Title: Special Topics in Physics - Lecture 13A

Date: Apr 09, 2008 07:00 PM

URL: http://pirsa.org/08040041

Abstract: The Problem of Time in Quantum Gravity and Cosmology

Time and Clocks

and their curious relationship

- Multifaceted nature of time
- Time in thermodynamics
- What is a clock? (Time is not "measured")
- Time dilation and the "clock hypothesis"
- Simultaneity: conventionality and relativity

} Periodicity (What is a clock?; Time dilation and the "clock hypothesis")

} Phase (Simultaneity)

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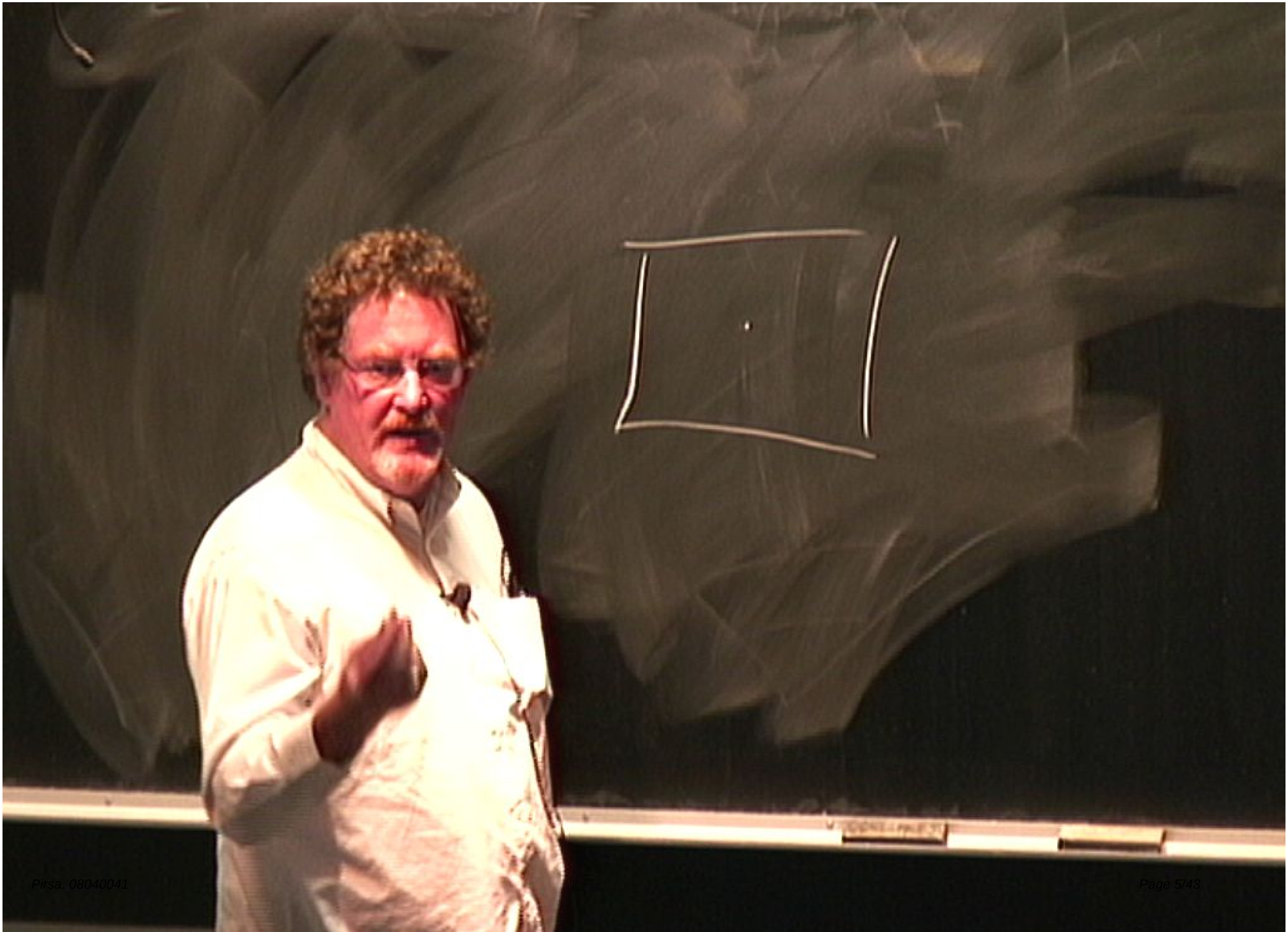
What is time?

- Time is what stops everything happening at once. J.A. Wheeler/Einstein
- Time is Nature's way of getting round the law of non-contradiction.
- Instants are not in time. Time is in instants. J. Barbour



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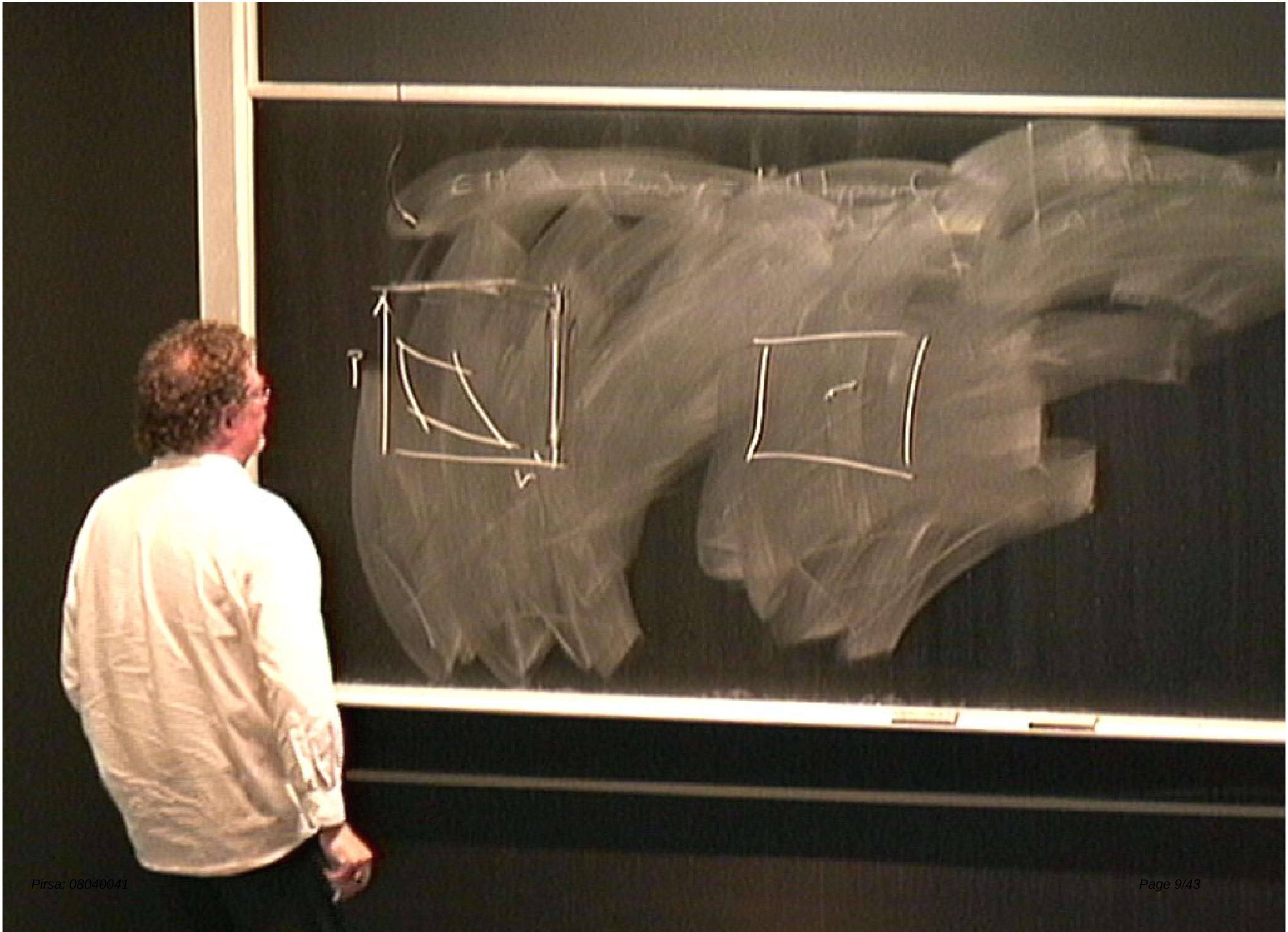
P
V

