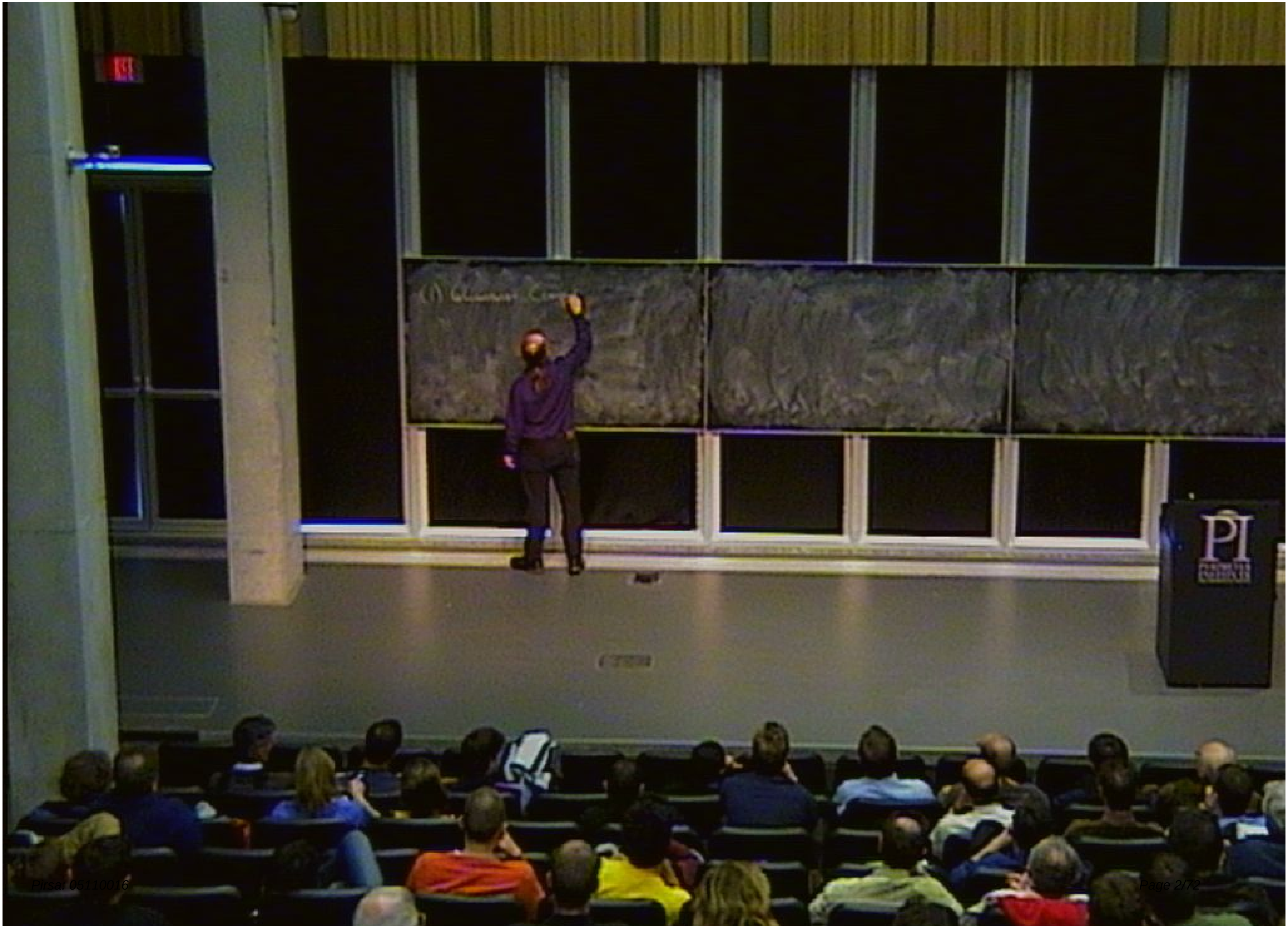
Title: Computing the universe.

Date: Nov 18, 2005 04:15 PM

URL: http://pirsa.org/05110016

Abstract:



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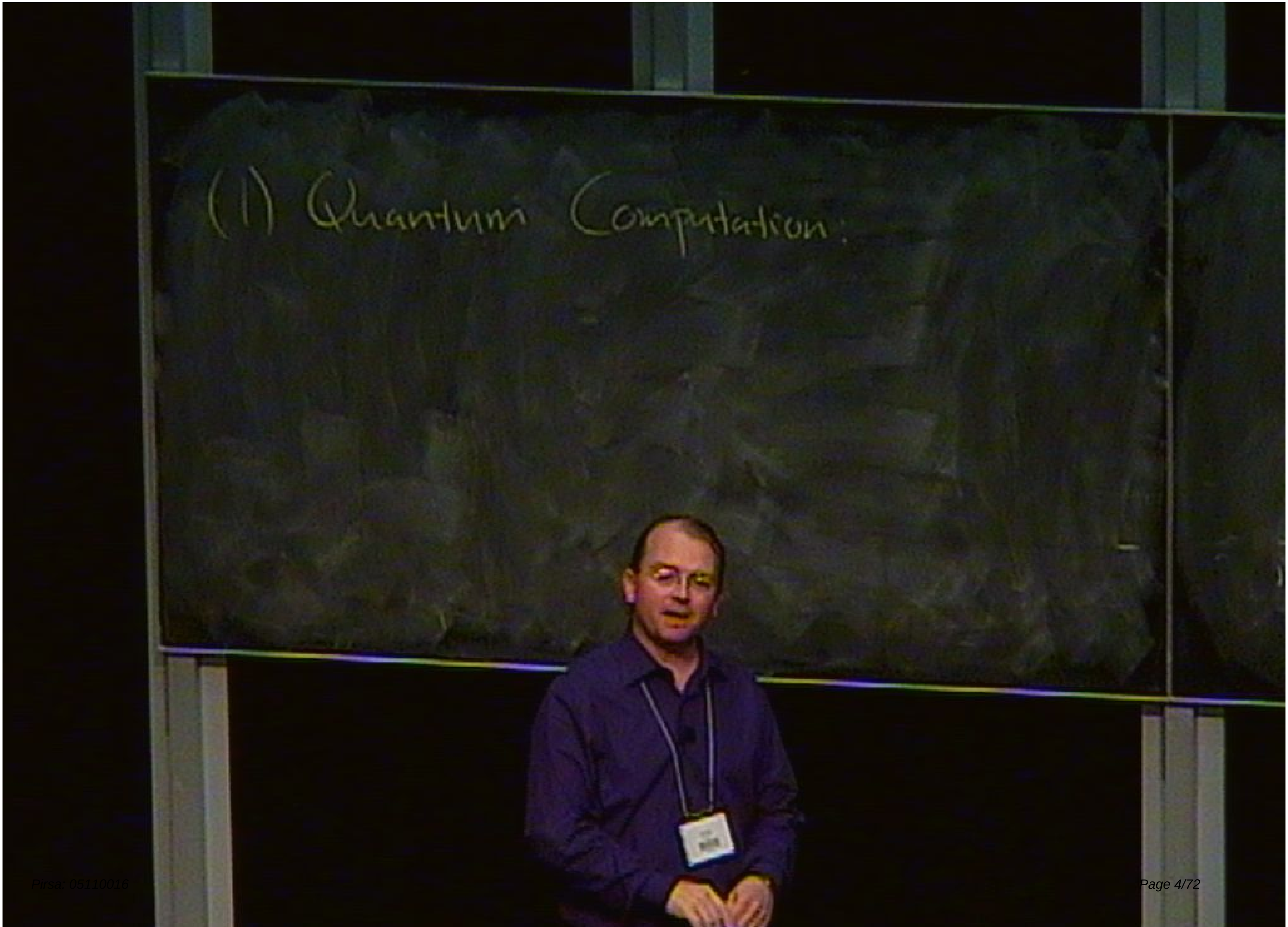
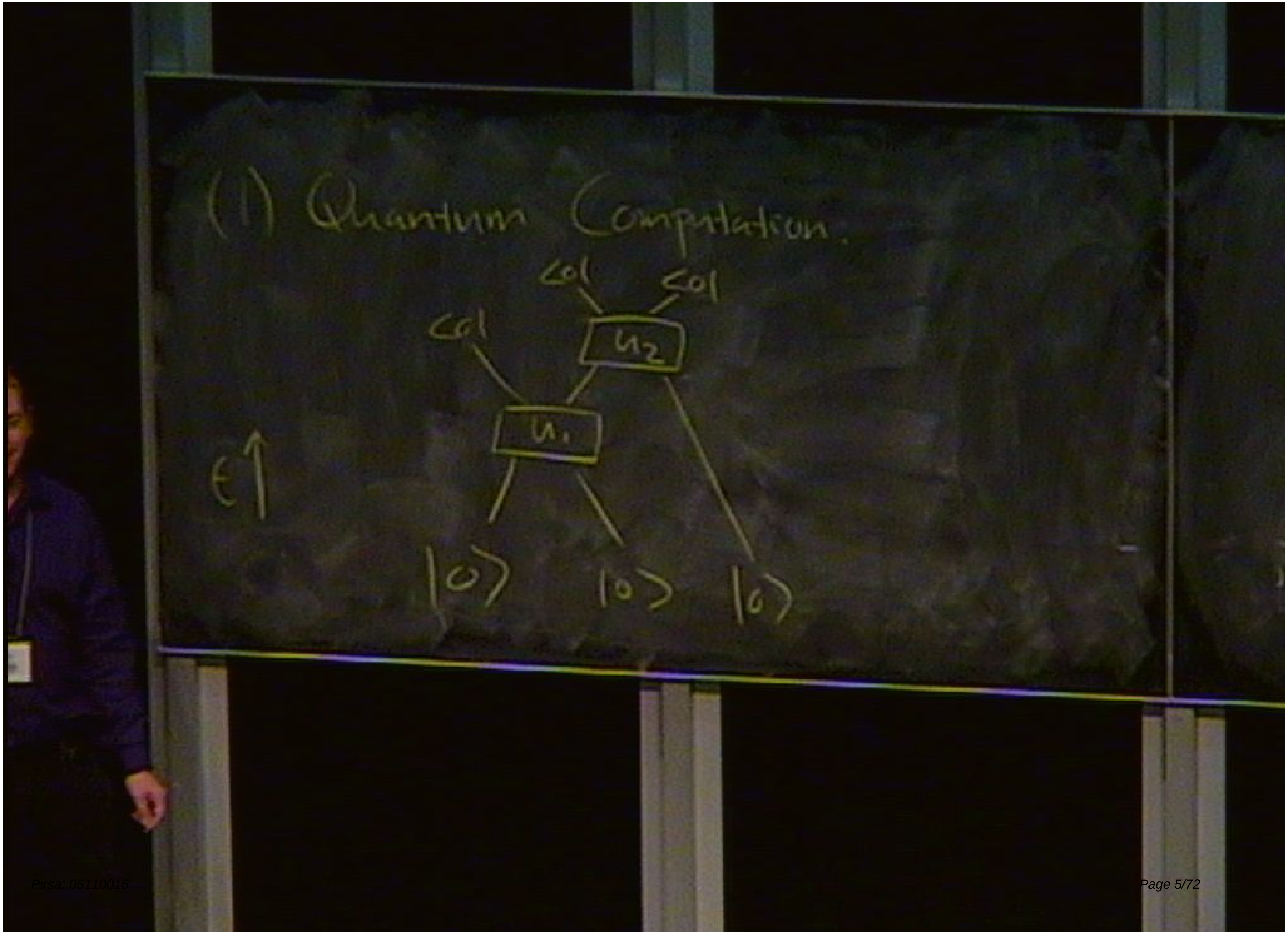
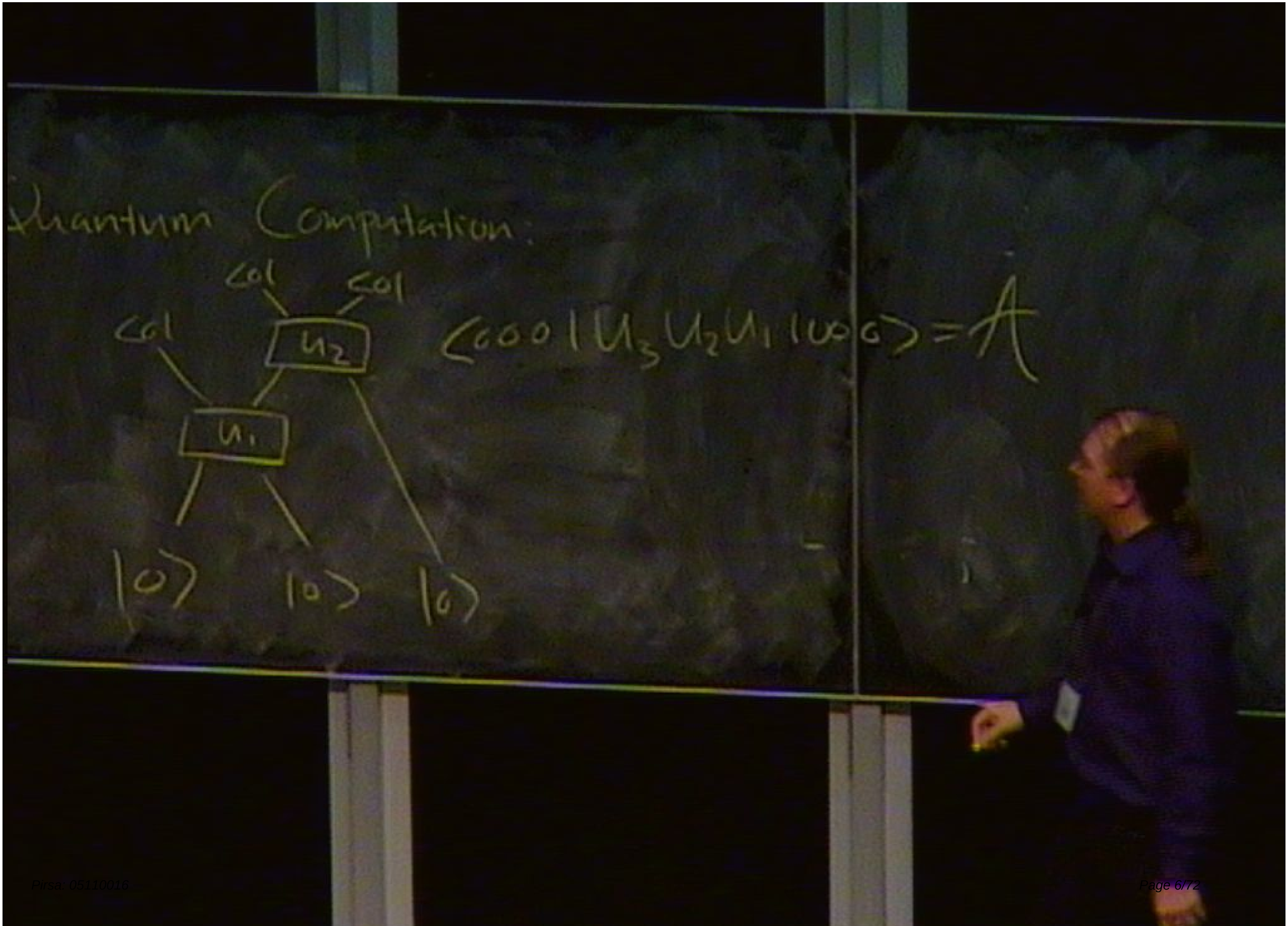
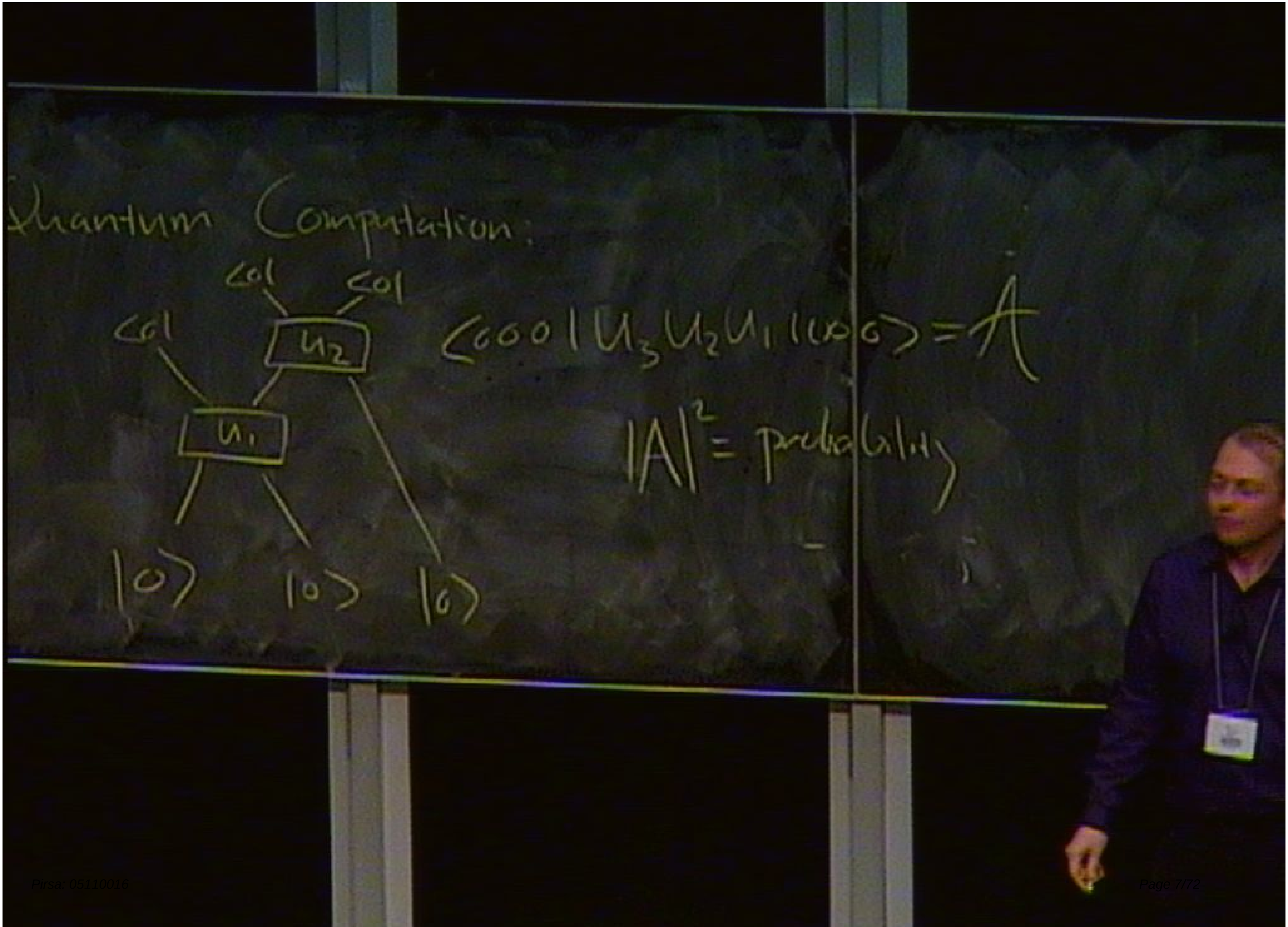
quant-ph/0110141

