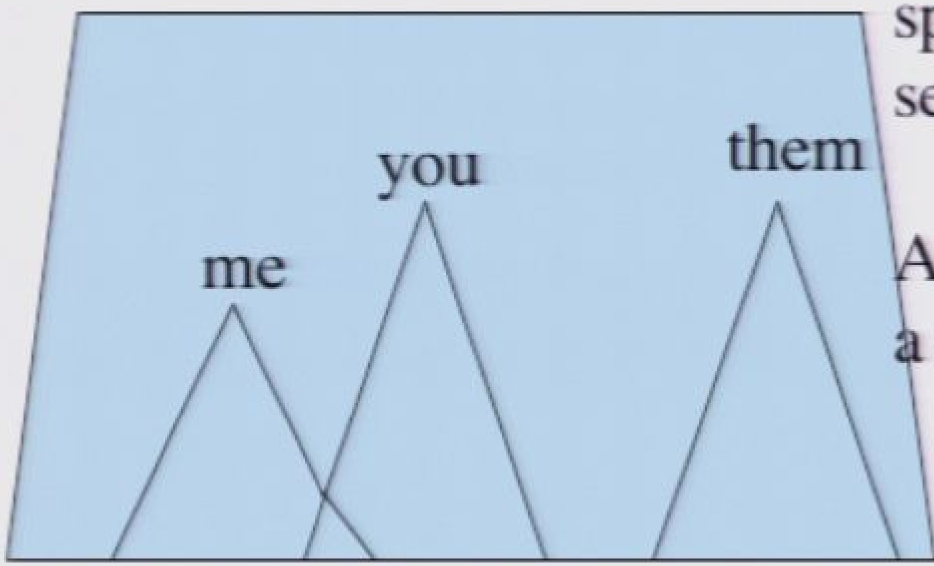

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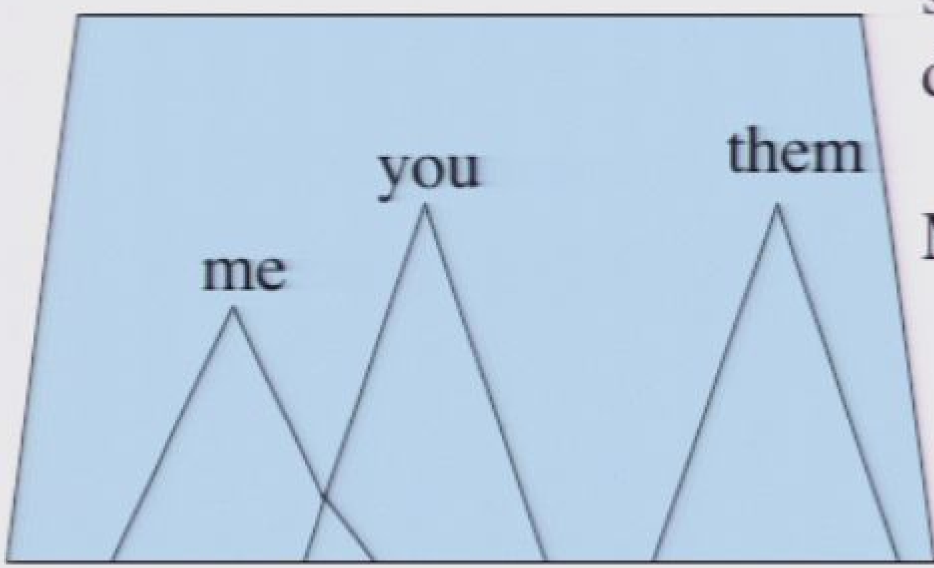

Could there be separate states and separate observables algebras for different observers?

Markopoulou, Hardy…

Why use a formalism, whose basic elements: the quantum state and the algebra of observables, correspond to nothing observable?

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Tentative conclusion:

Quantum mechanics applies to only small subsystems of the universe. A new formalism is needed for the whole universe.

This would not have:

- universal state and observer independent, algebra of observables
- a separation of dynamics and kinematics,
- a separation of laws from initial conditions
- a dependence on observers outside the system
- a dependence on clocks outside the system
- a linear state space or linear evolution.

It would:

- use only observables accessible to observers inside the system
- refer to time only in terms of changes seeable from inside the system