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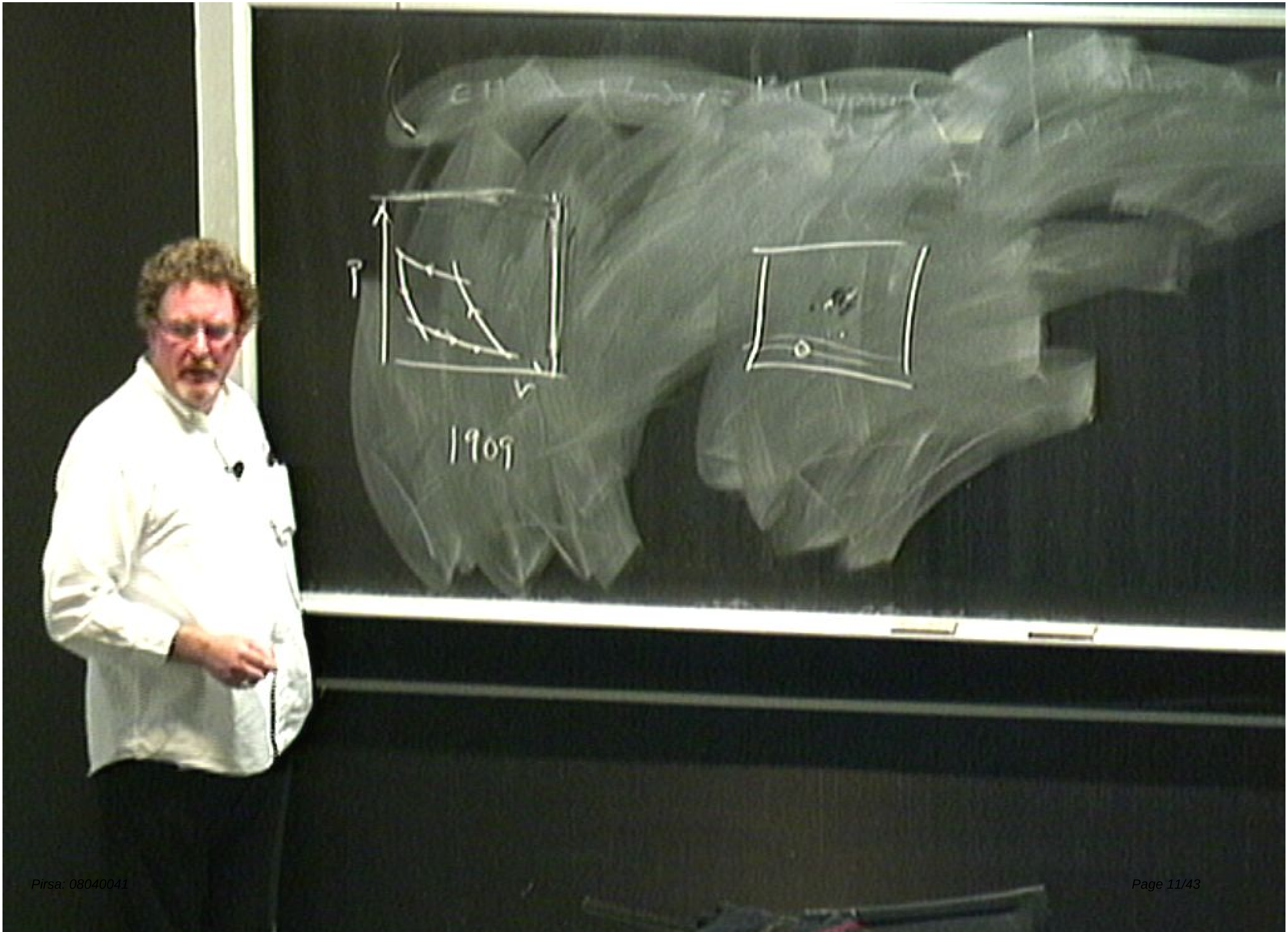
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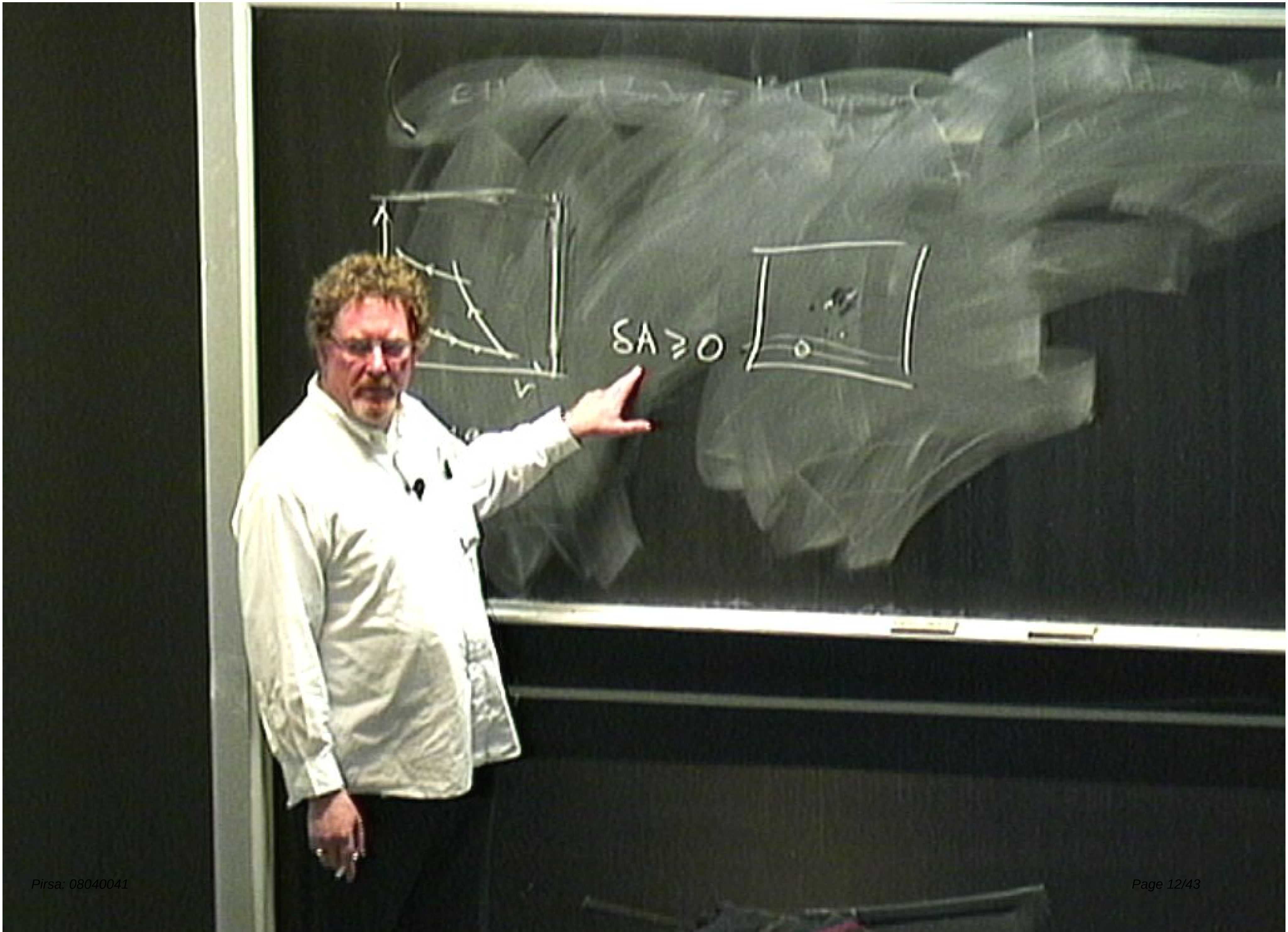
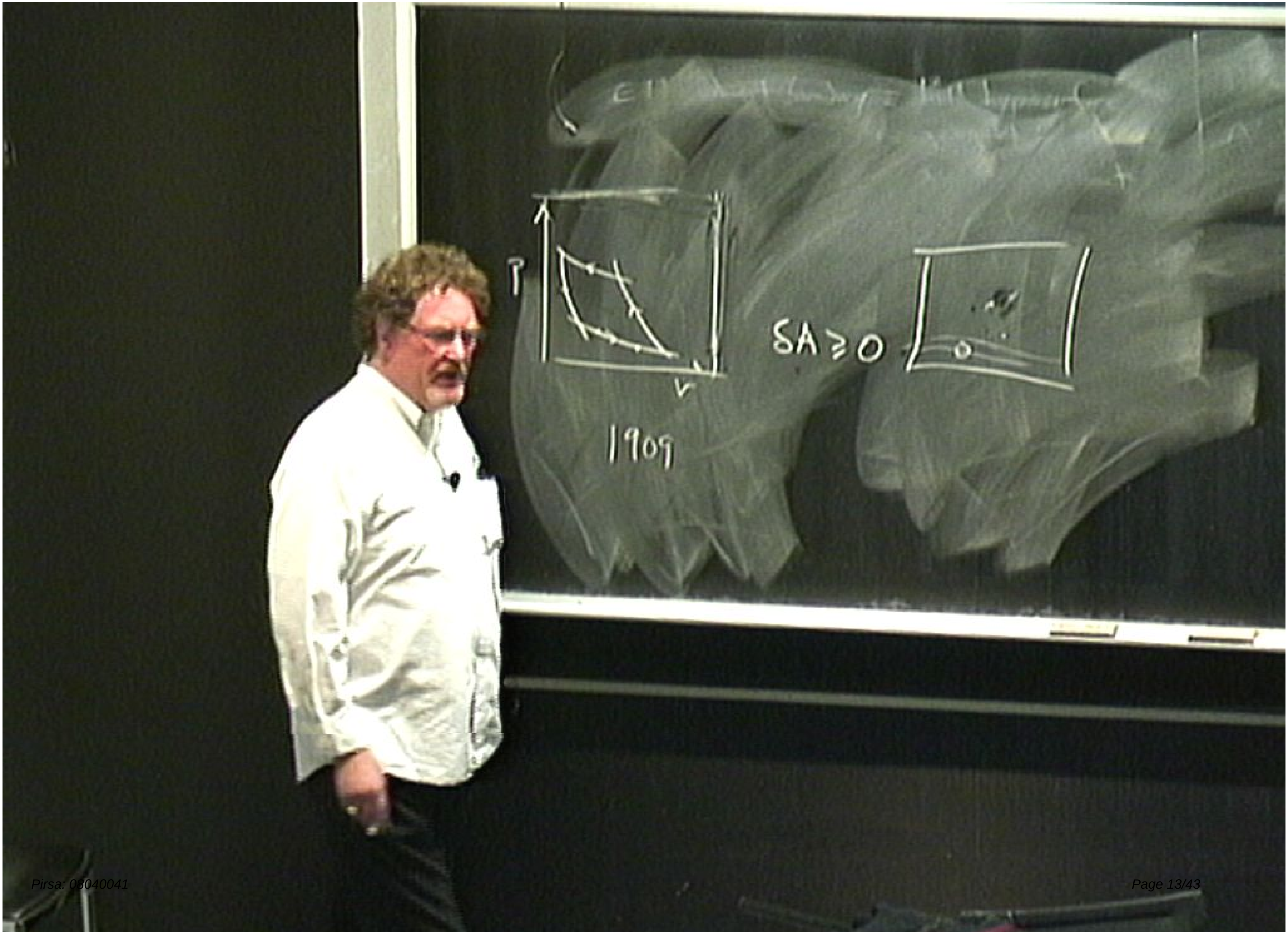
1909


δA ≥ 0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The problem of the standard of time

G. F FitzGerald
(1890s) :

" ... there is every reason for assuming that the Earth rotates on its axis more uniformly than any clock we can construct".