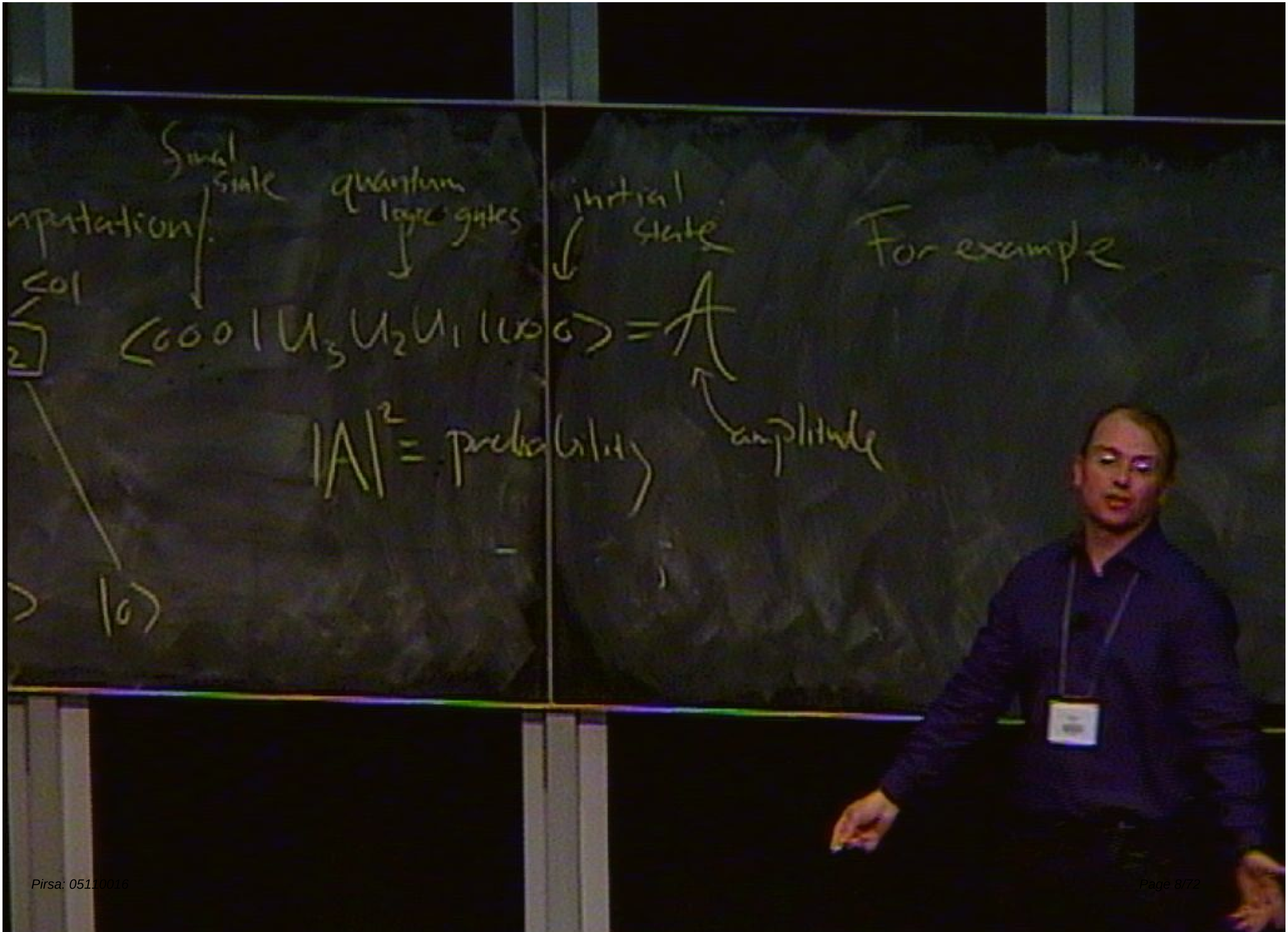
quant-ph/0501135


(1) Quantum Computation:


(1) Quantum Computation.
<0|
<0|
<0|
U2
U1
t
|0>
|0>
|0>


Quantum Computation:
$\langle 0|$ $\langle 0|$ $\langle 0|$
U_2
U_1
$|0\rangle$ $|0\rangle$ $|0\rangle$
$\langle 000|U_3U_2U_1|000\rangle = A$


Quantum Computation:
<0|
<0|
<0|
U2
U1
|0>
|0>
|0>
<000|U3U2U1|000> = A
|A|2 = probability


final state
quantum logic gates
initial state
For example
mputation
<000|U3U2U1|000> = A
amplitude
|A|2 = probability

amplitude

For example, $U = e^{-iS\theta}$

$$S = \sigma_x^1 \sigma_x^2 + \sigma_y^1 \sigma_y^2 + \sigma_z^1 \sigma_z^2$$

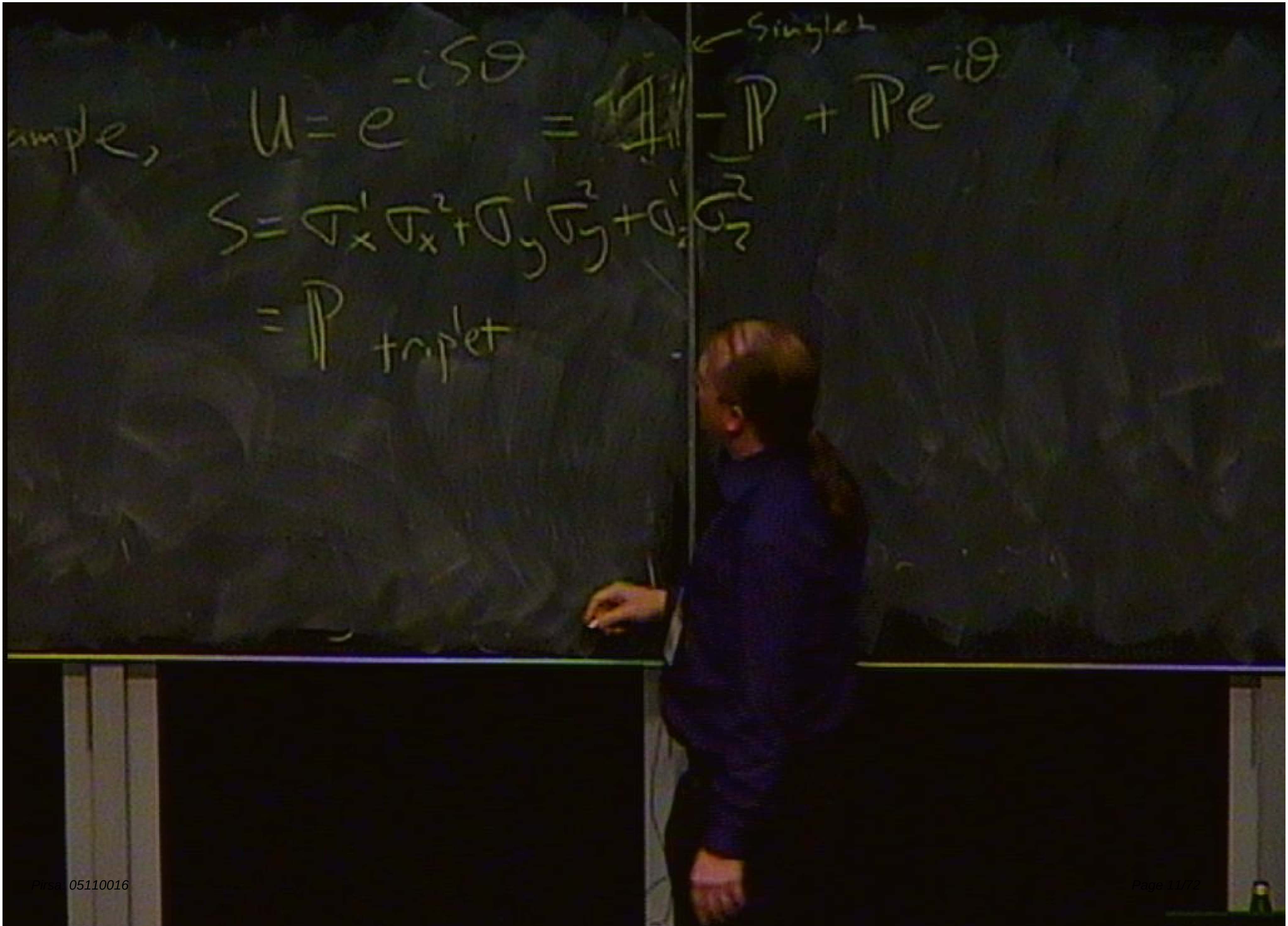
$$= \mathbb{P}_{\text{triplet}}$$

amplitude

For example, $U = e^{-iS\theta}$

$$S = \sigma_x^1 \sigma_x^2 + \sigma_y^1 \sigma_y^2 + \sigma_z^1 \sigma_z^2$$

$$= \mathbb{P}_{\text{triplet}}$$


← singlet
ample, $U = e^{-iS\theta} = \ \ -\mathbb{P} + \mathbb{P}e^{-i\theta}$
$S = \sigma_x^1\sigma_x^2 + \sigma_y^1\sigma_y^2 + \sigma_z^1\sigma_z^2$
$= \mathbb{P}_{\text{triplet}}$

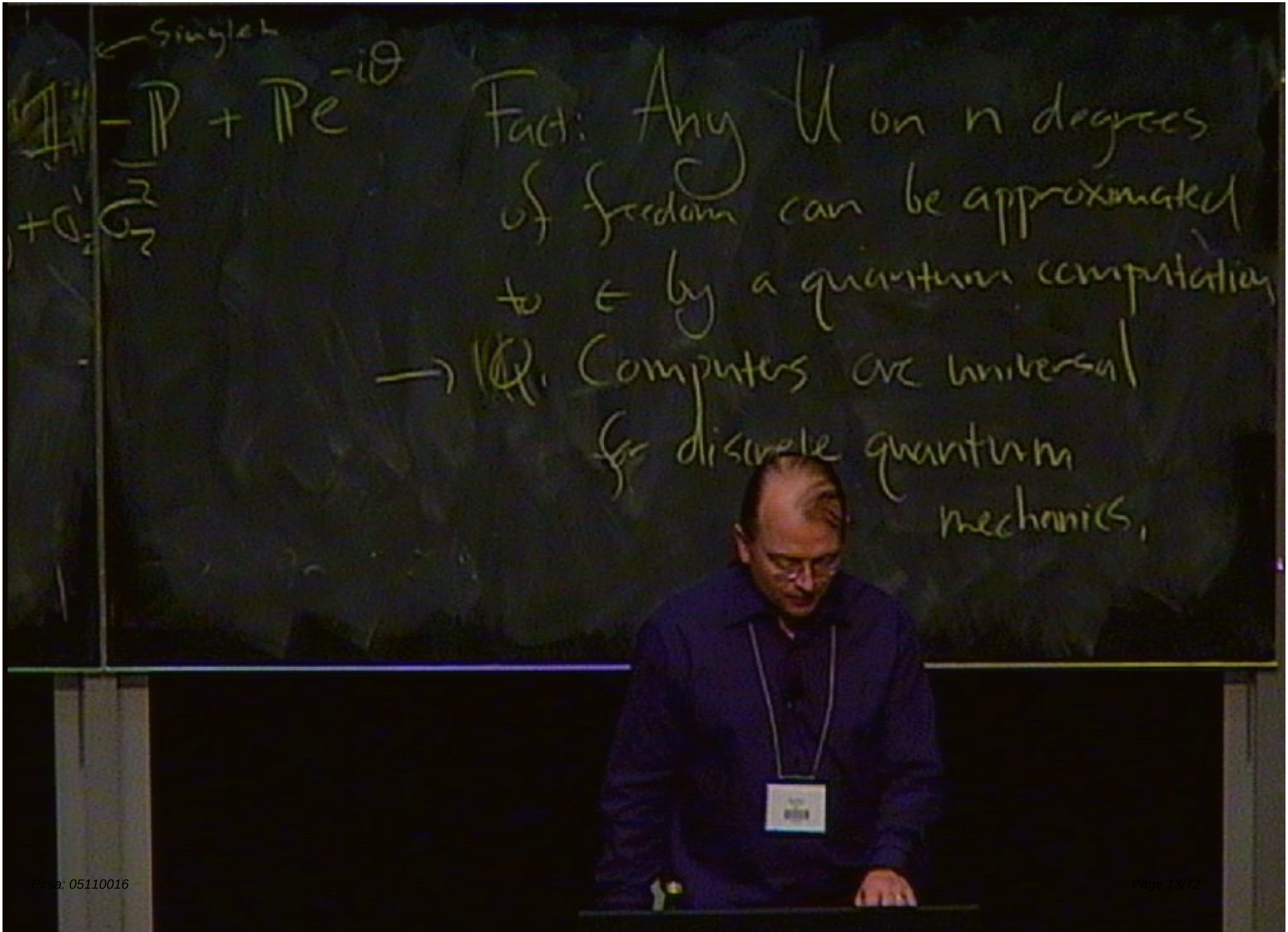
← Singlet

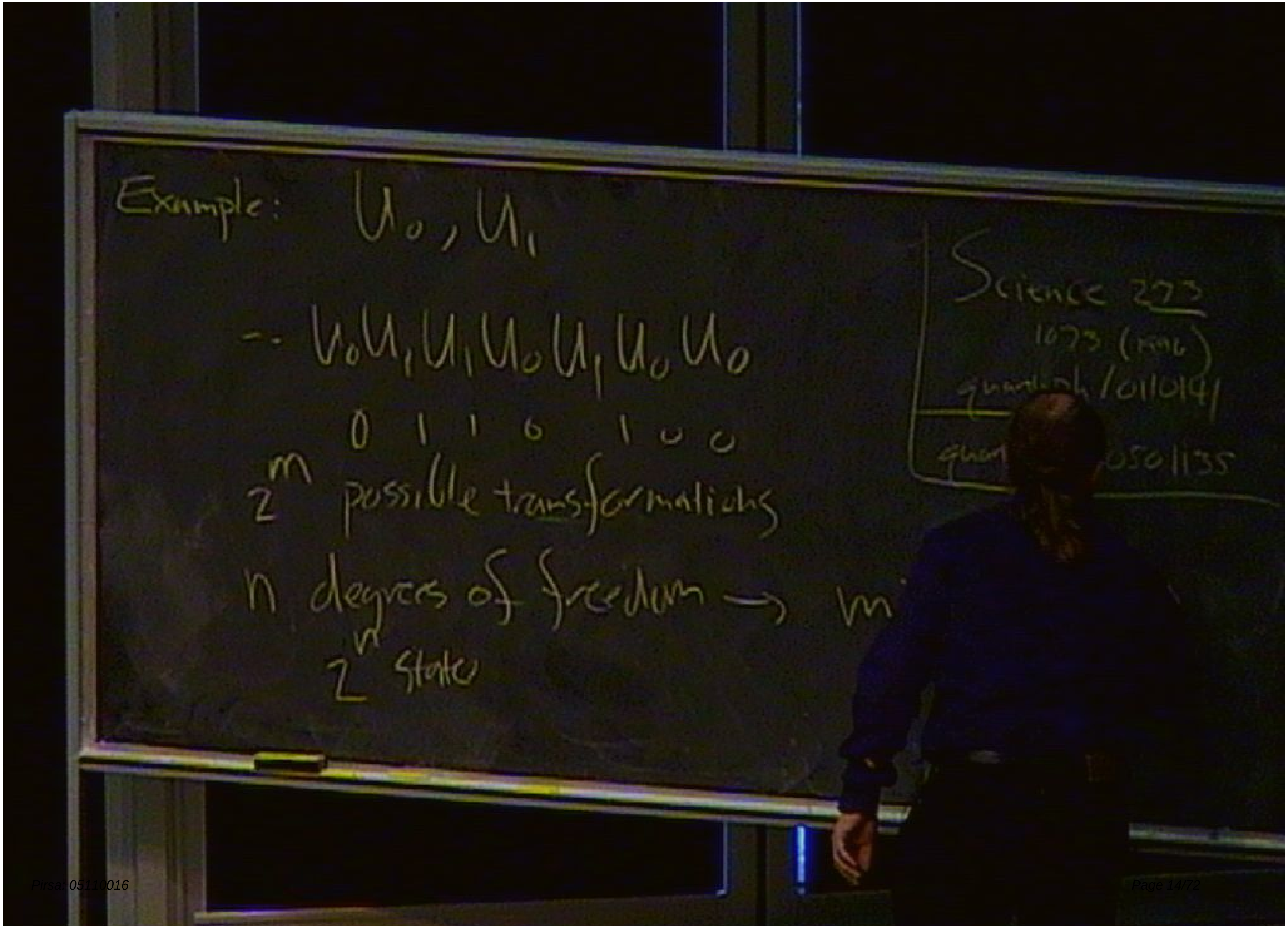
$\mathbb{1} - \mathbb{P} + \mathbb{P}e^{-i\theta}$

$+ \vec{\sigma}_1 \cdot \vec{\sigma}_2$

Fact: Any U on n degrees of freedom can be approximated to ϵ by a quantum computation

→ Q. Computers are universal for discrete quantum


Singlet
Fact: Any U on n degrees of freedom can be approximated to ε by a quantum computation
Q. Computers are universal for discrete quantum mechanics,


Example: U0 , U1
... U0 U1 U1 U0 U1 U0 U0
0 1 1 0 1 0 0
2^m possible transformations
n degrees of freedom → m
2^n states
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050||35

Example: U_0, U_1

$\rightarrow U_0 U_1 U_1 U_0 U_1 U_0 U_0$

0 1 1 0 1 0 0

2^m possible transformations

n degrees of freedom $\rightarrow$ $m > 2^{2n} \log 1/\epsilon$

2^n states

can get within ϵ of any U

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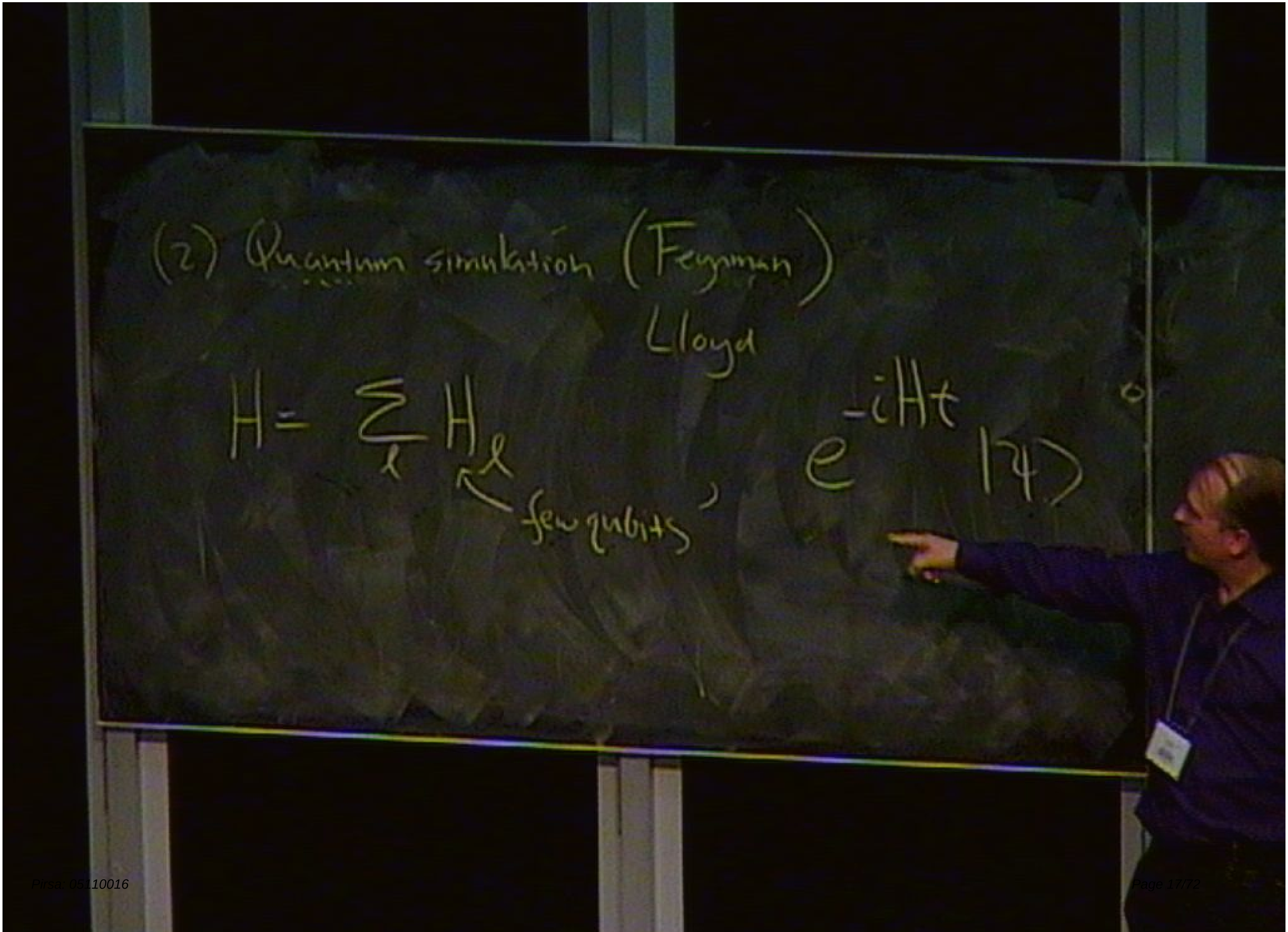
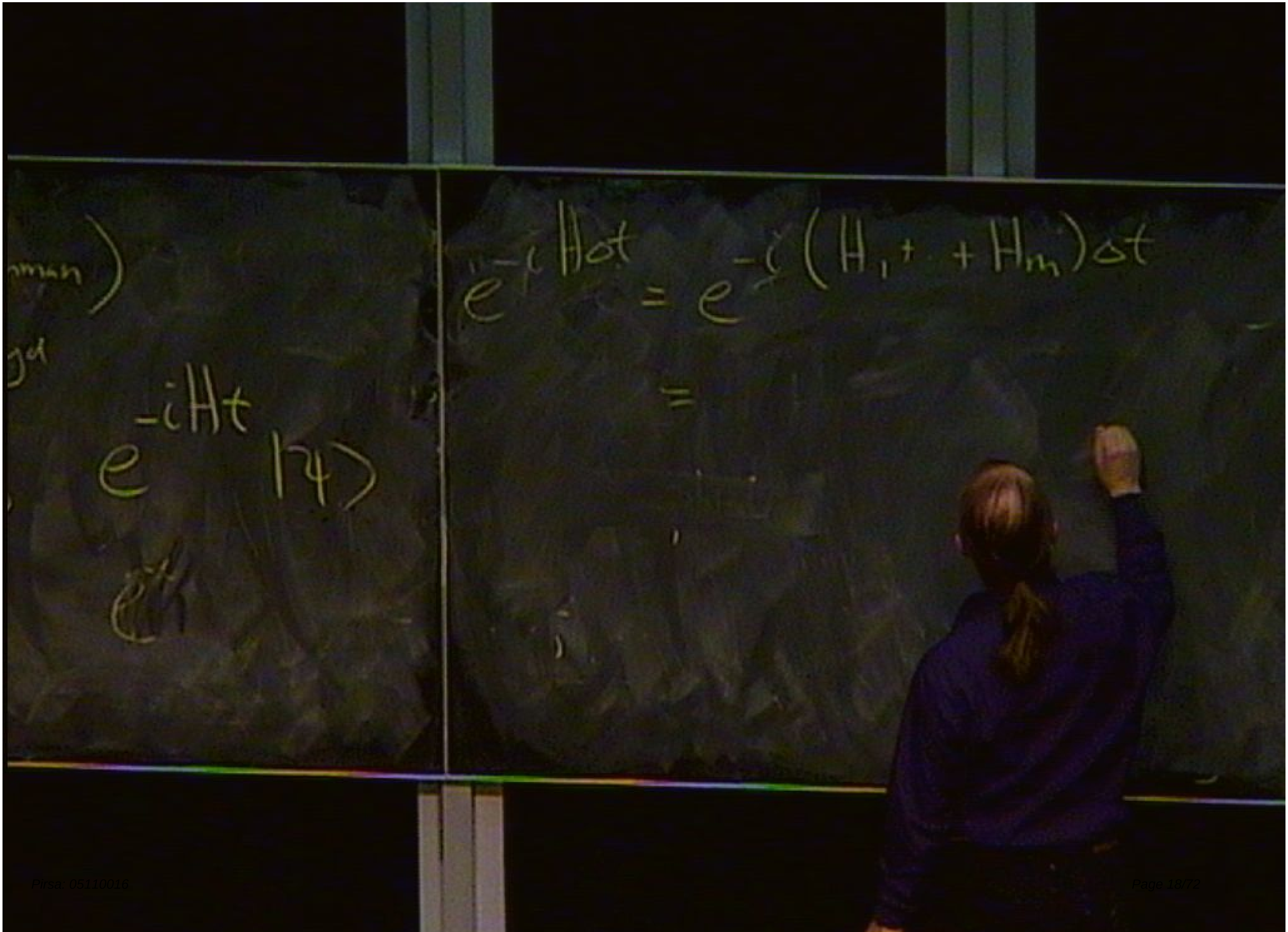
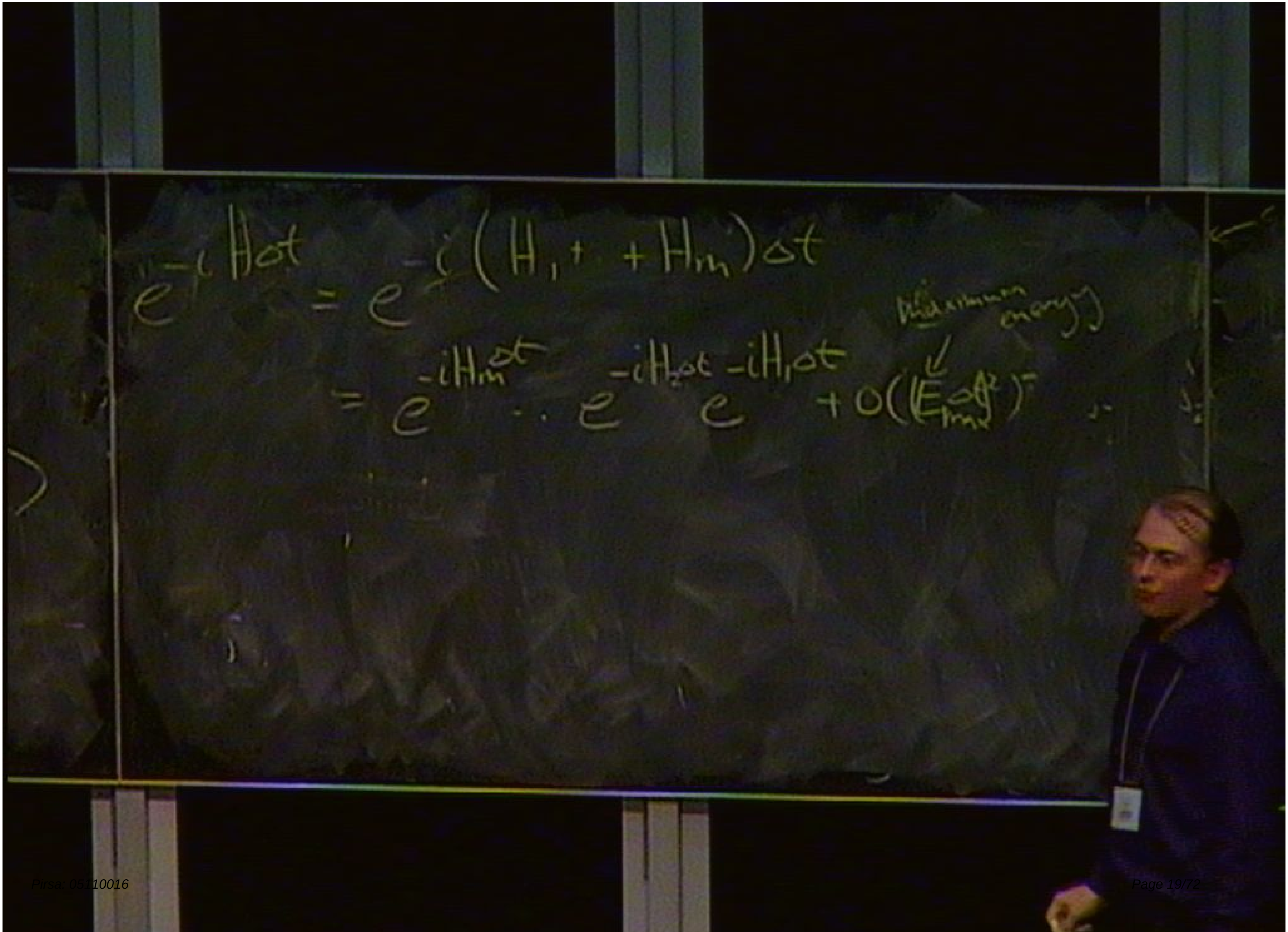
quant-ph/050113

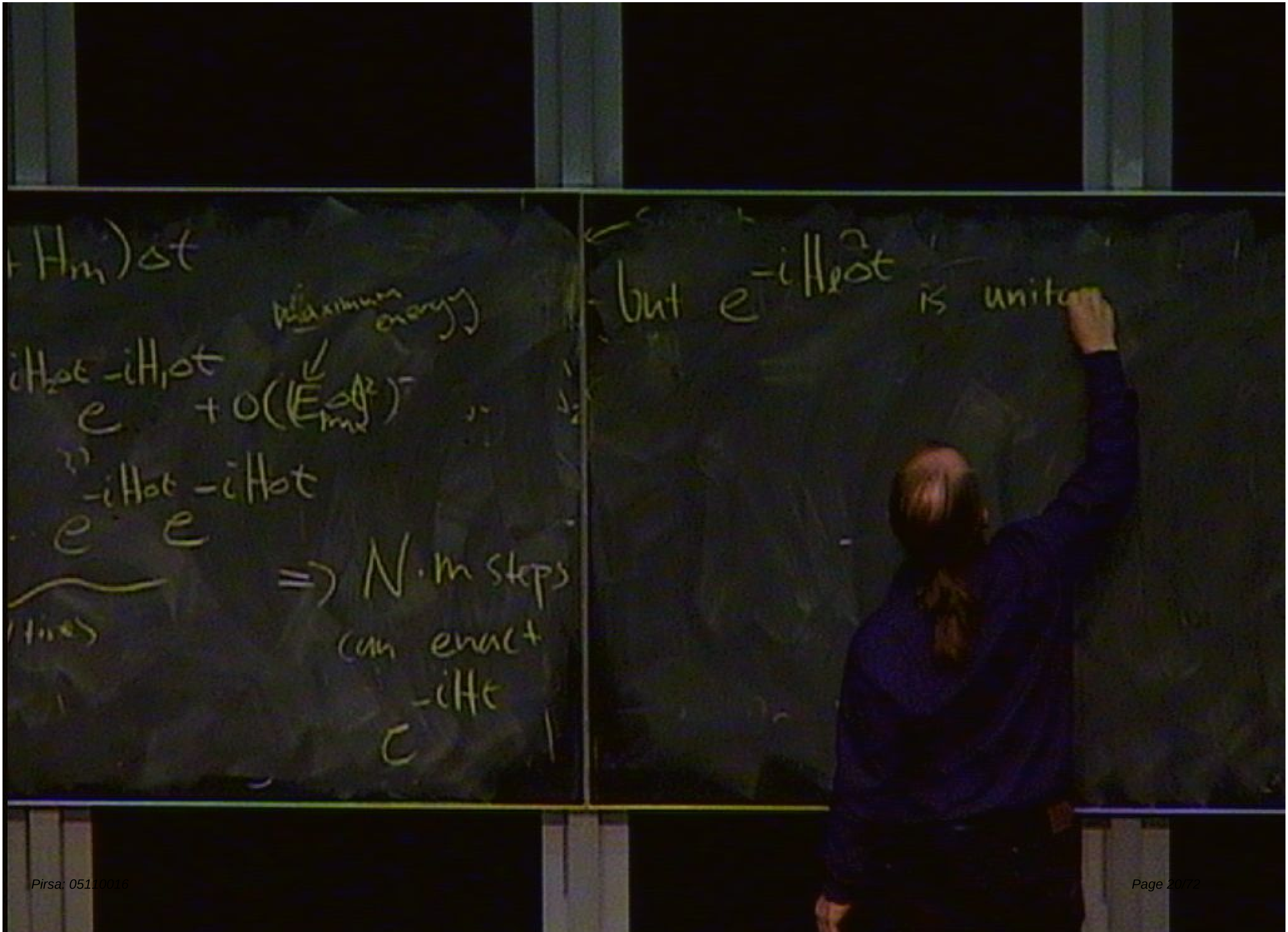
(2) Quantum simulation (Feynman)


(2) Quantum simulation (Feynman)
Lloyd
$H = \sum_l H_l$
few qubits
$e^{-iHt} |\psi\rangle$



$e^{-iH\Delta t} = e^{-i(H_1 + \cdots + H_m)\Delta t}$
$=$
$e^{-iHt} |\psi\rangle$


$e^{-iH\Delta t} = e^{-i(H_1 + \cdots + H_m)\Delta t}$
maximum energy
$= e^{-iH_m\Delta t} \cdots e^{-iH_2\Delta t} e^{-iH_1\Delta t} + O((E_{max}\Delta t)^2)$


+ Hm) δt
maximum energy
-iH2δt -iH1δt
e + O((Emax δt)²)
-iHδt -iHδt
e e
=> N·m steps
can enact
-iHt
e
but e-iHlδt is unit

but $e^{-iH_\ell \delta t}$ is unitary on a few qubits.

n steps

enact

iHt

Example: U_0, U_1

$\cdots U_0 U_1 U_1 U_0 U_1 U_0 U_0$

$0 \; 1 \; 1 \; 0 \; 1 \; 0 \; 0$

2^m possible transformations

n degrees of freedom $\rightarrow$ $m > 2^{2n} \log 1/\epsilon$

2^n states

can get within ϵ of any U.