But the rotation rate is changing:

testimony of ancient eclipses
frictional resistance of the tides

So ". . . how on earth can we discover a change in our standard itself?"

How do we find a "more ultimate standard of time"?

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What is duration?

Duration is defined by ideal clocks. (Einstein)

What is an ideal clock?

"By a clock we understand anything characterized by a phenomenon passing periodically through identical phases so that we must assume, by virtue of the principle of sufficient reason, that all that happens in a given period is identical with all that happens in an arbitrary period."
Einstein 1910

vs.

Ideal clocks are defined by duration. (Newton, FitzGerald, Poincaré, Barbour, ..)

What is duration?

The choice of a temporal parameter that makes the basic laws of physics take their simplest form.

There is no ideal clock (apart from the universe as a whole).

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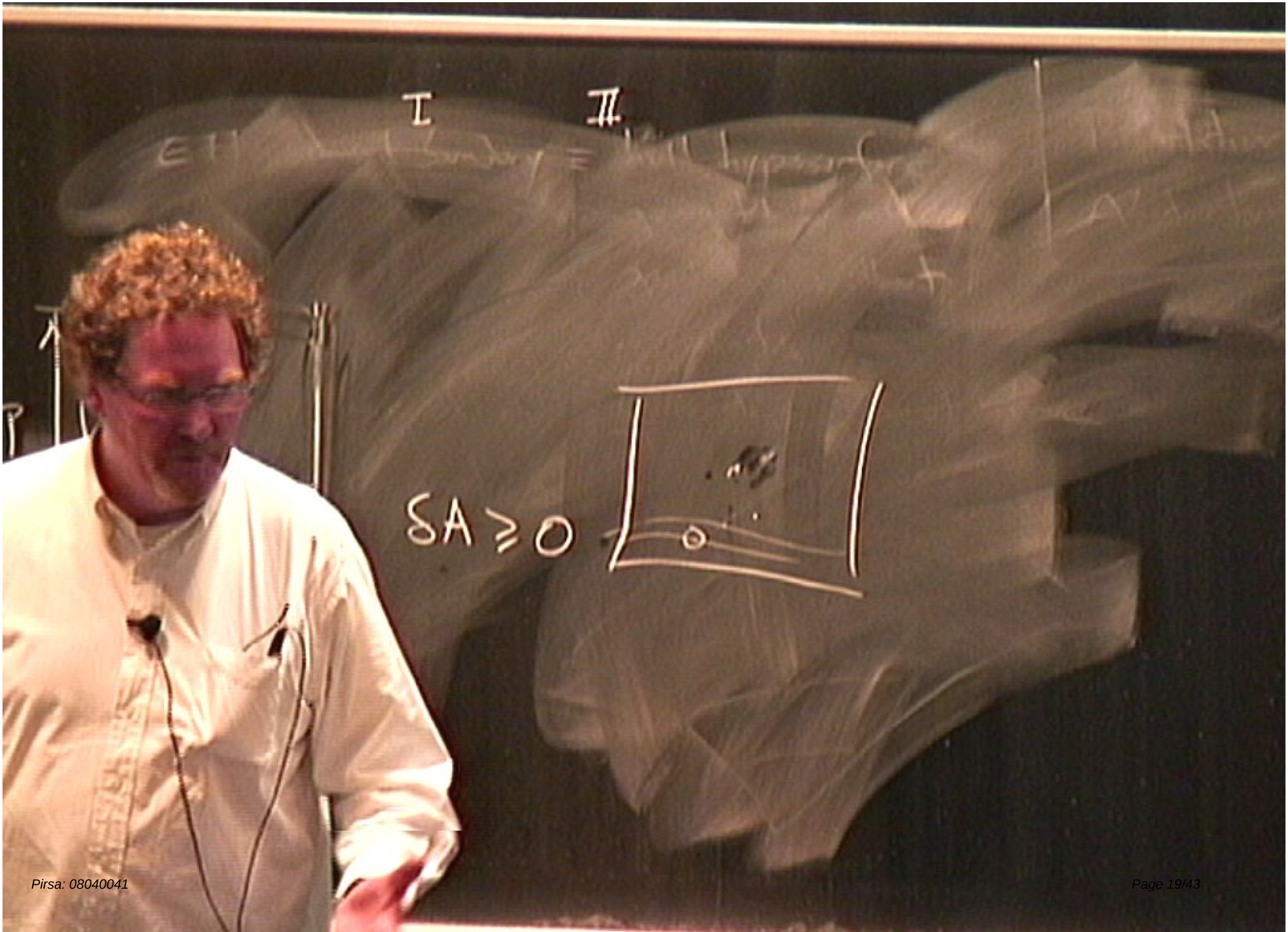
I
II
δA ≥ 0


I
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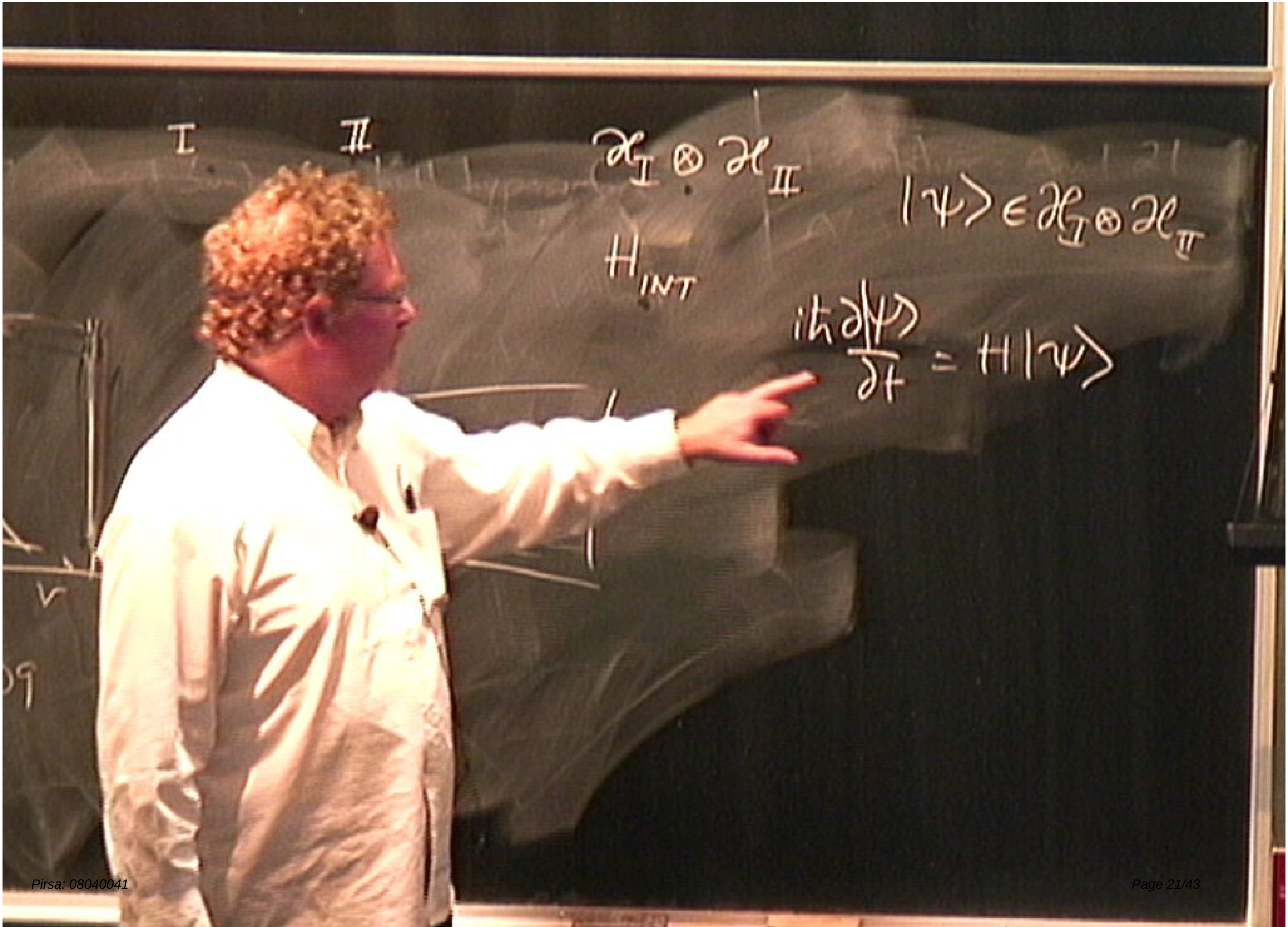
$\mathcal{H}_{I} \otimes \mathcal{H}_{II}$
1909


I
II
$\mathcal{H}_I \otimes \mathcal{H}_{II}$
H_{INT}
$|\psi\rangle \in \mathcal{H}_I \otimes \mathcal{H}_{II}$
$i\hbar \frac{\partial|\psi\rangle}{\partial t} = H|\psi\rangle$