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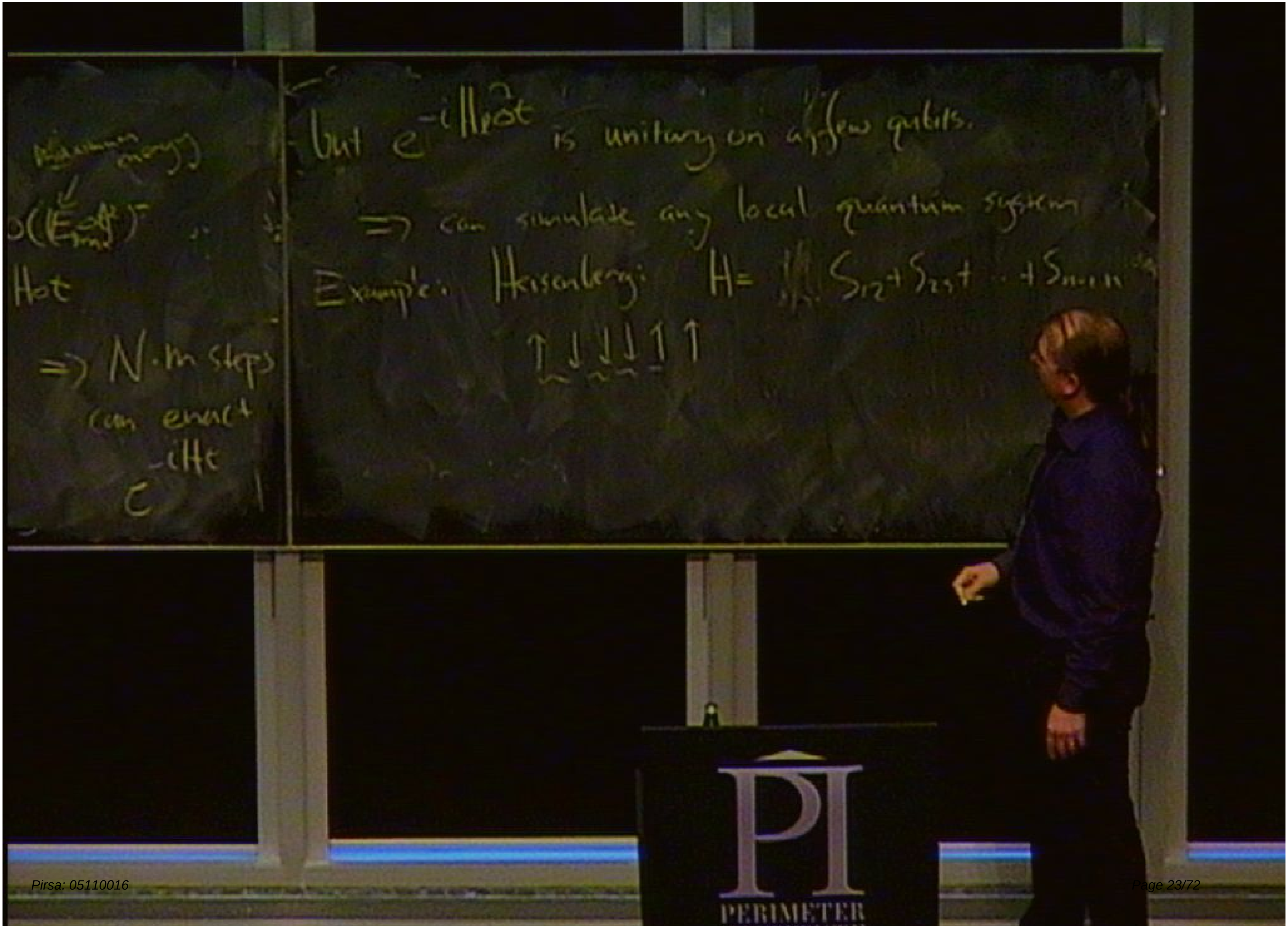
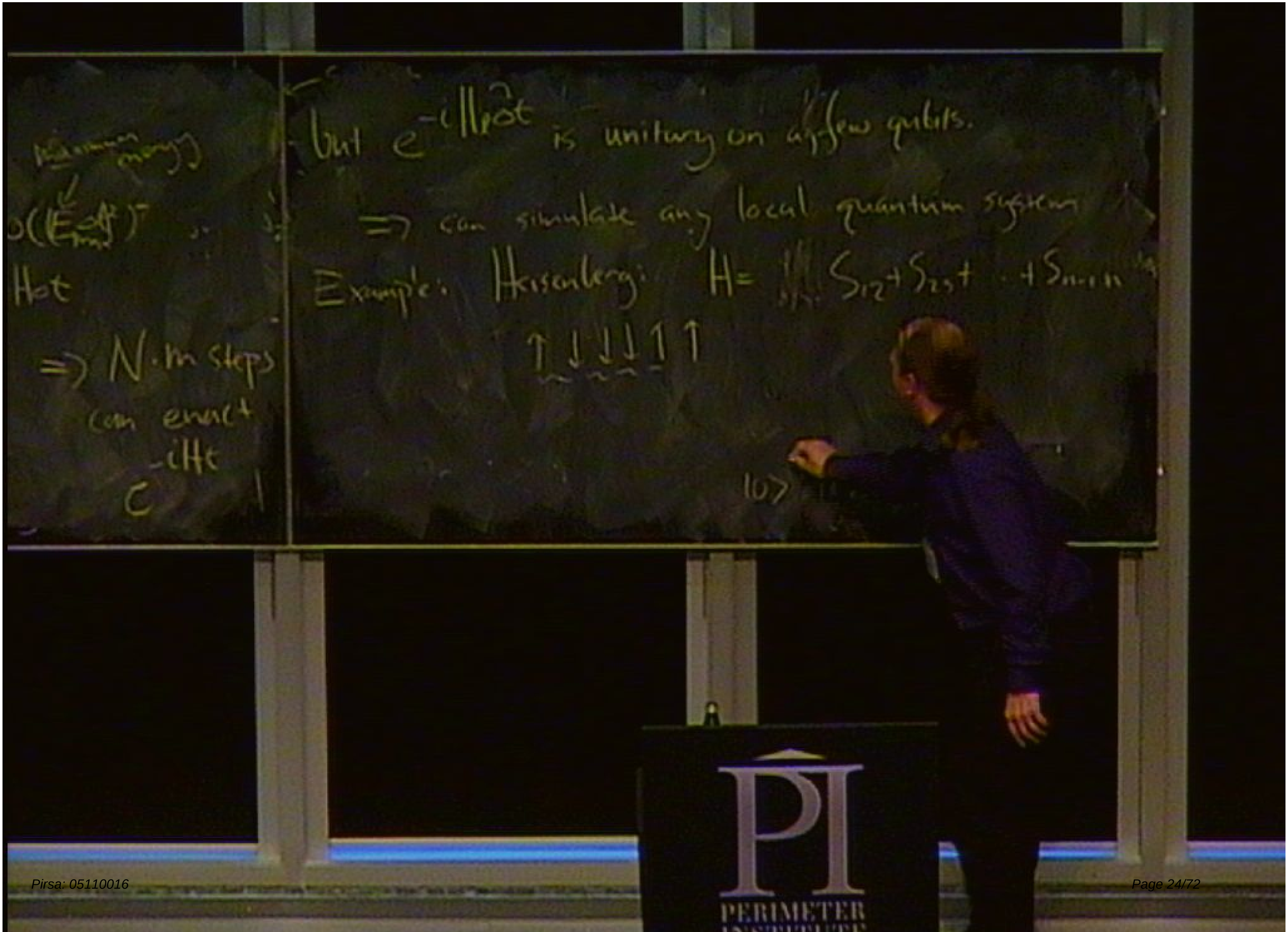
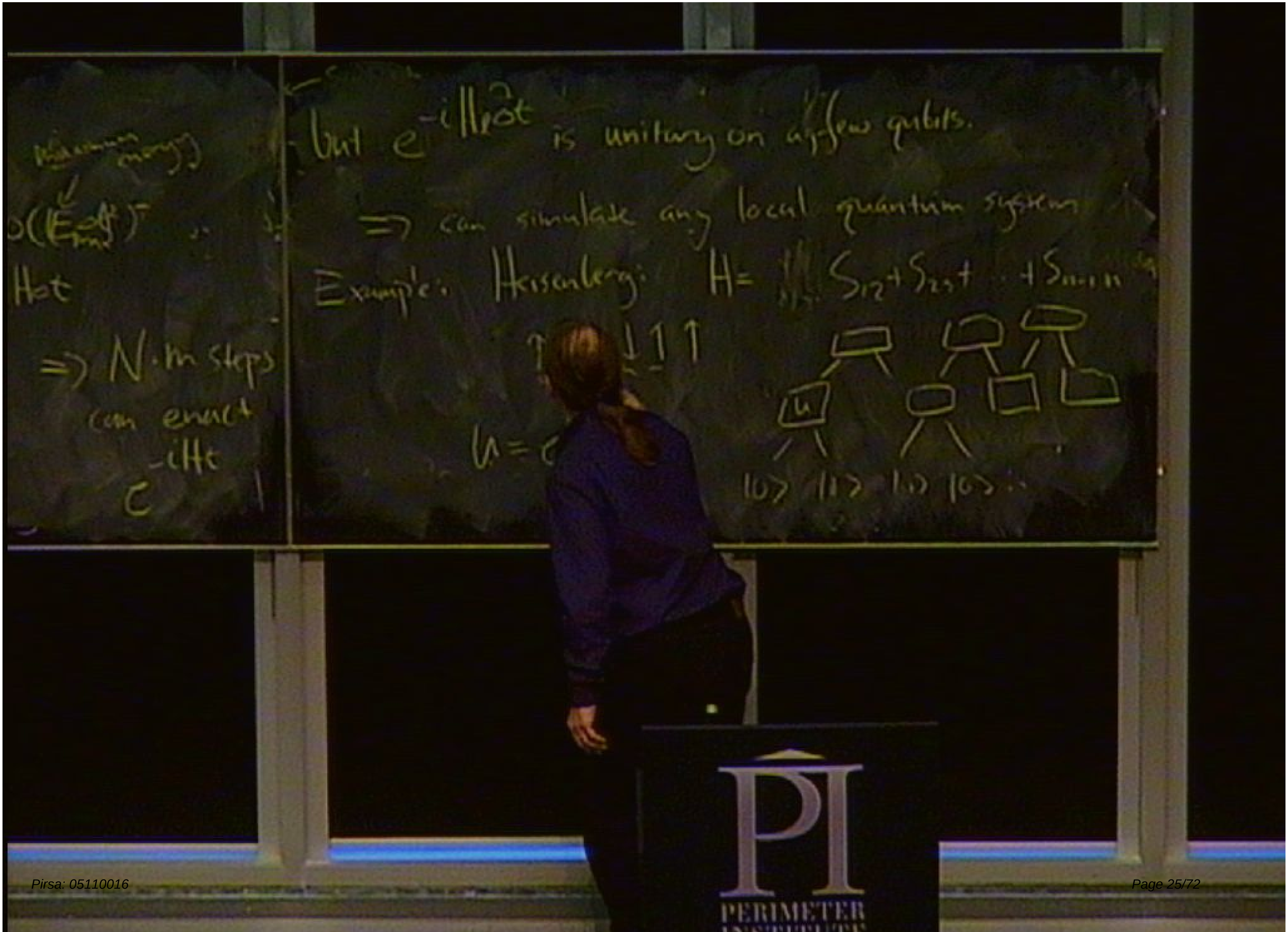
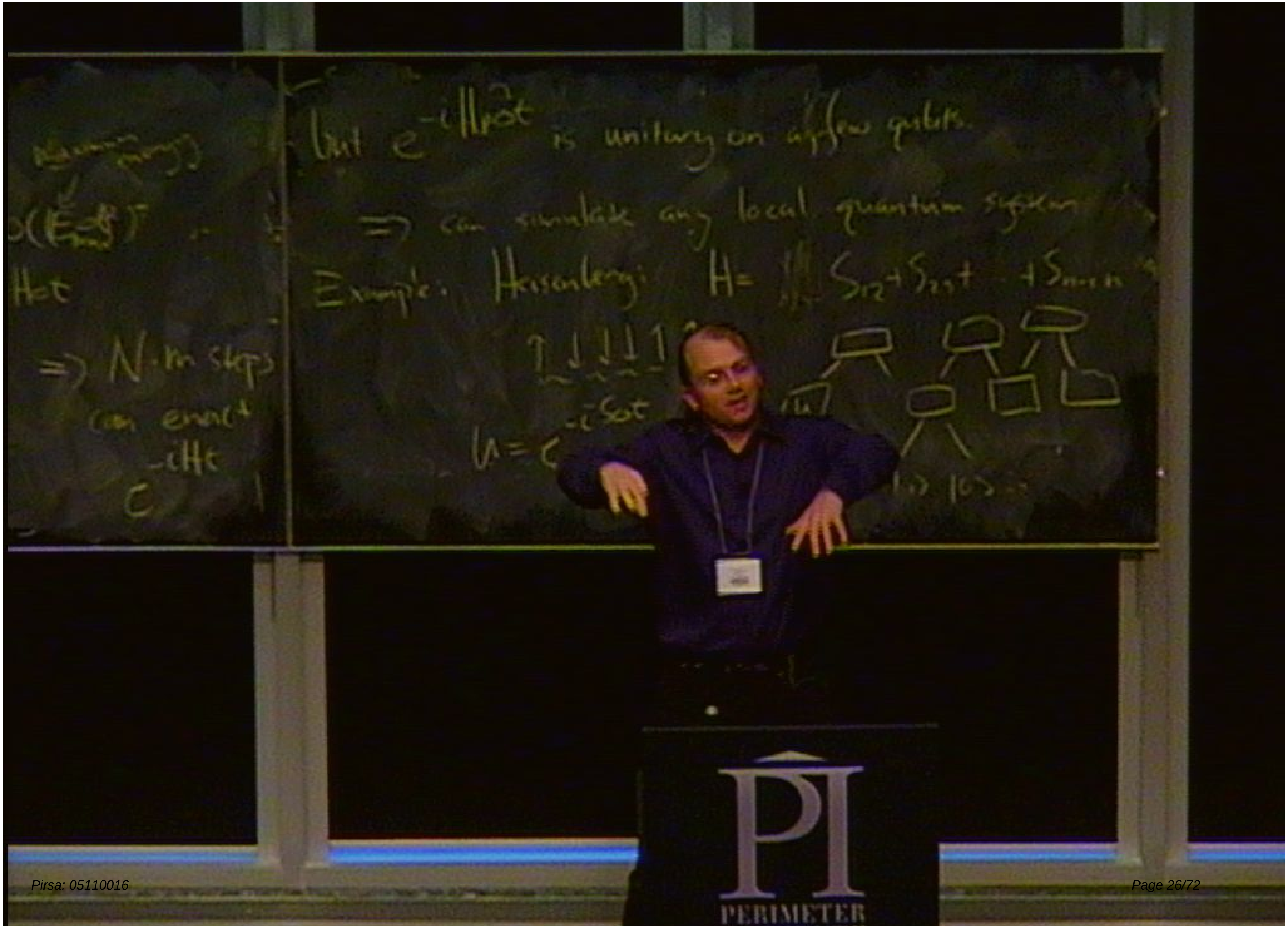
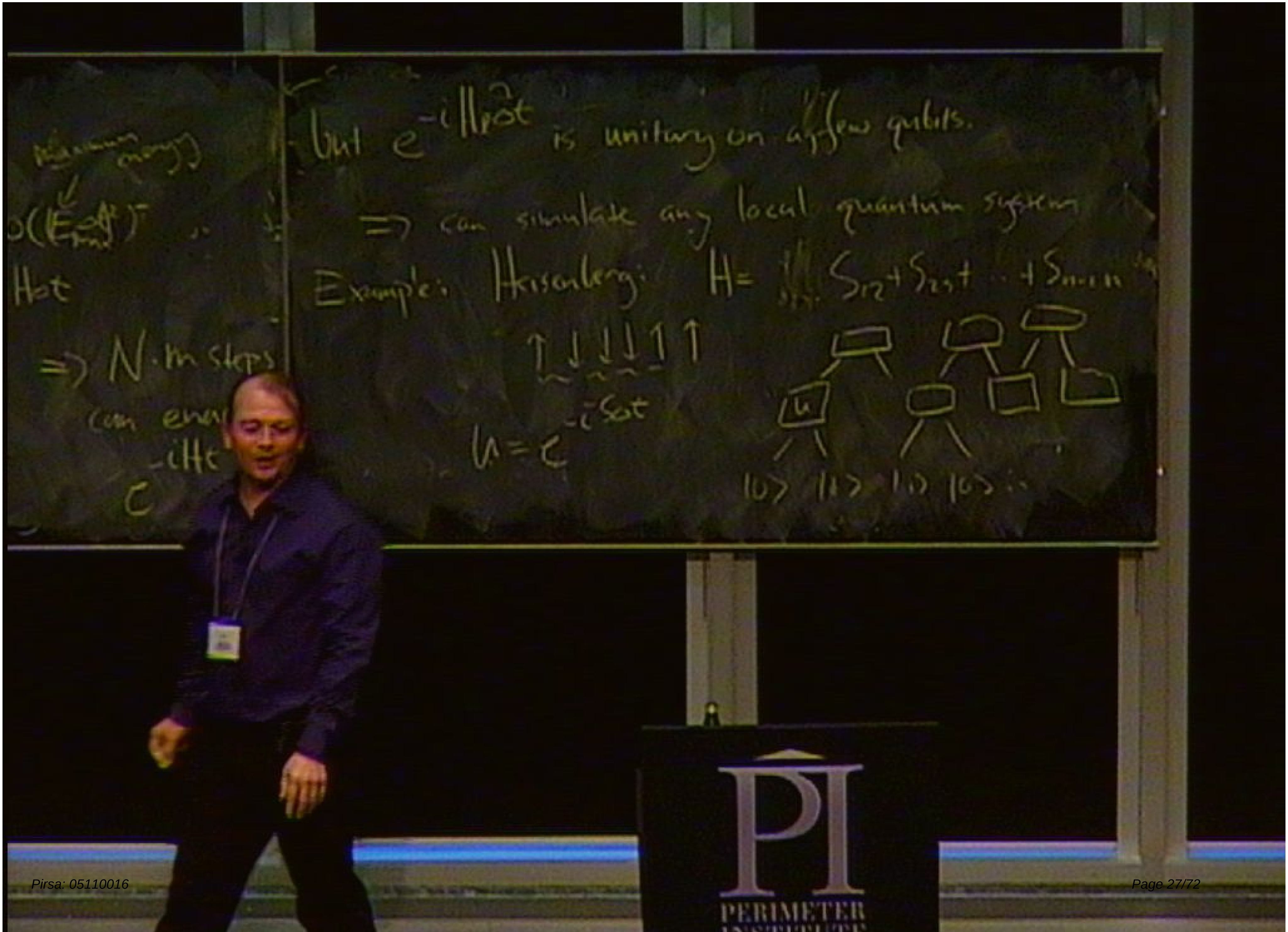

but e is unitary on a few qubits.
⇒ can simulate any local quantum system
Example: Heisenberg: H=
Hot
⇒ N·m steps
can enact
PERIMETER

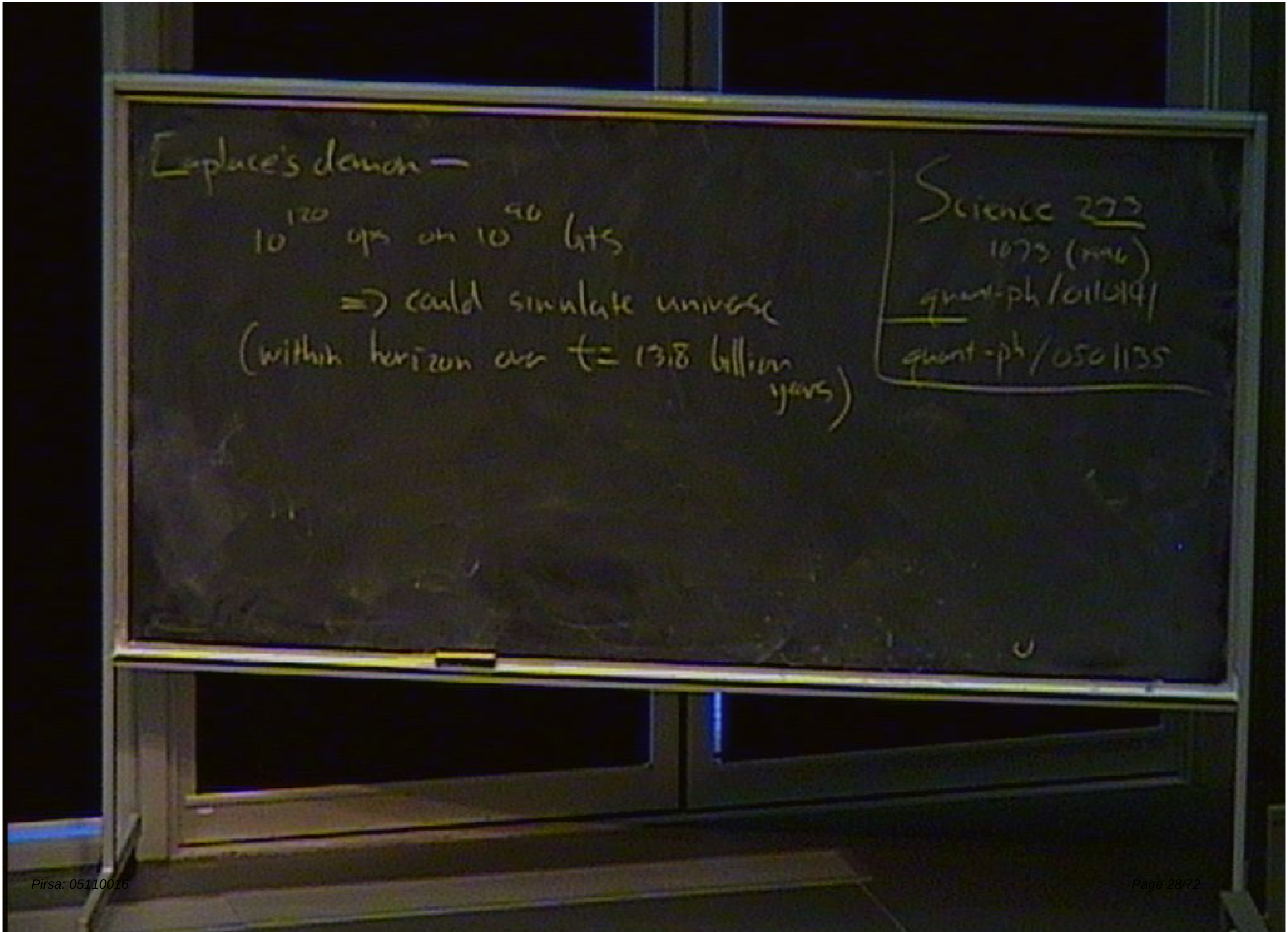


but e^{-iH∂t} is unitary on a few qubits.
⇒ can simulate any local quantum system
Example: Heisenberg: H = S12 + S23 + ... + Sn-1,n
↑ ↓ ↓ ↓ ↑ ↑
|0⟩
Hot
⇒ N·m steps
can enact
e^{-iHt}


but e^{-iH_{12}δt} is unitary on a few qubits.
⇒ can simulate any local quantum system
Example: Heisenberg: H = S12 + S23 + ... + S
⇒ N·m steps
can enact
e^{-iHt}
|0⟩ |1⟩ |1⟩ |0⟩


is unitary on a few qubits.
⇒ can simulate any local quantum system
Example: Heisenberg:
⇒ N·m steps
can enact
PERIMETER


but e is unitary on a few qubits.
⇒ can simulate any local quantum system
Example: Heisenberg:
⇒ N·m steps
PERIMETER


Laplace's demon —
10^120 ops on 10^90 bits
⇒ could simulate universe
(within horizon over t = 13.8 billion years)
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quant-ph/0501135

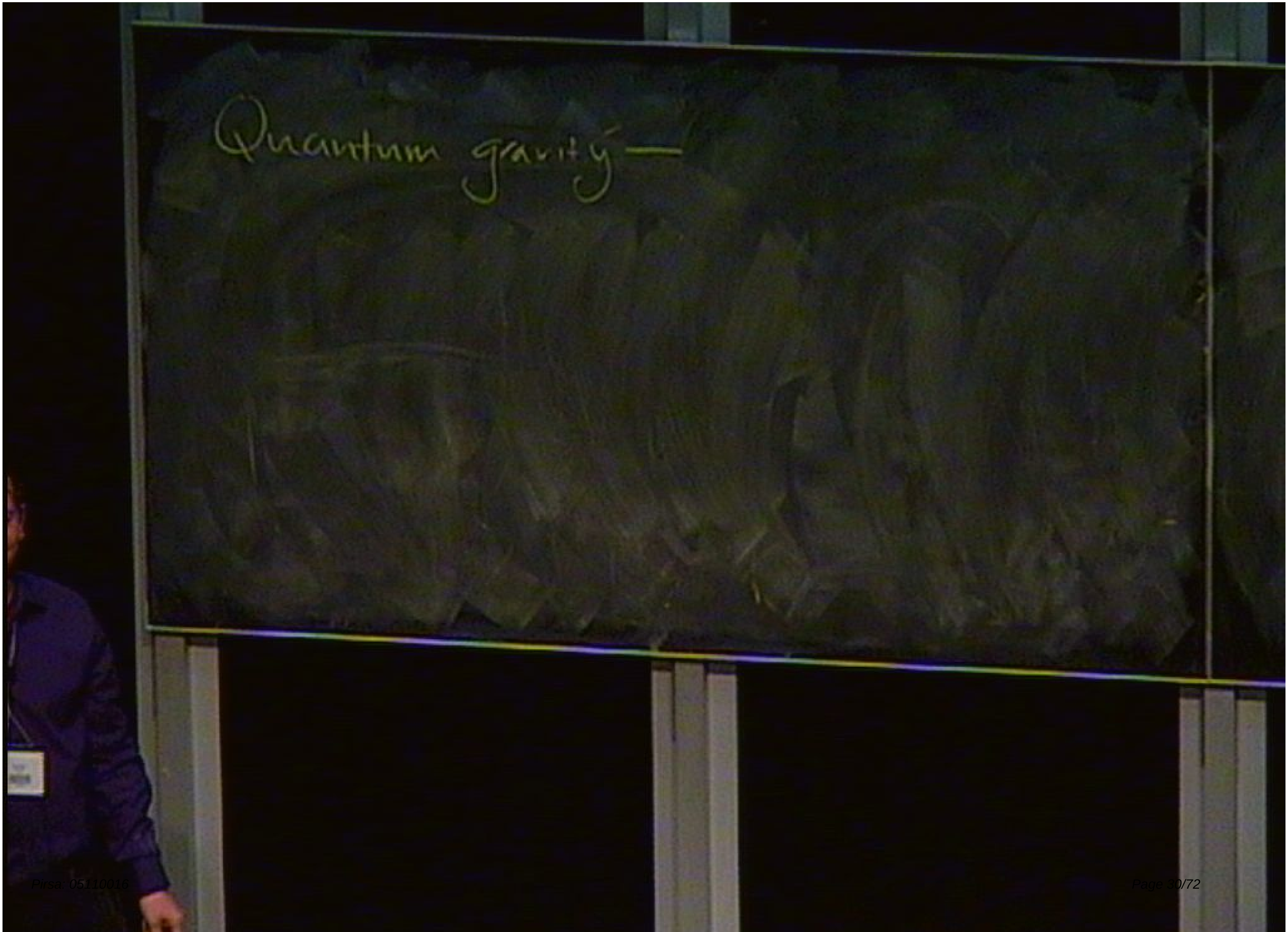
(2) Quantum simulation (Feynman)

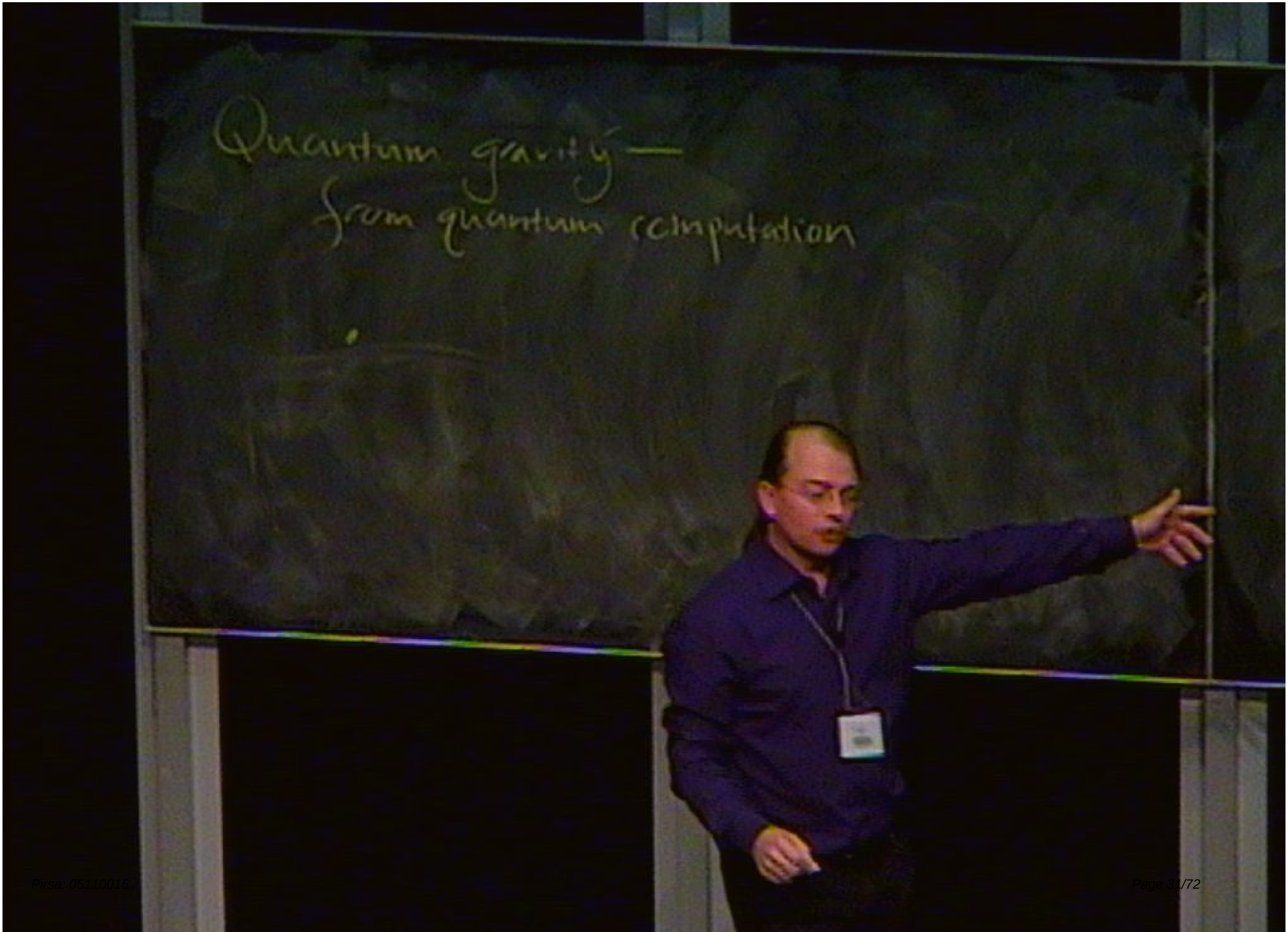
Lloyd

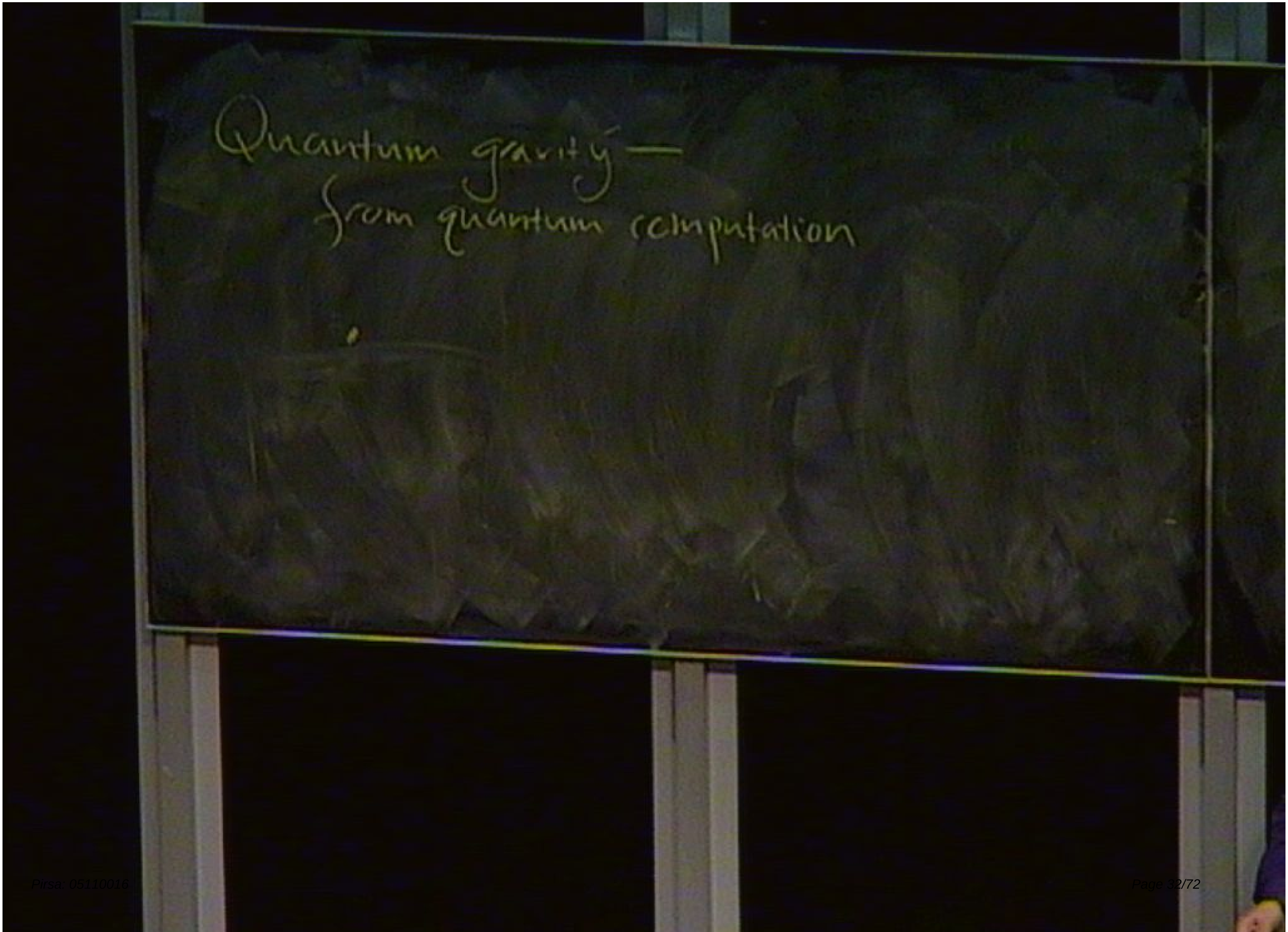
$$H = \sum_{\ell} H_{\ell} \quad , \quad e^{-iHt}|\psi\rangle$$