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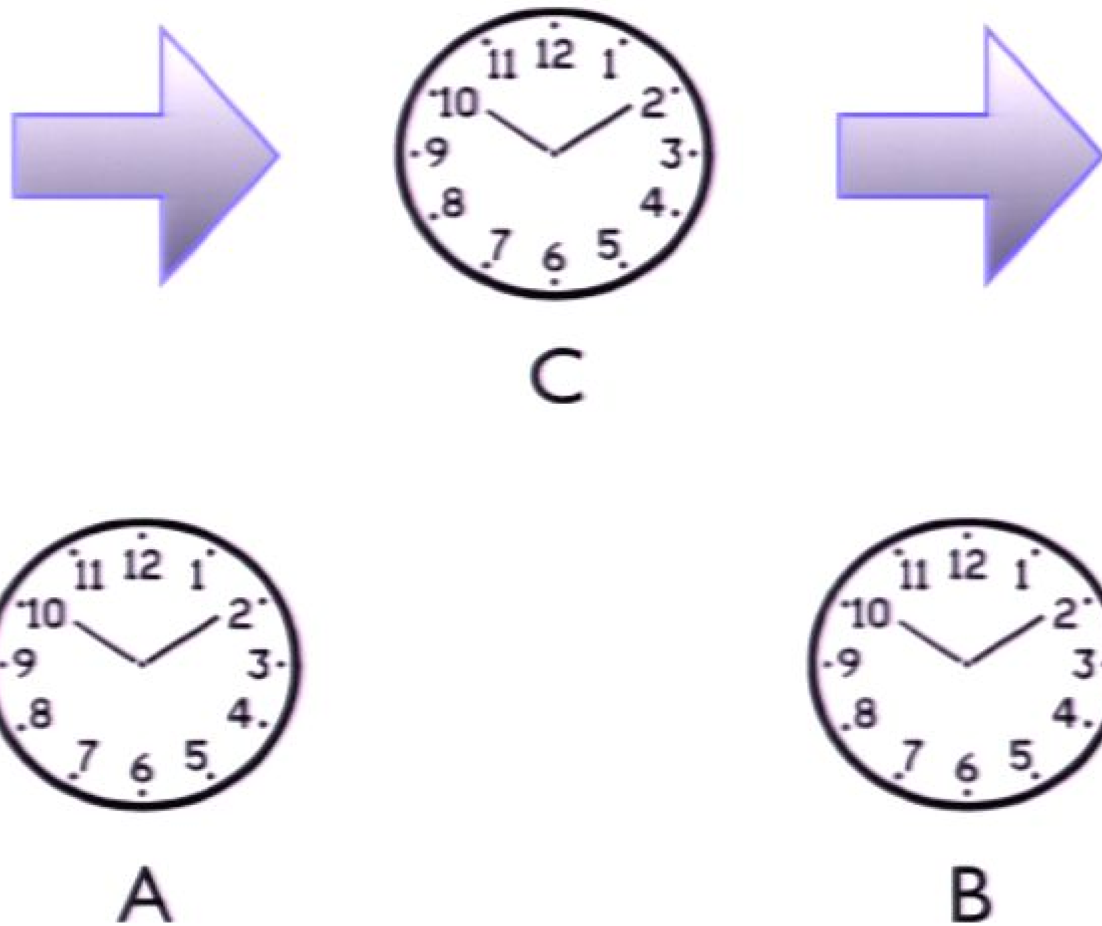
Duration (ii)

Time dilation:

difference between proper time and coordinate time



proper time
(one clock)

coordinate time
(two synchronized clocks)

Premonitions of time dilation

Joseph Larmor (1857–1942)

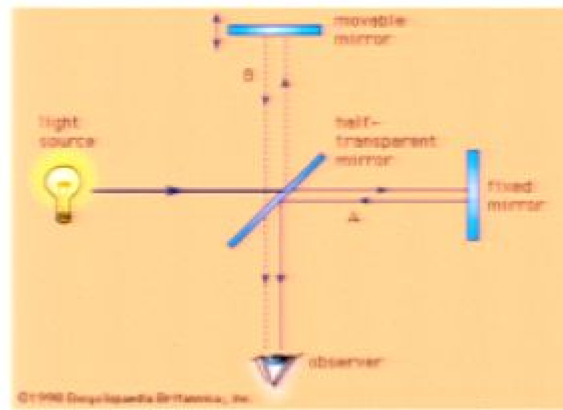
In 1897, predicted time dilation for a moving system of orbiting charged particles (inspiration for Bell 1976?)

Hendrik Antoon Lorentz (1853–1928)

In 1899, independently predicted time dilation for a moving source of monochromatic light.

Janssen (1995)

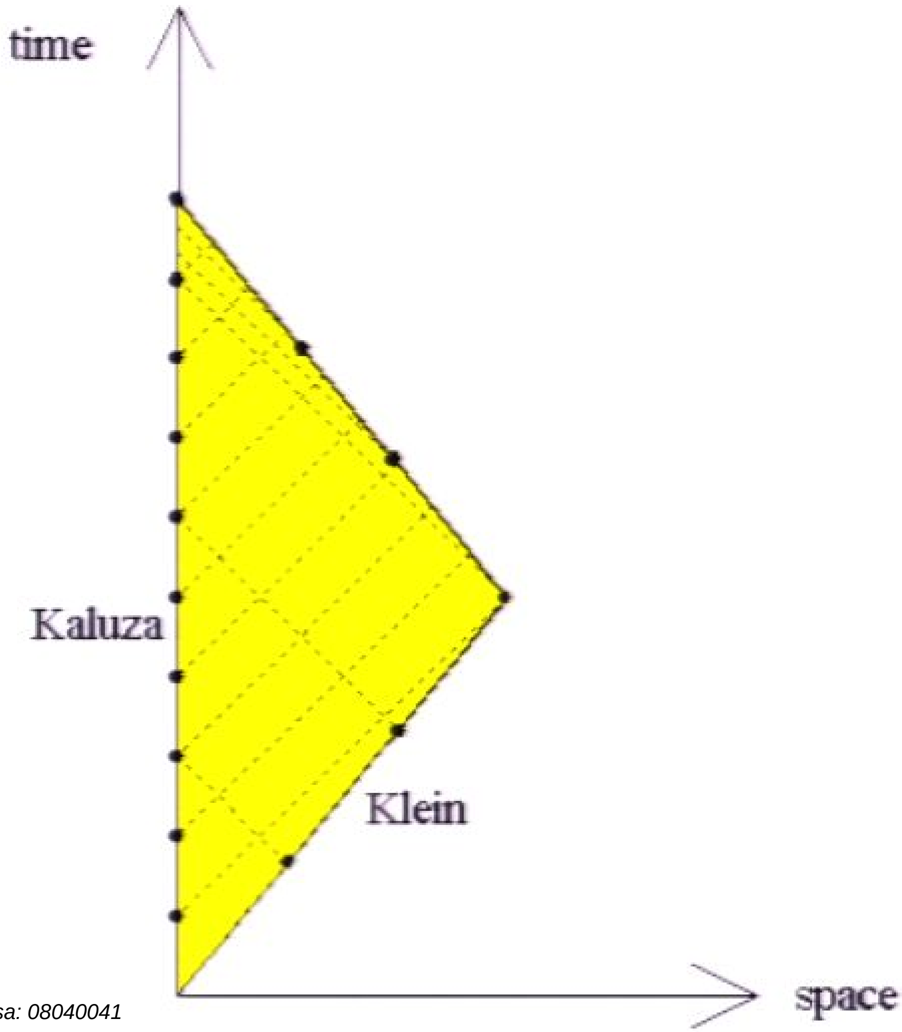
Ives (1937), Kittel (1974), Bell (1976), vs Rindler (1970)



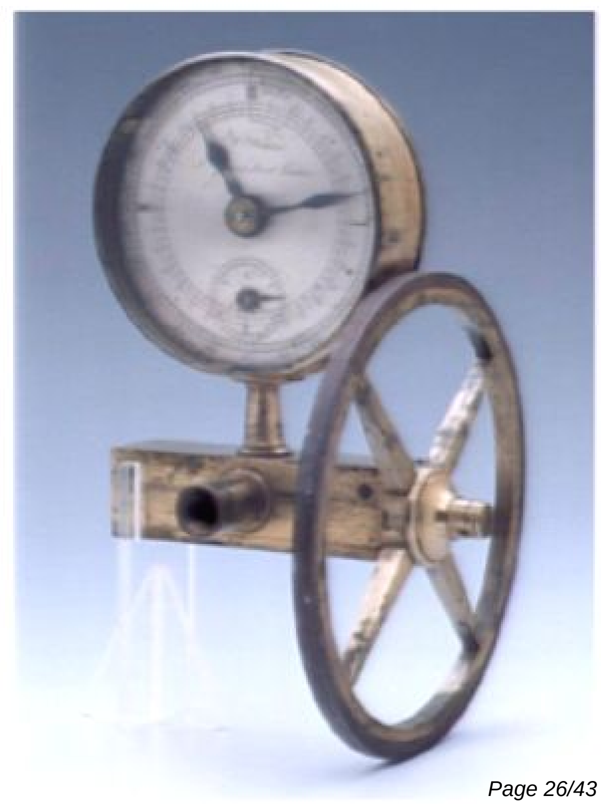
1888 Liénard version: implies FitzGerald-Lorentz deformation, and (k-dependent) time dilation for light source