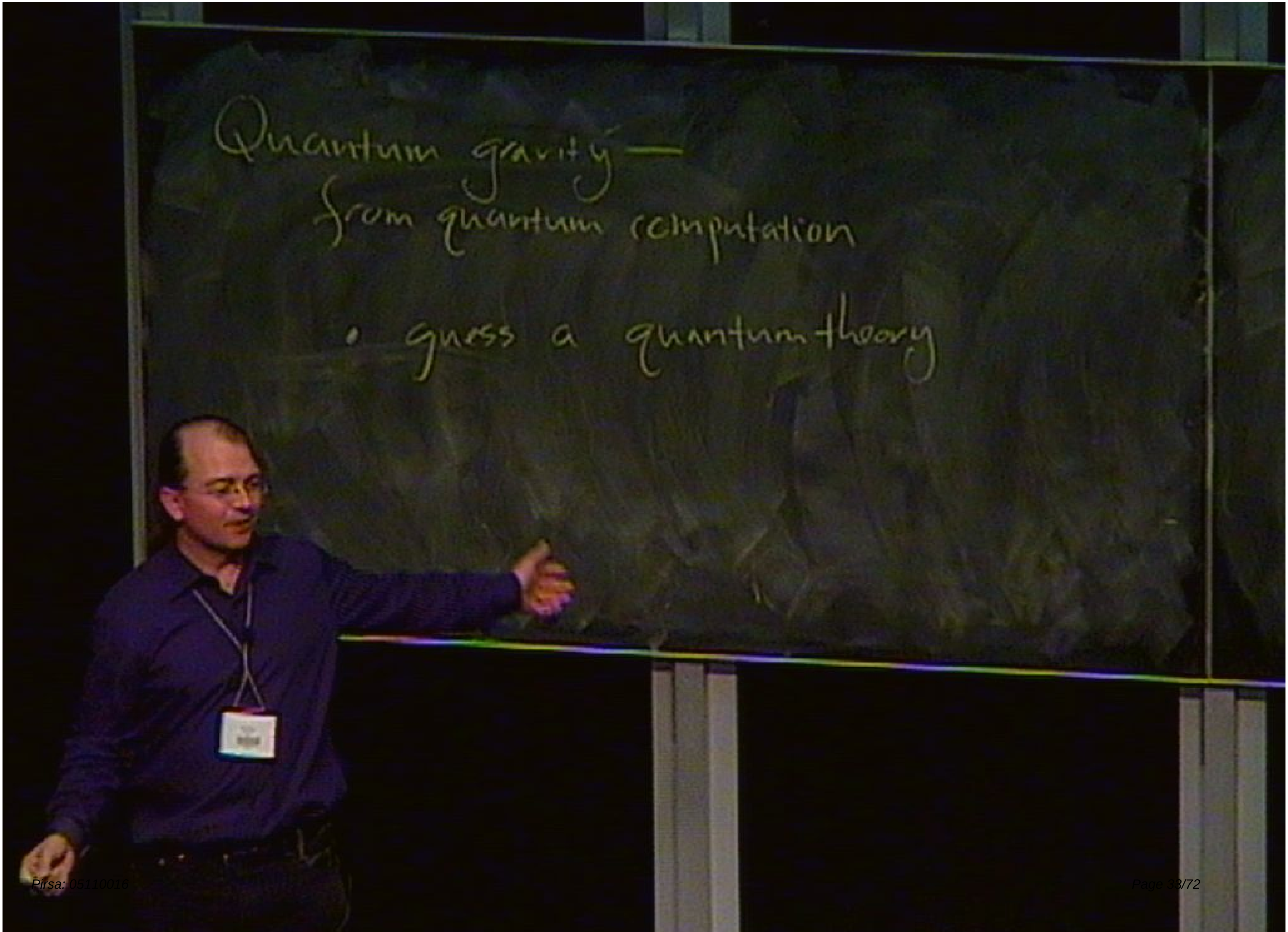
few qubits

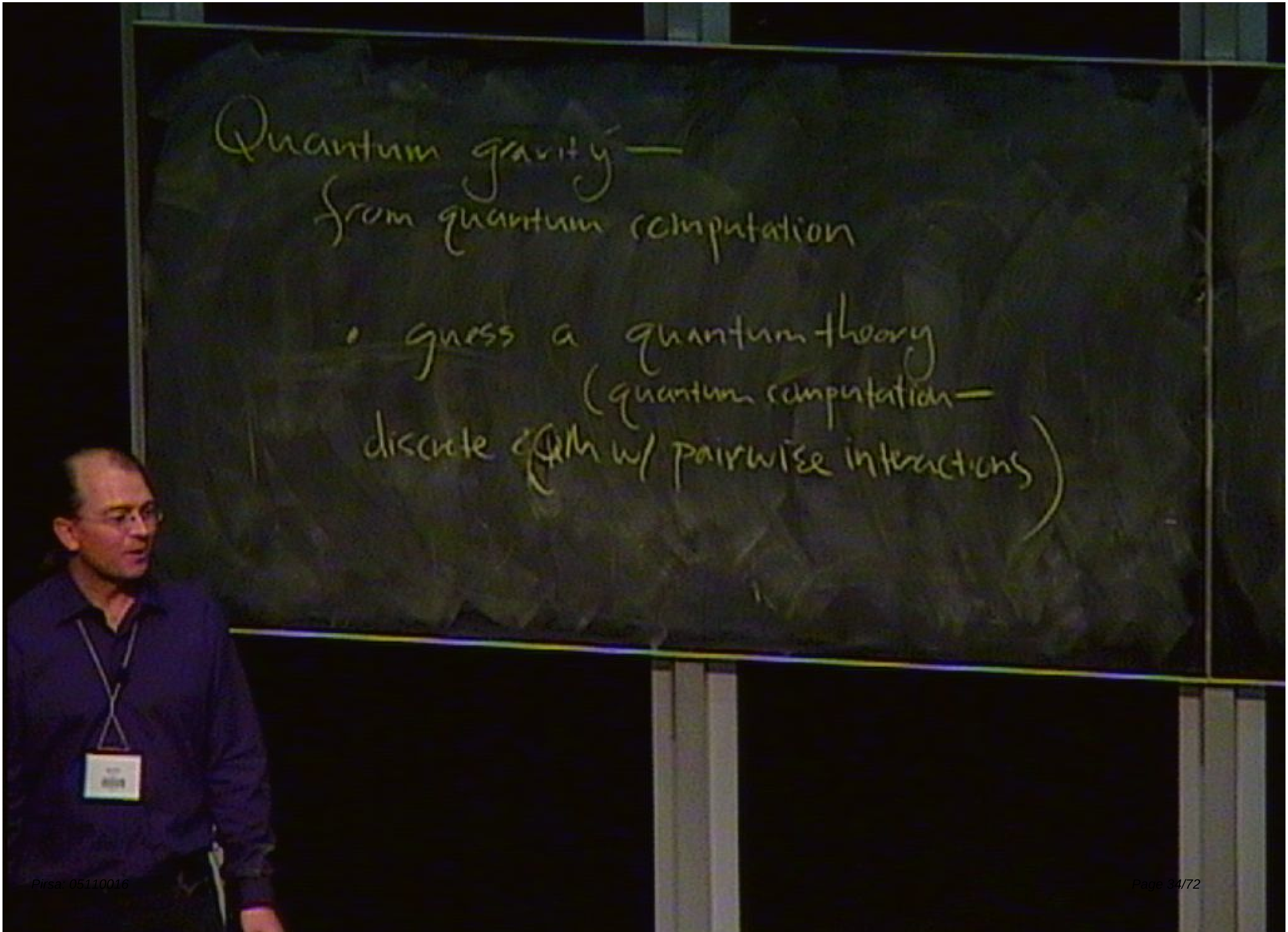
e^{iH}

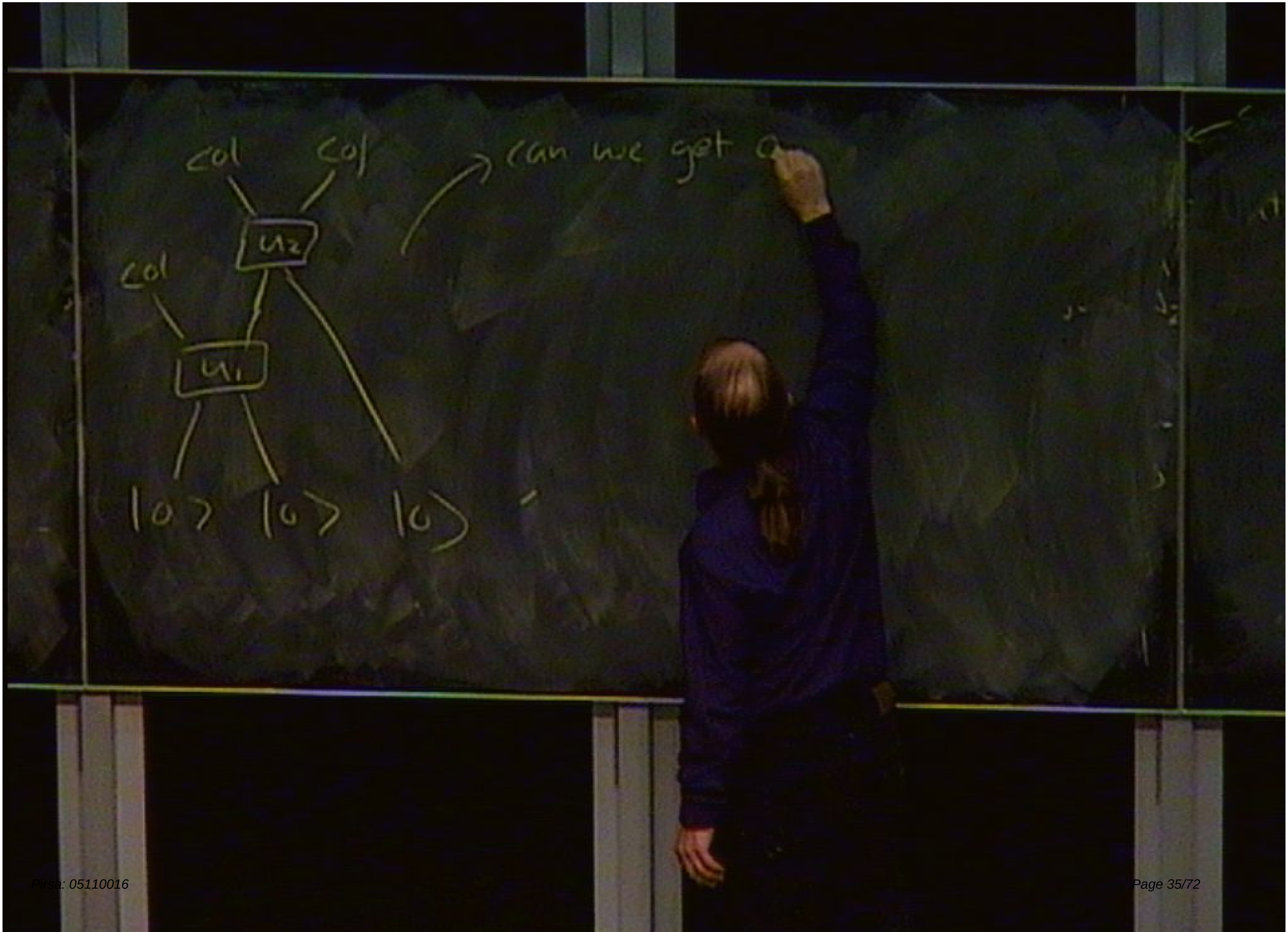

Quantum gravity —

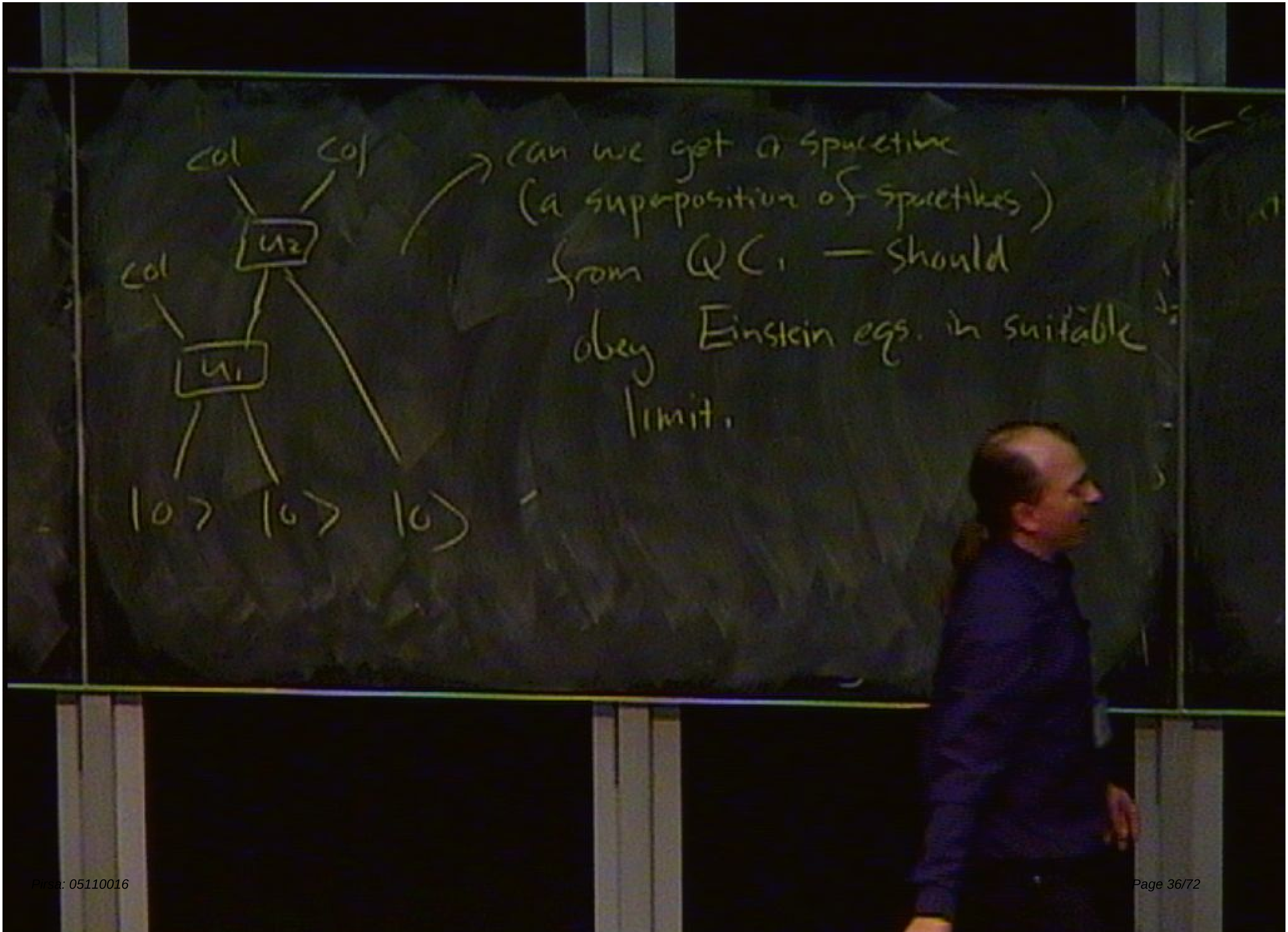

Quantum gravity —
from quantum computation


Quantum gravity —
from quantum computation

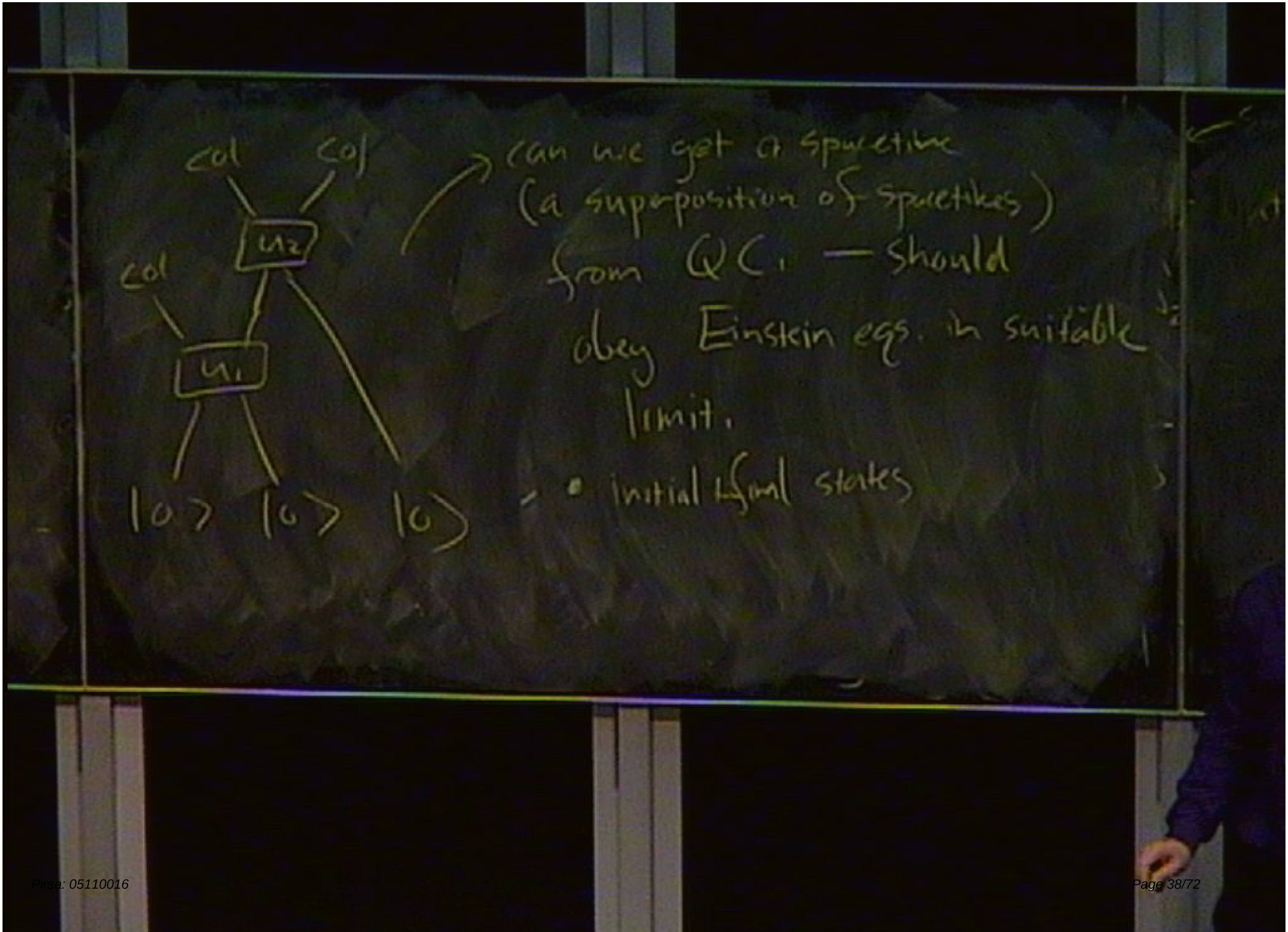

Quantum gravity —
from quantum computation
• guess a quantum theory

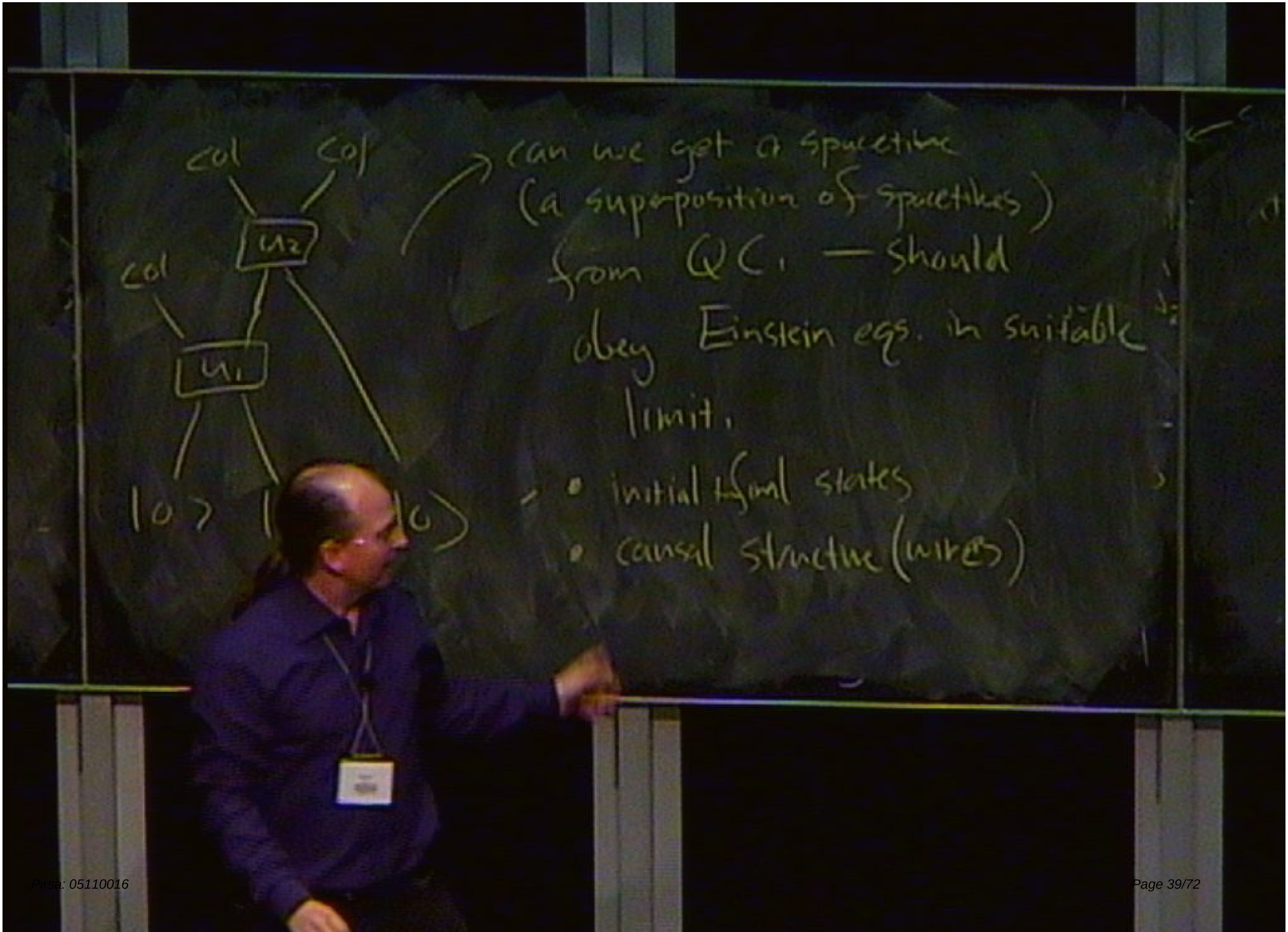

Quantum gravity —
from quantum computation
• guess a quantum theory
(quantum computation —
discrete QM w/ pairwise interactions)


col
col
col
U_2
U_1
|0> |0> |0>
can we get a

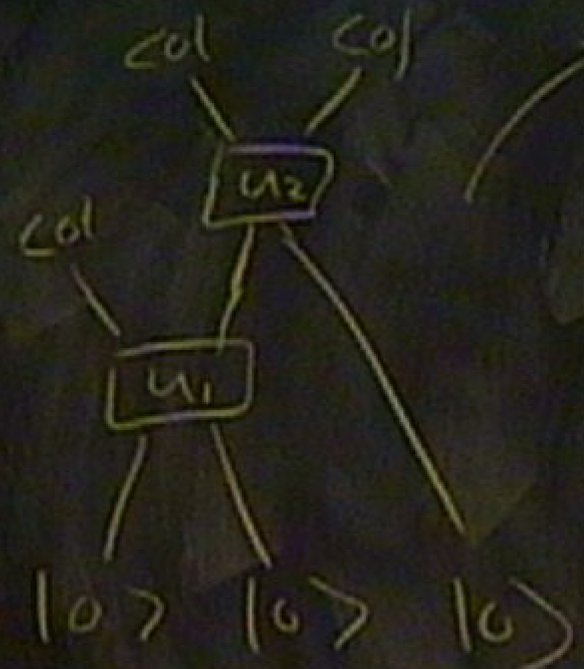

col
col
u2
col
u1
|0> |0> |0>
can we get a spacetime
(a superposition of spacetimes)
from QC, — should