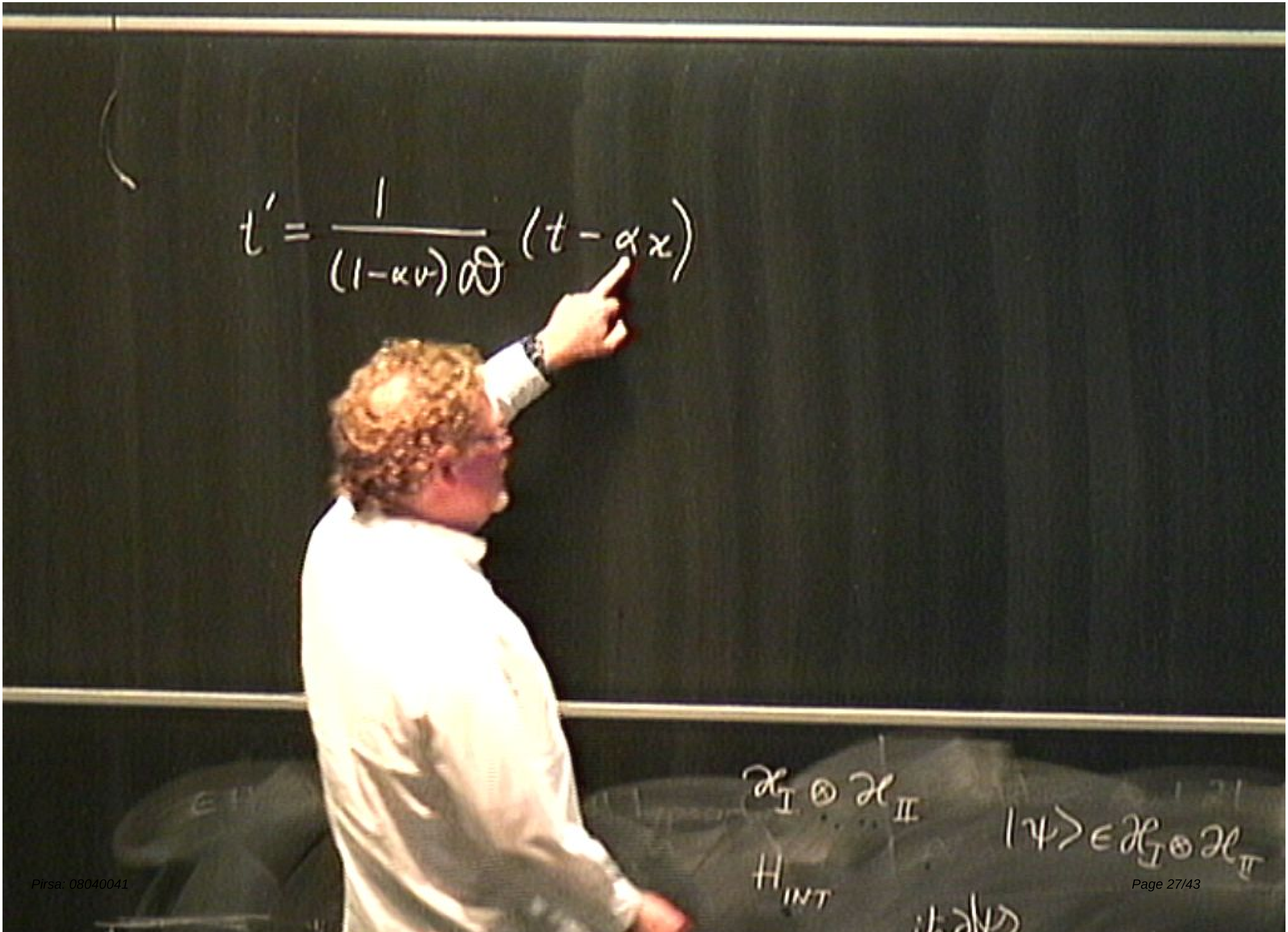
Universal Time Dilation

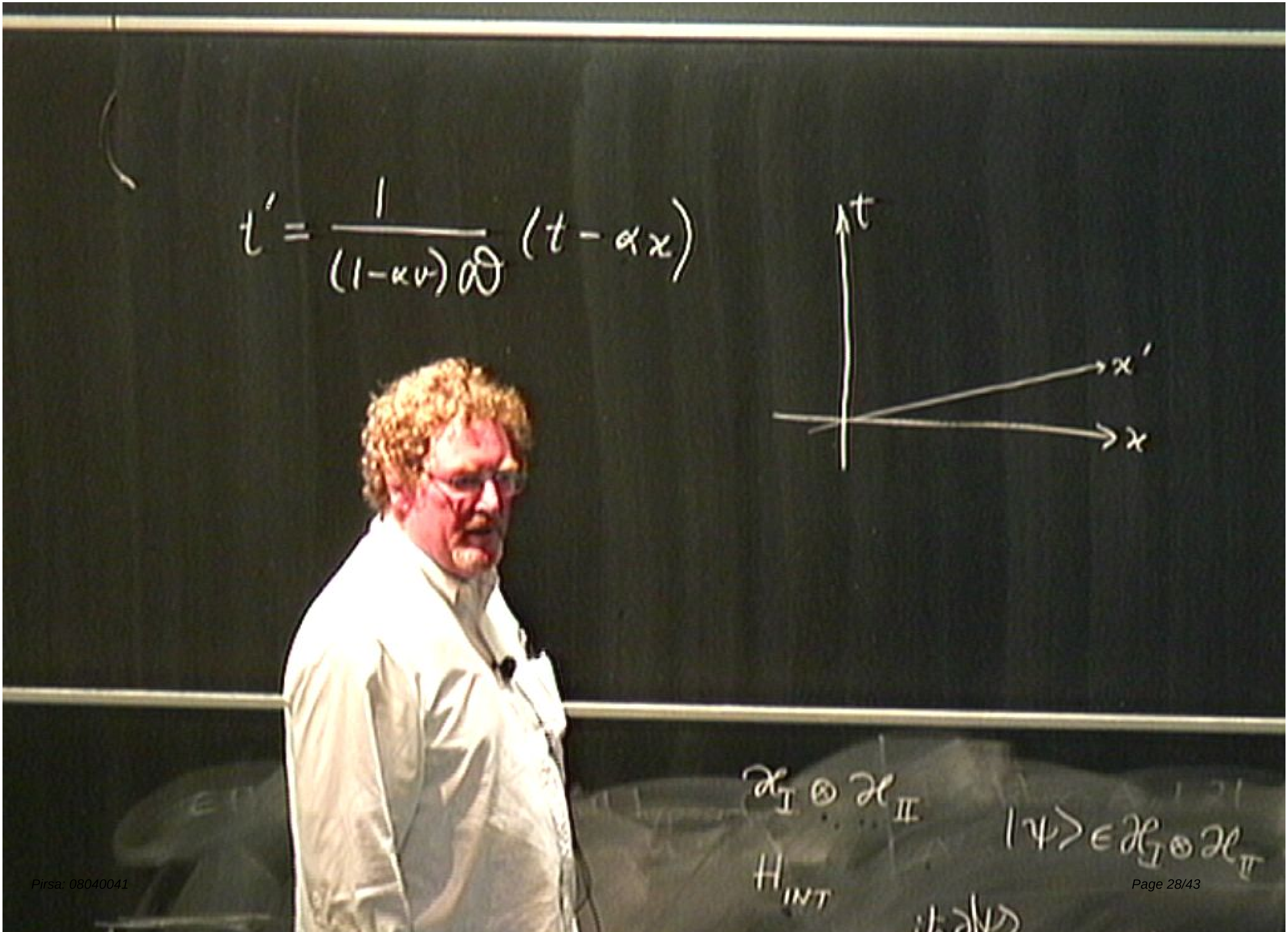
Einstein's 1905 discovery



waywiser




t′ = 1/((1−αv)ϑ) (t − αx)
ℋ_I ⊗ ℋ_II
|ψ⟩ ∈ ℋ_I ⊗ ℋ_II
H_INT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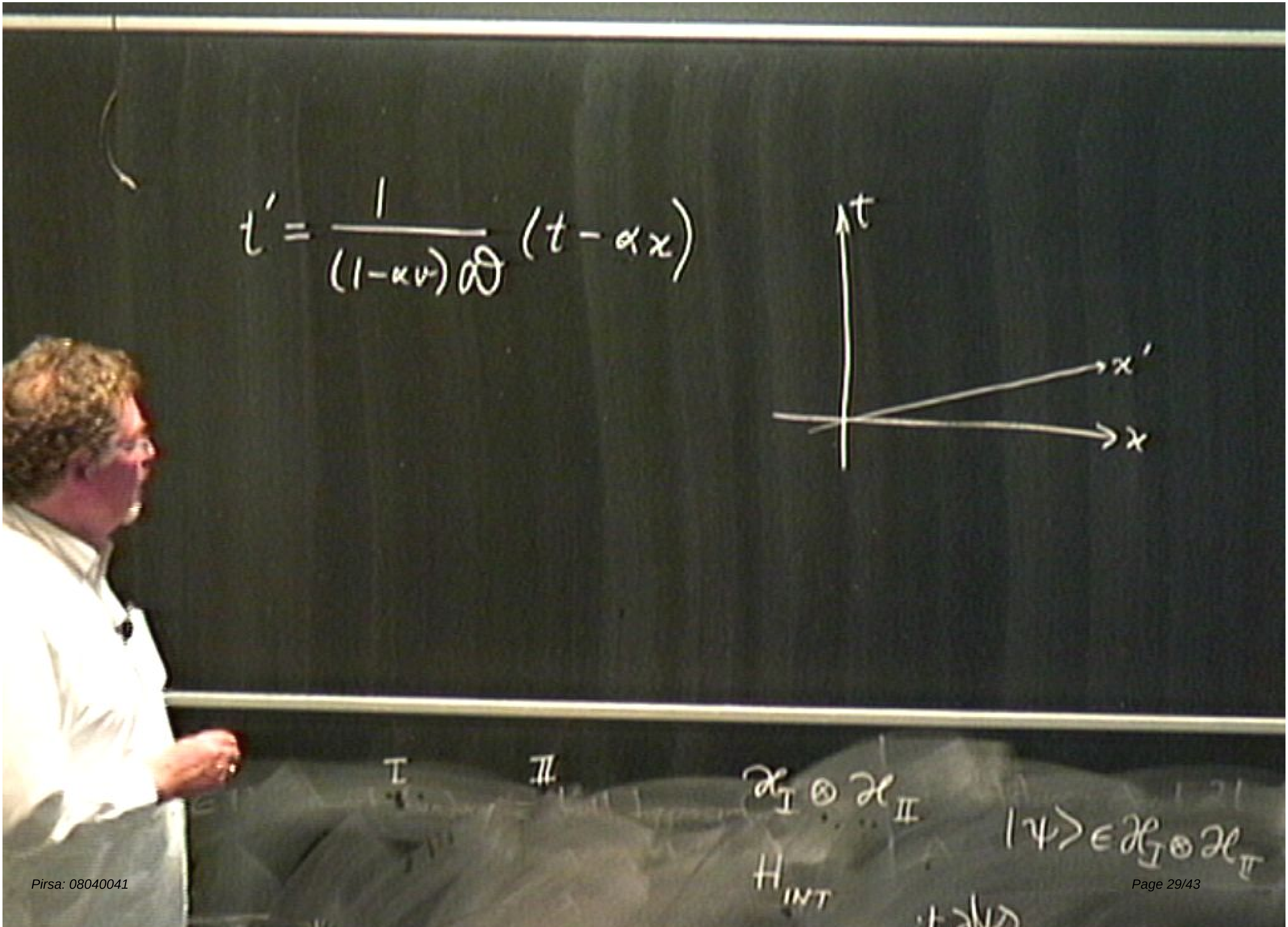