obey Einstein eqs. in suitable
limit.

can we get a spacetime (a superposition of spacetimes) from QC. — should obey Einstein eqs. in suitable limit.


col
col
U2
col
U1
|0>
|0>
|0>
can we get a spacetime
(a superposition of spacetimes)
from QC. — should
obey Einstein eqs. in suitable
limit.
• initial/final states

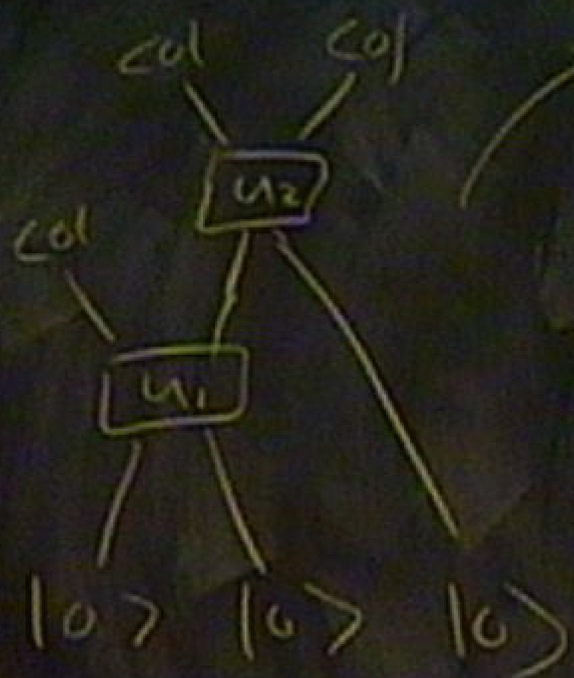


⟨0| ⟨0|
U2
⟨0|
U1
|0⟩ |0⟩
can we get a spacetime
(a superposition of spacetimes)
from QC. — should
obey Einstein eqs. in suitable
limit.
• initial + final states
• causal structure (wires)



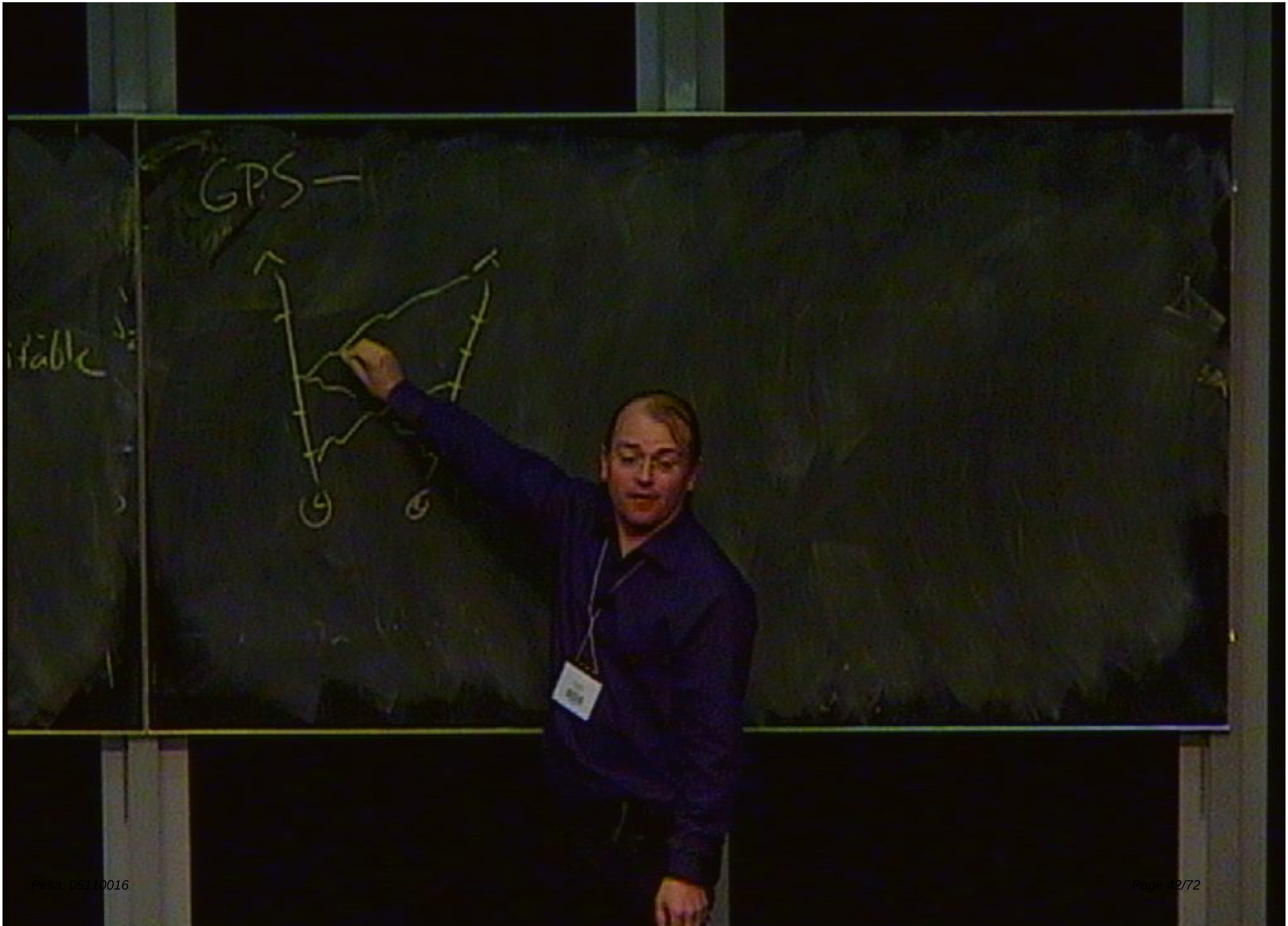
can we get a spacetime
(a superposition of spacetimes)
from QC. — should
obey Einstein eqs. in suitable
limit.

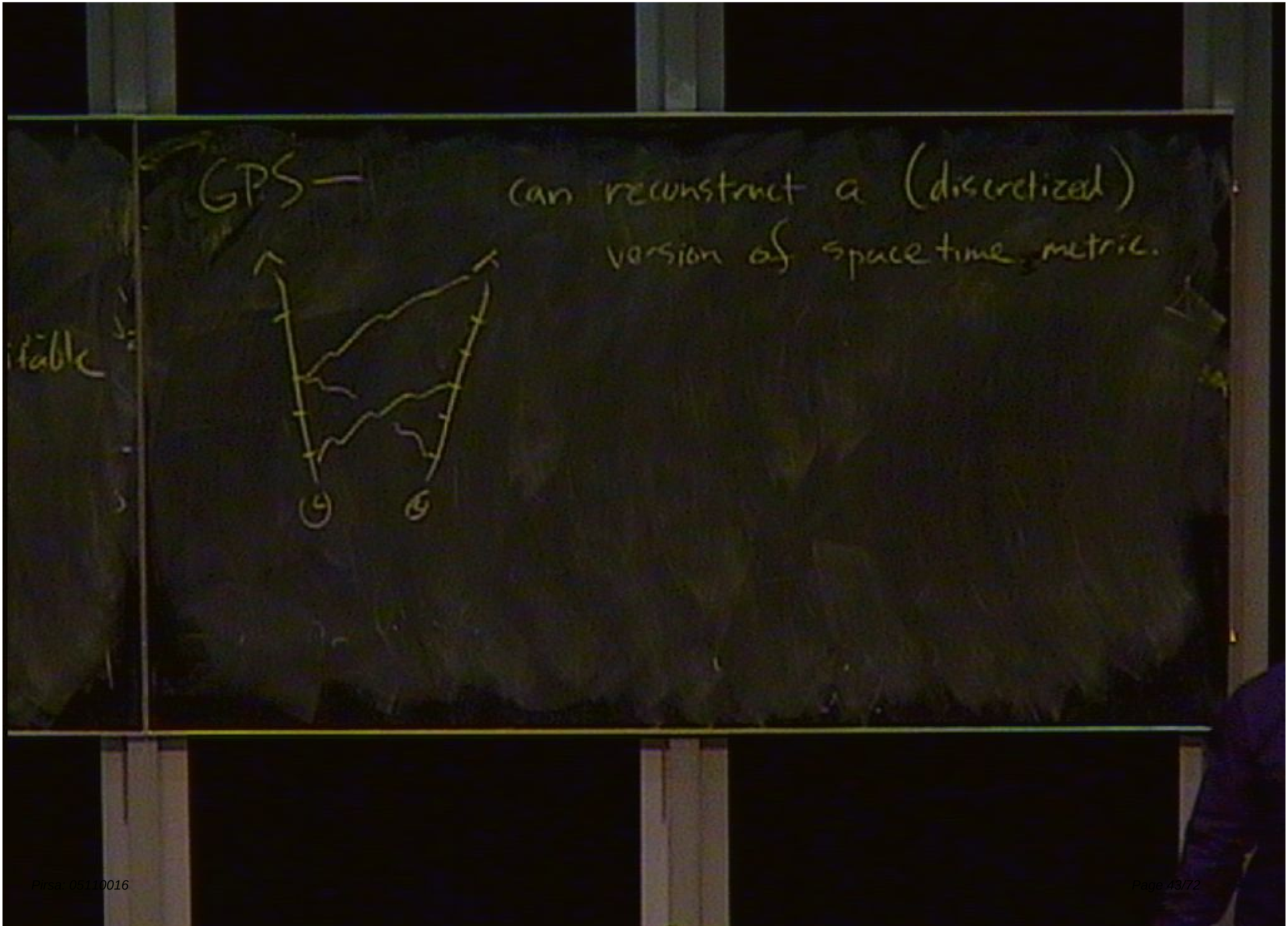
- initial + final states
- causal structure (wires)