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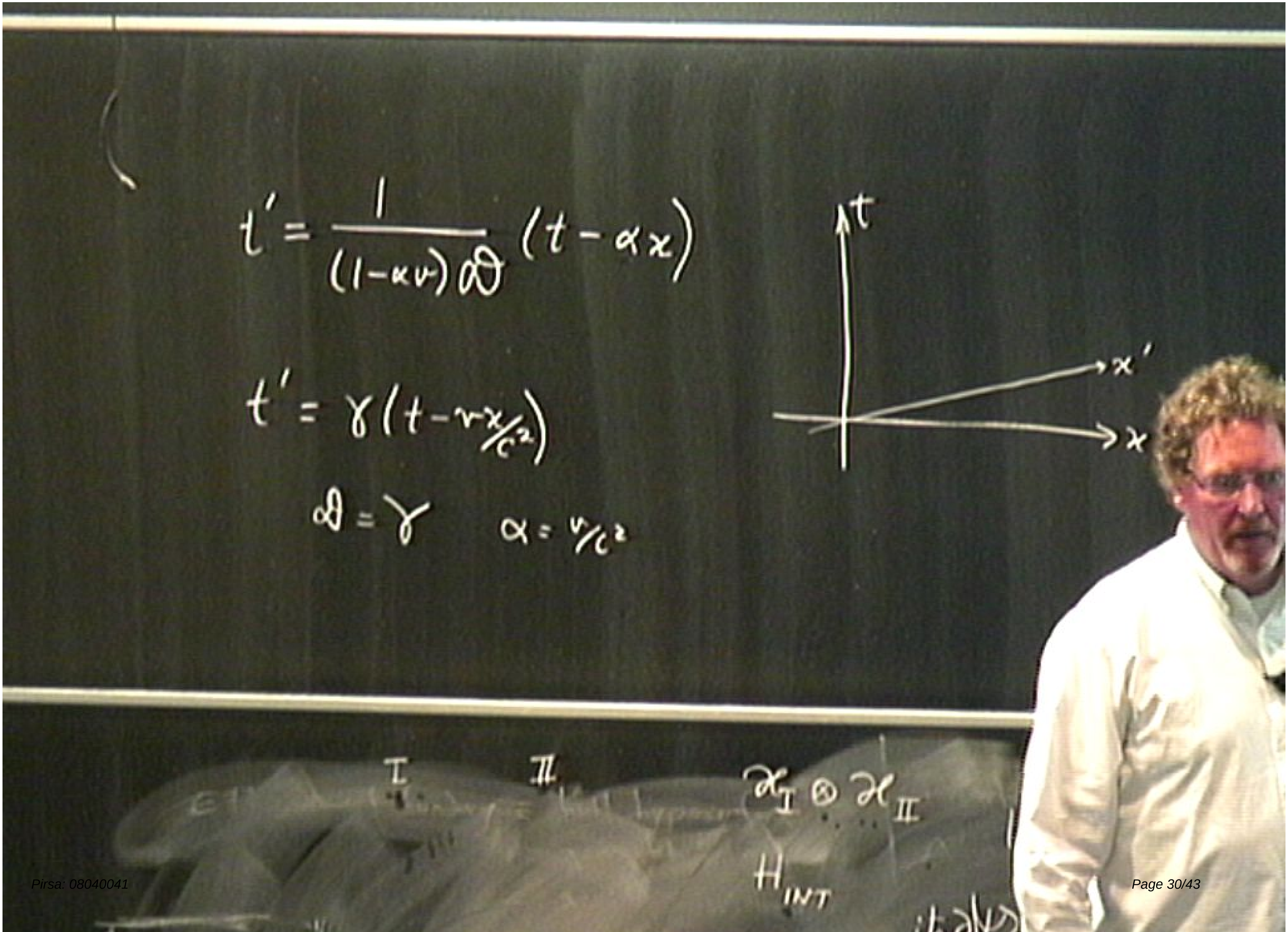
$t' = \frac{1}{(1-\alpha v)\vartheta}(t - \alpha x)$
$t' = \gamma(t - vx/c^2)$
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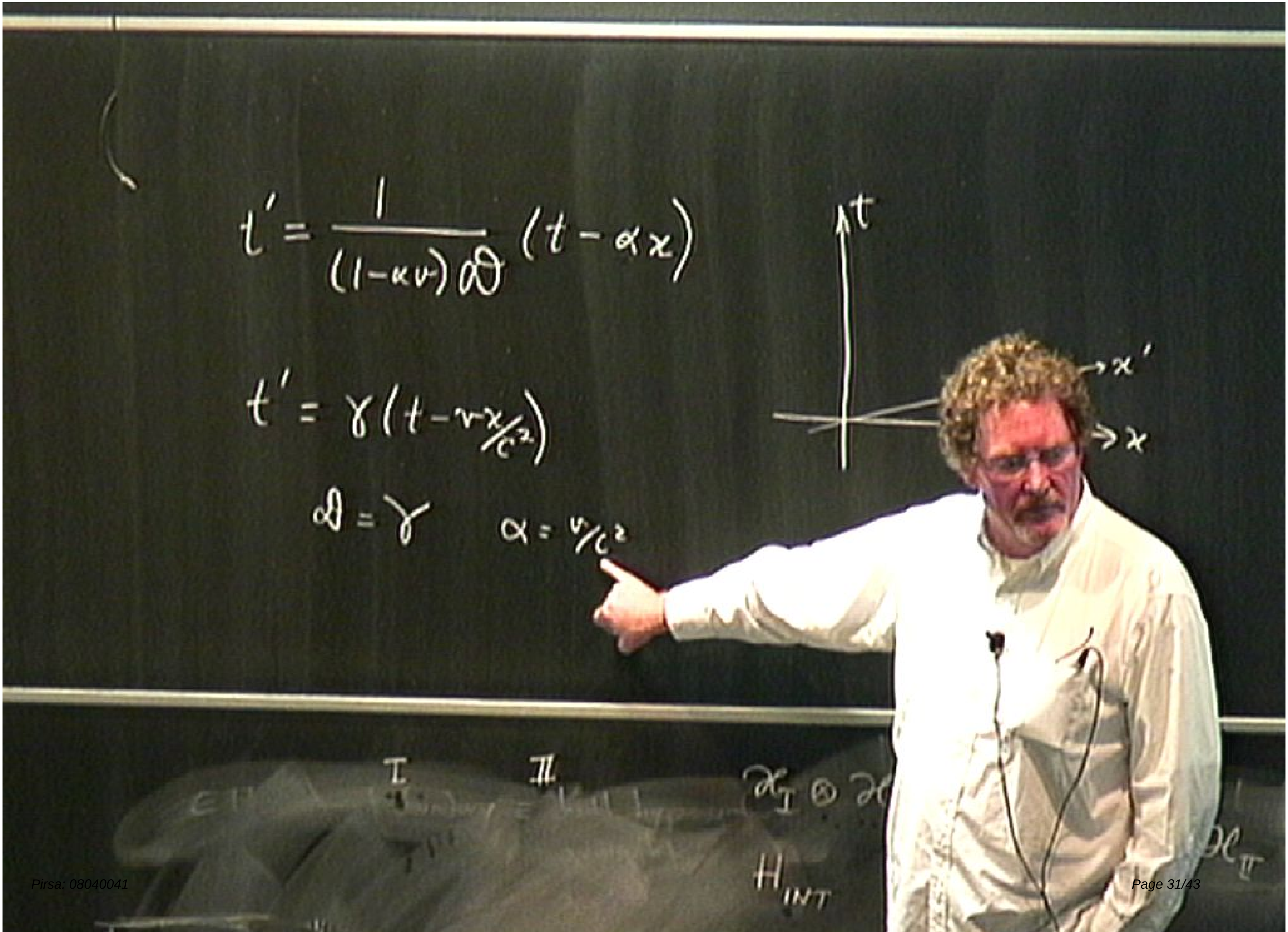

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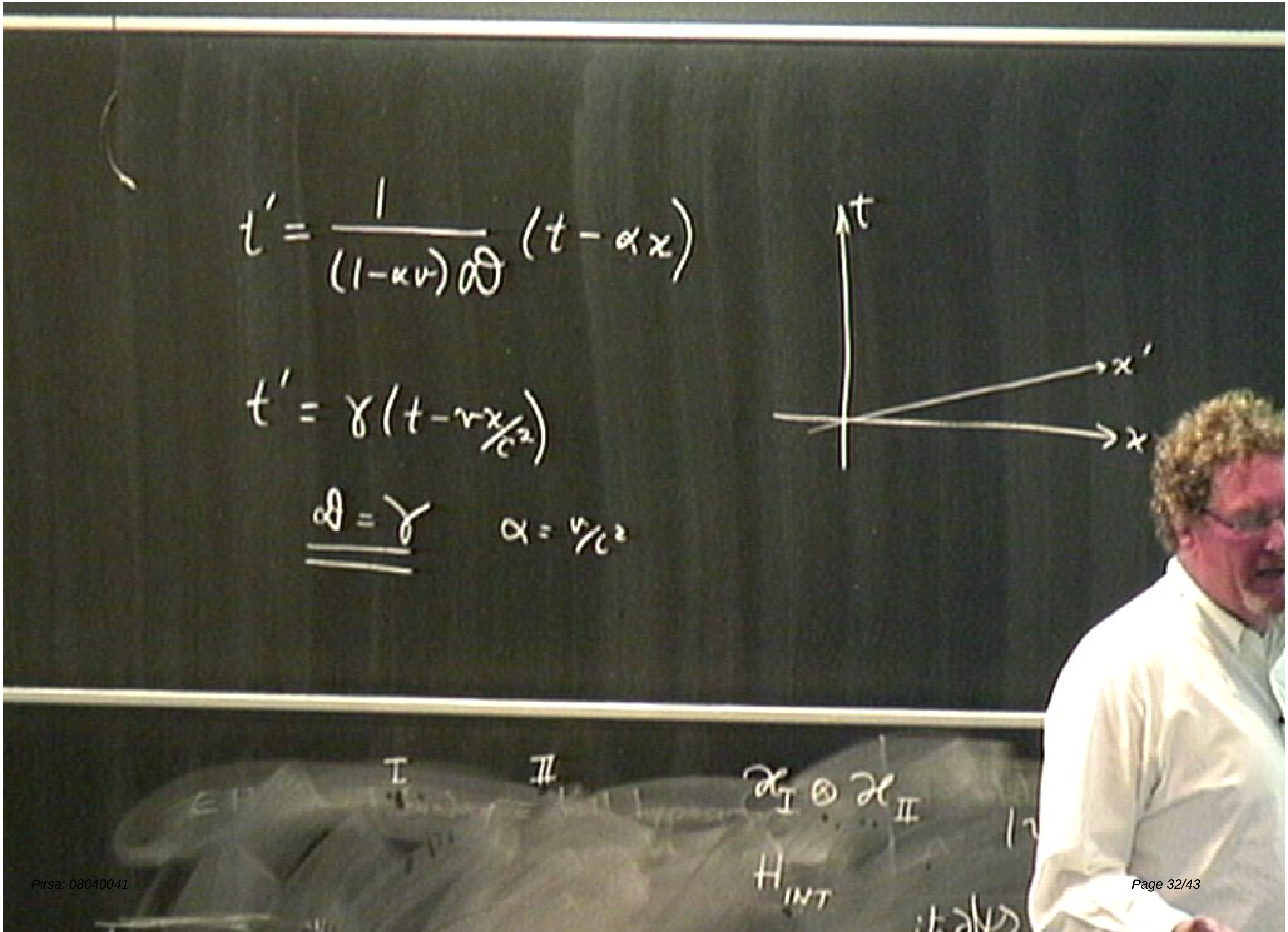
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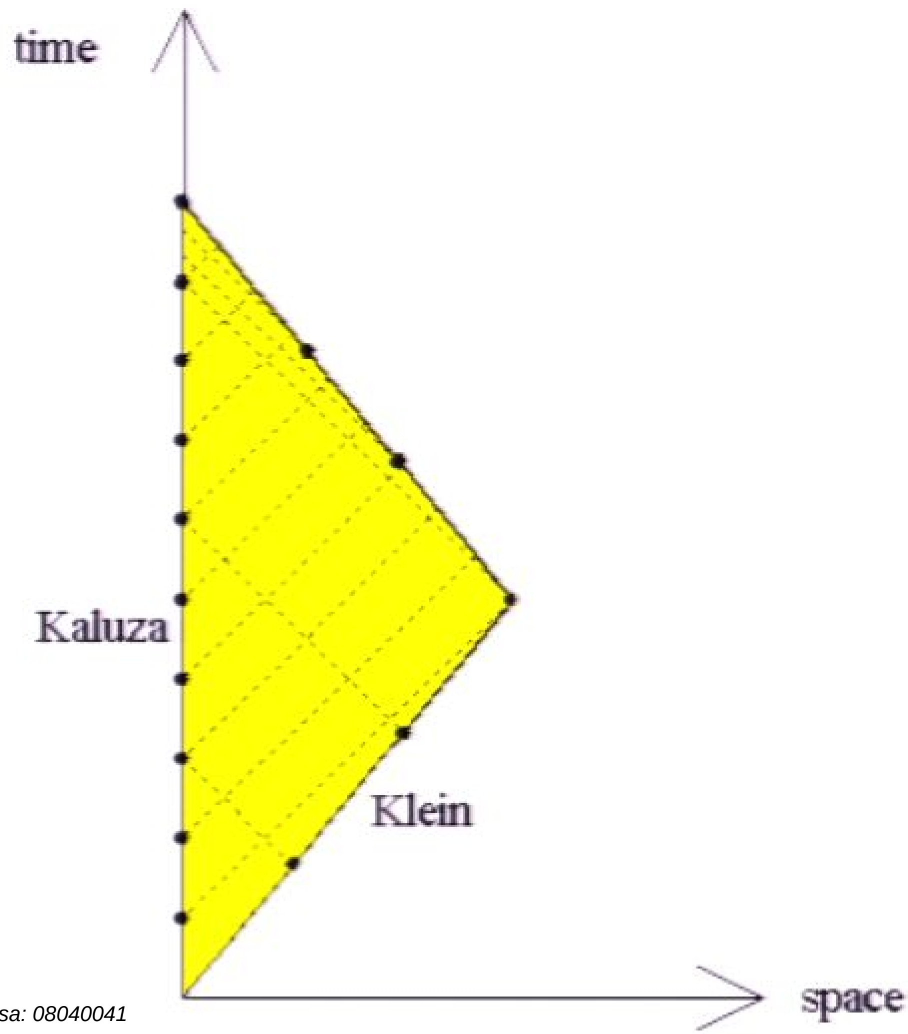

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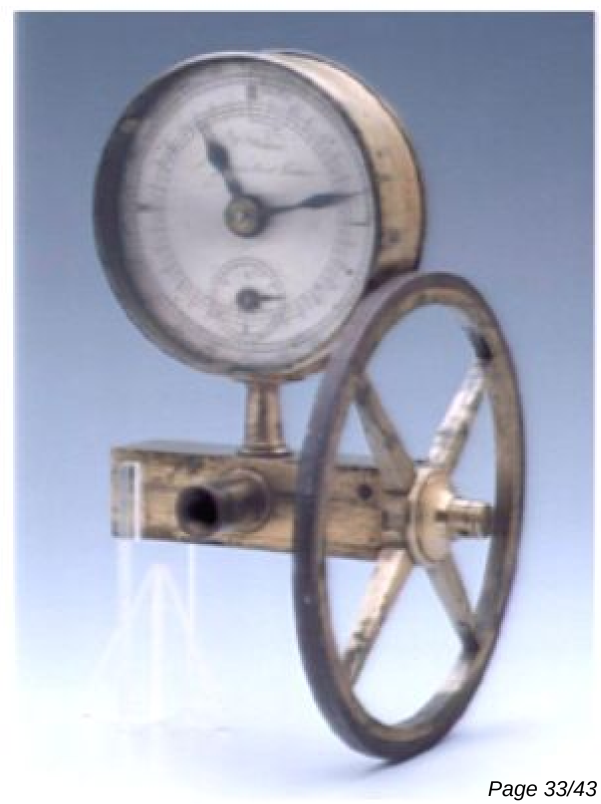

How to explain time dilation?

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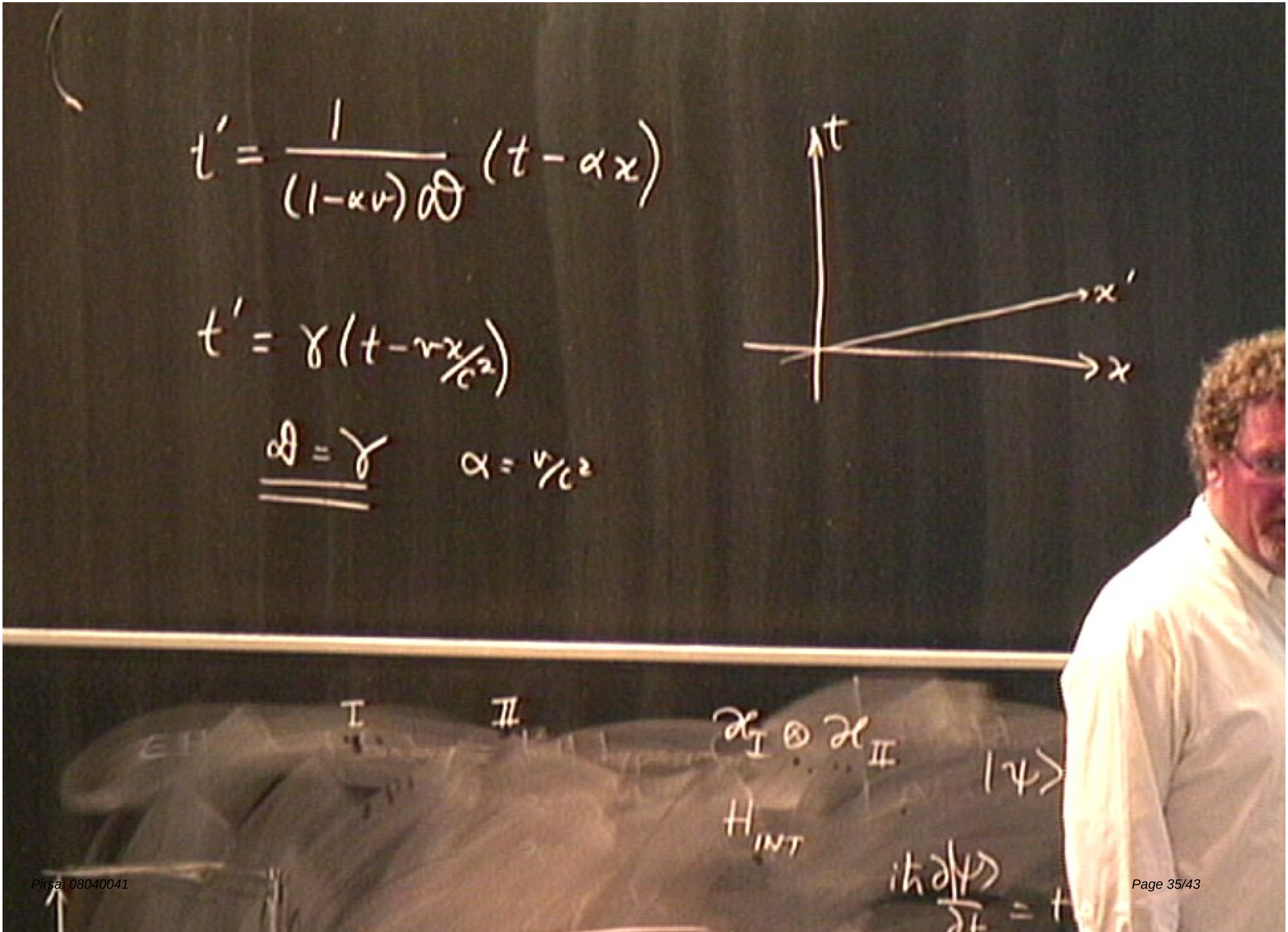
- It takes Minkowski's 1908 geometrization of the theory.
- Appeal must be made to the quantum theory of matter.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Einstein's misgivings

- limitations of thermodynamic template (1907, 1908)
  SR only a "(half) salvation" to the "predicament" posed by the MM experiment

- treatment of rods and clocks as primitive bodies, and not "moving atomic configurations" (1921, 1949)

- the special role of light (1935, 1949)

"The special theory of relativity grew out of the Maxwell electromagnetic equations. But ... the Lorentz transformation, the real basis of special-relativity theory, in itself has nothing to do with the Maxwell theory." (1935) "... the Lorentz transformation transcended its connection with Maxwell's equations and had to do with the nature of space and time in general." (1955)

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Strong (Einstein) equivalence principle

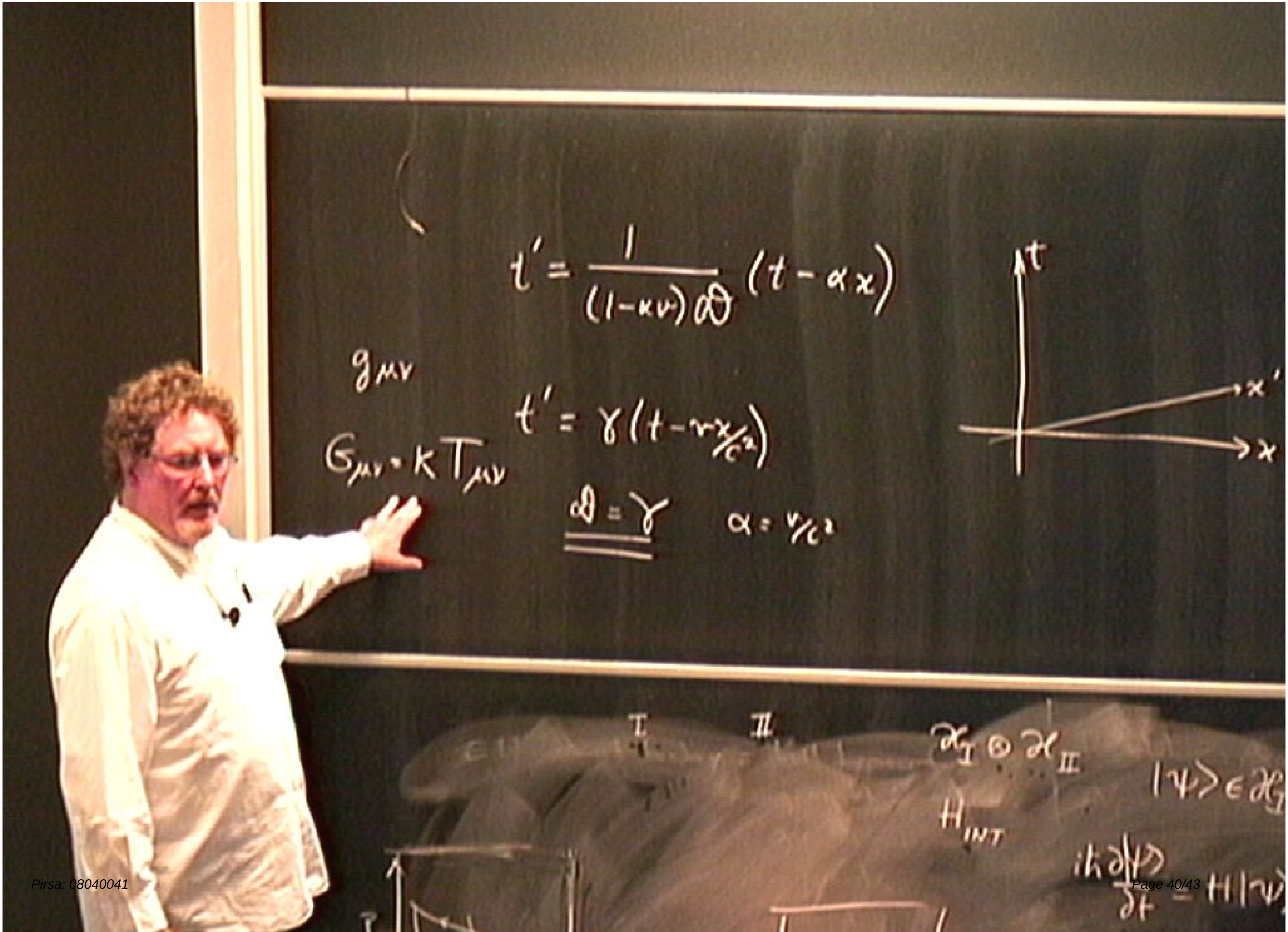
"... in any and every local Lorentz frame, anywhere and anytime in the universe, all the (nongravitational) laws of physics must take on their familiar special relativistic forms." *Misner, Thorne and Wheeler (1973), p. 386.*

"At each point of space-time it is possible to find a coordinate transformation such that the gravitational field variables can be eliminated from the field equations of matter." *Ohanian (1975).*

Two components:

I. *Universality.* All non-gravitational interactions pick out the same family of privileged local frames. (There is only one affine connection, a necessary condition for a "*geometrical*" theory like Einstein's.)

II. *Minimal coupling.* (E.g. The curvature tensor does not appear in the generalized Maxwell equations.)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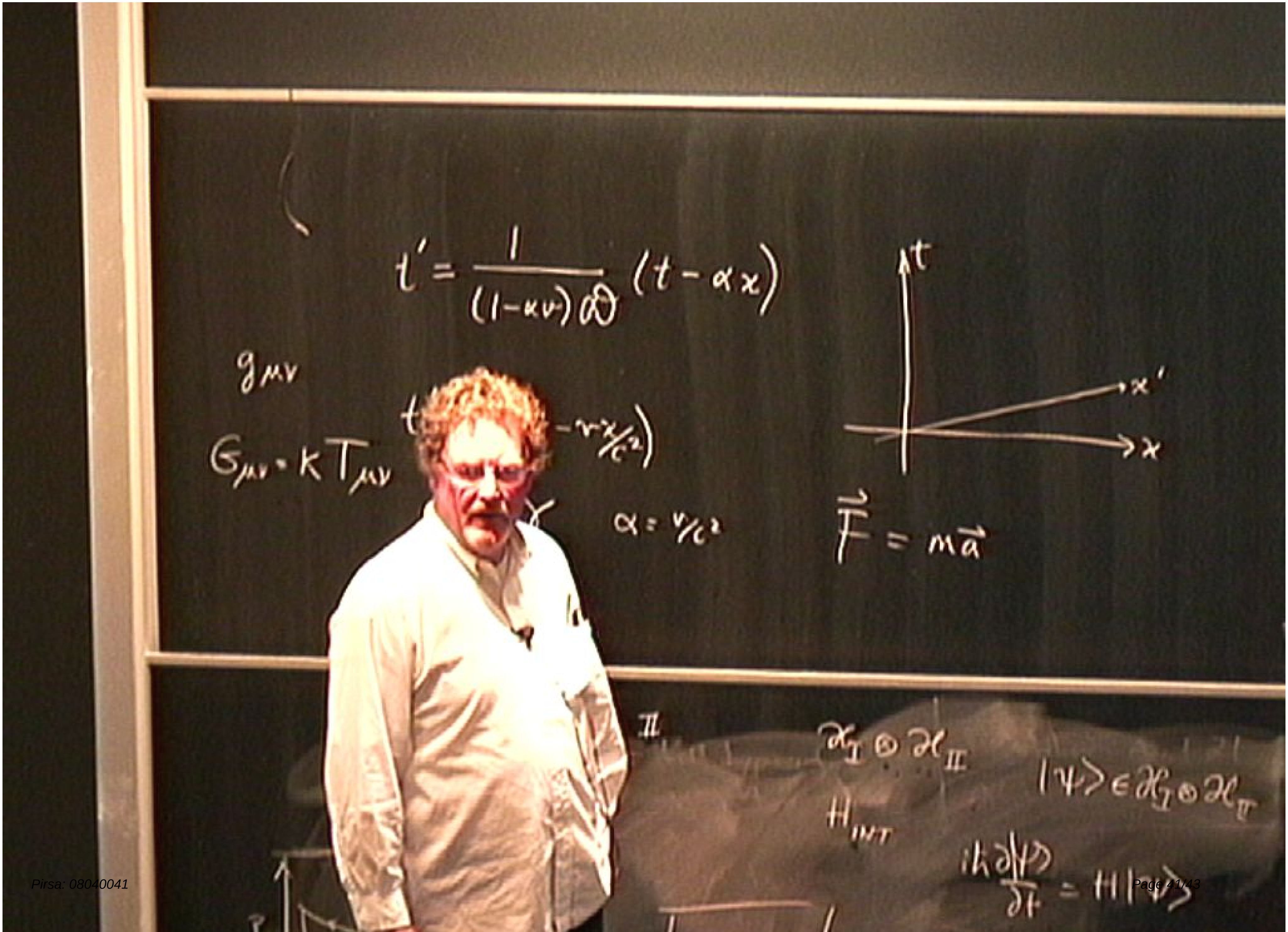

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Distant Simultaneity