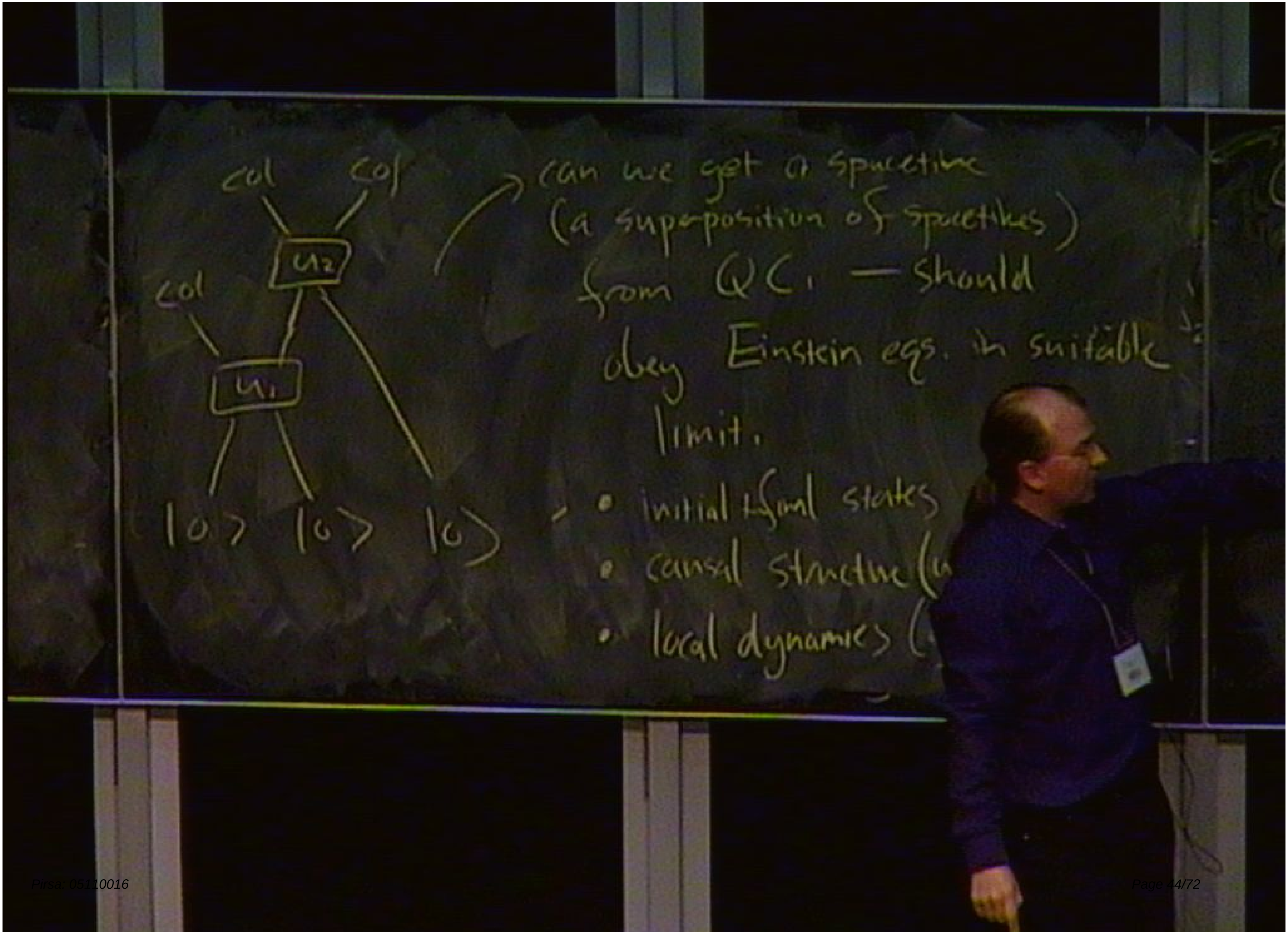


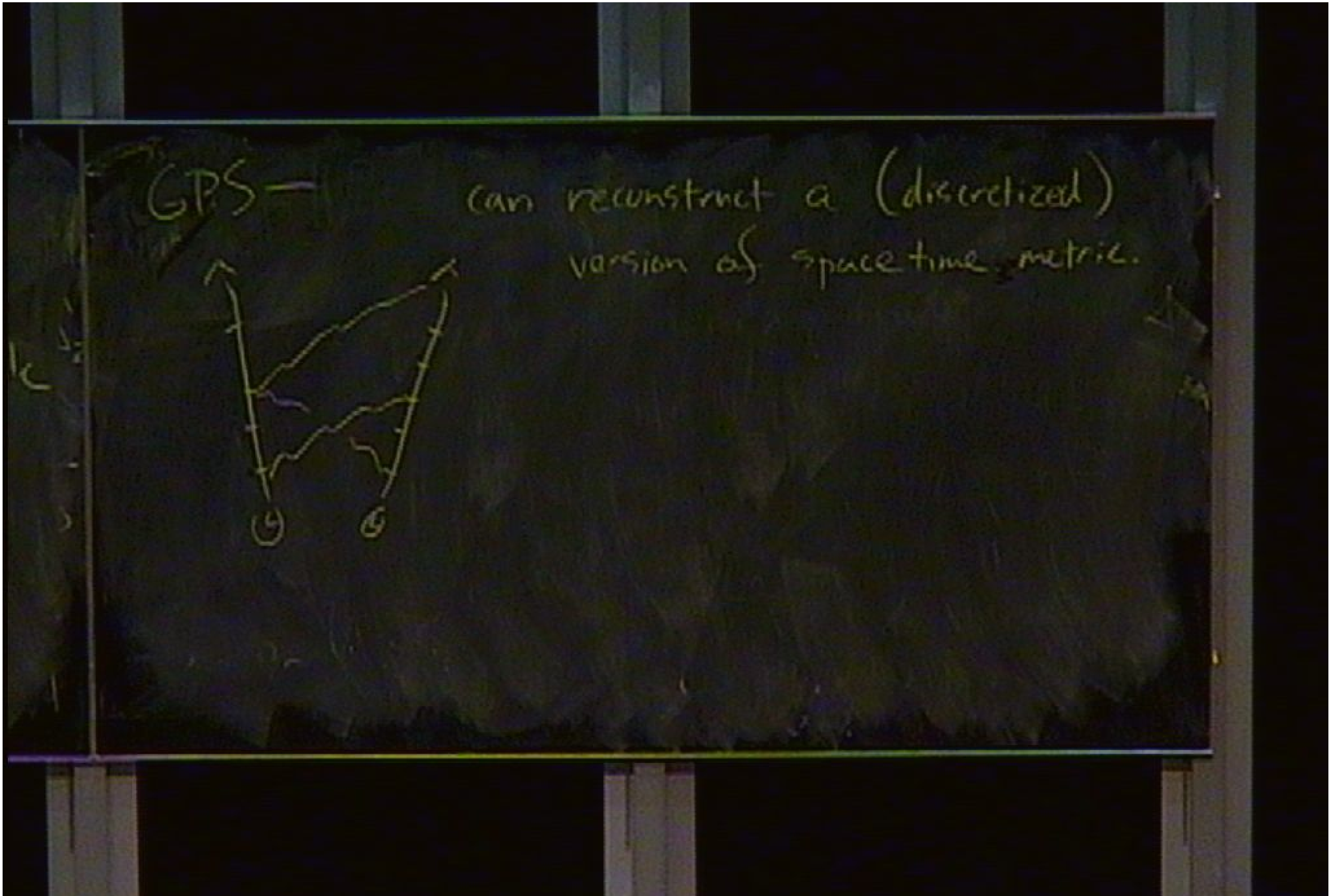
can we get a spacetime
(a superposition of spacetimes)
from QC. — should
obey Einstein eqs. in suitable
limit.

- initial + final states
- causal structure (wires)
- local dynamics (gates)


GPS—


GPS —
can reconstruct a (discretized)
version of spacetime metric.
itable


col
col
col
U2
U1
|0>
|0>
|0>
can we get a spacetime
(a superposition of spacetimes)
from QC. — should
obey Einstein eqs. in suitable
limit.
• initial & final states
• causal structure
• local dynamics


GPS —
can reconstruct a (discretized)
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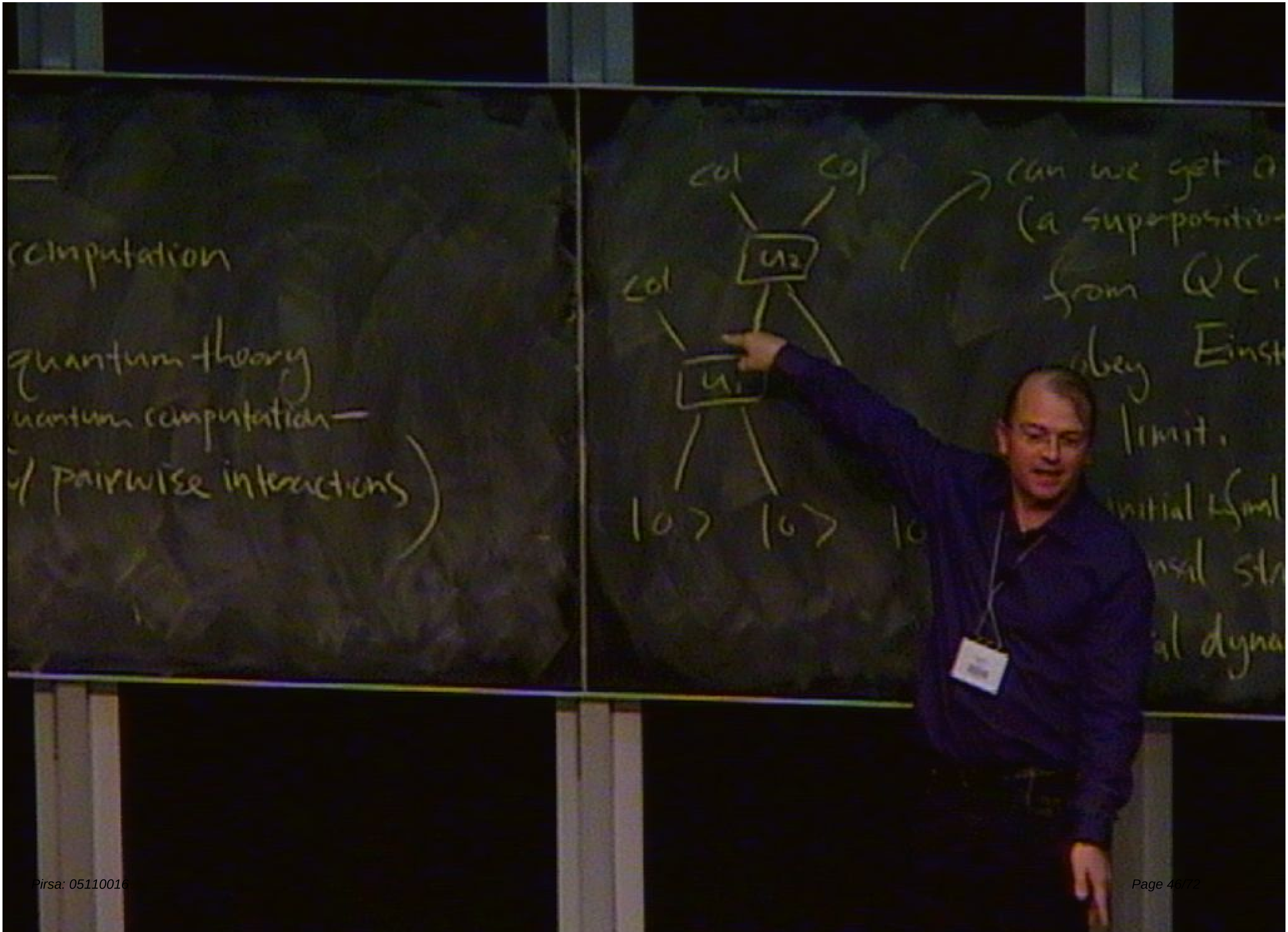
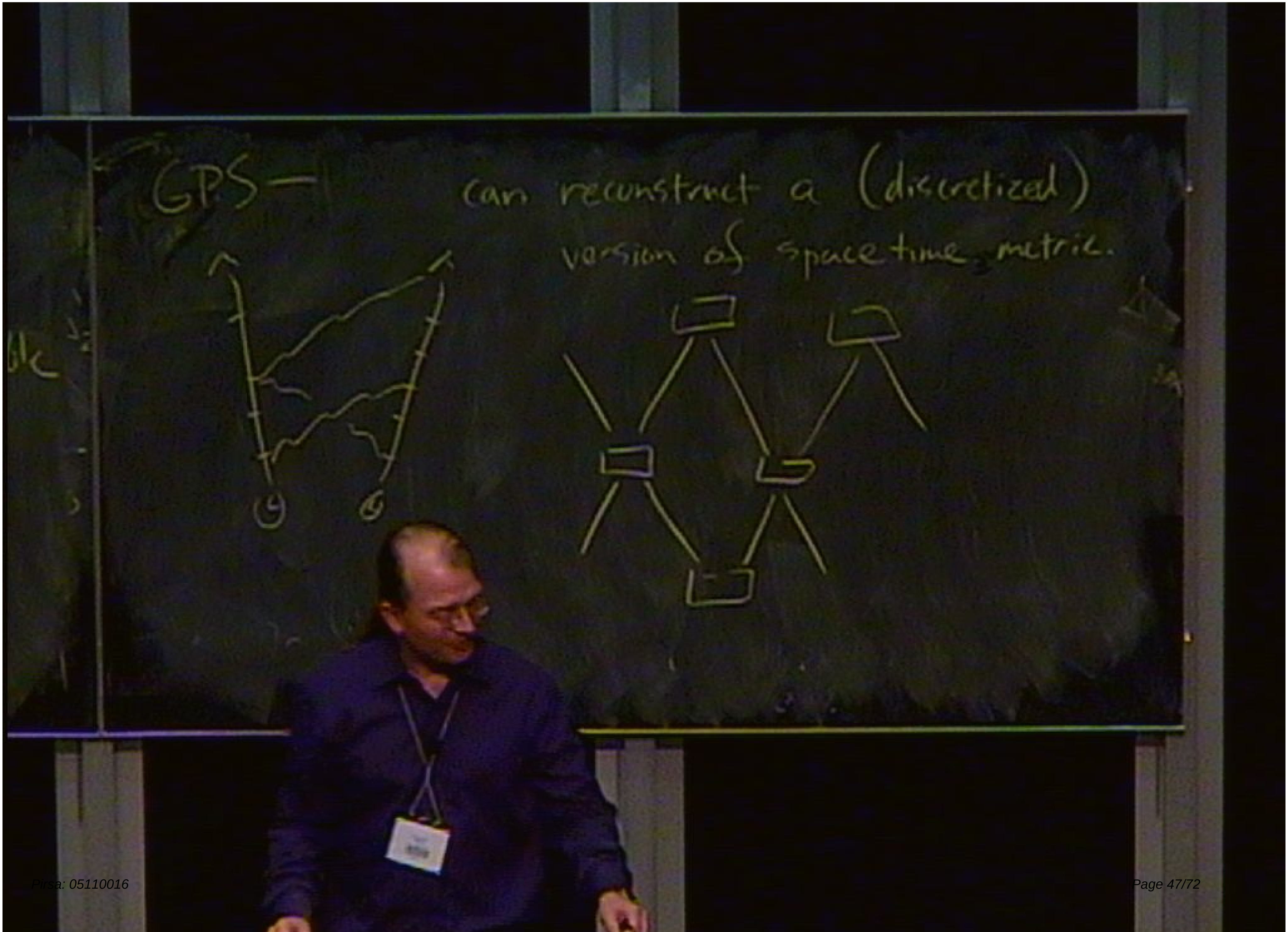

computation
quantum theory
quantum computation—
pairwise interactions
col
col
col
U_2
U_1
$|0\rangle$ $|0\rangle$
can we get
(a superposition
from QC
obey
limit.


GPS —
can reconstruct a (discretized)
version of spacetime metric.

irs)

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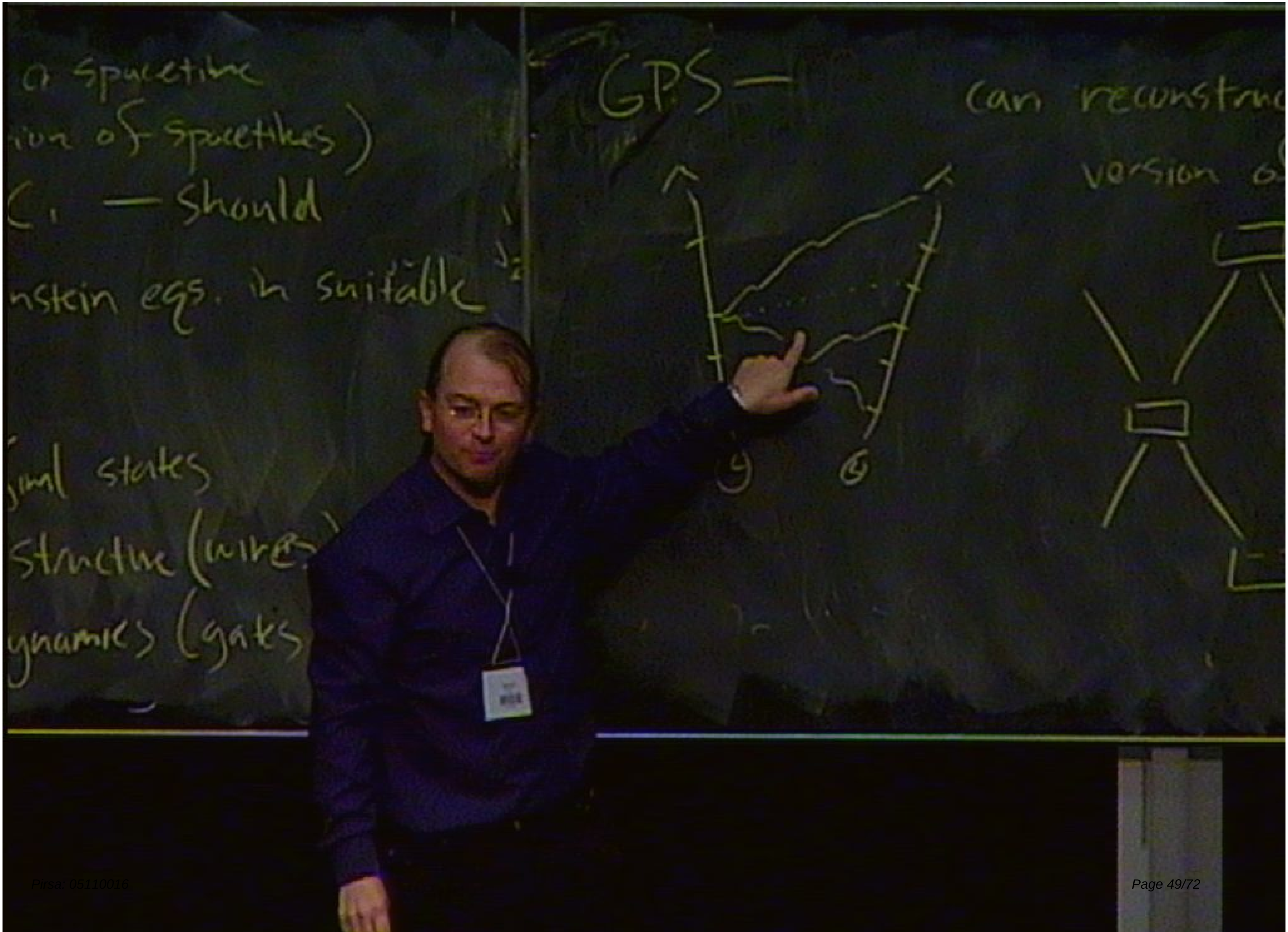
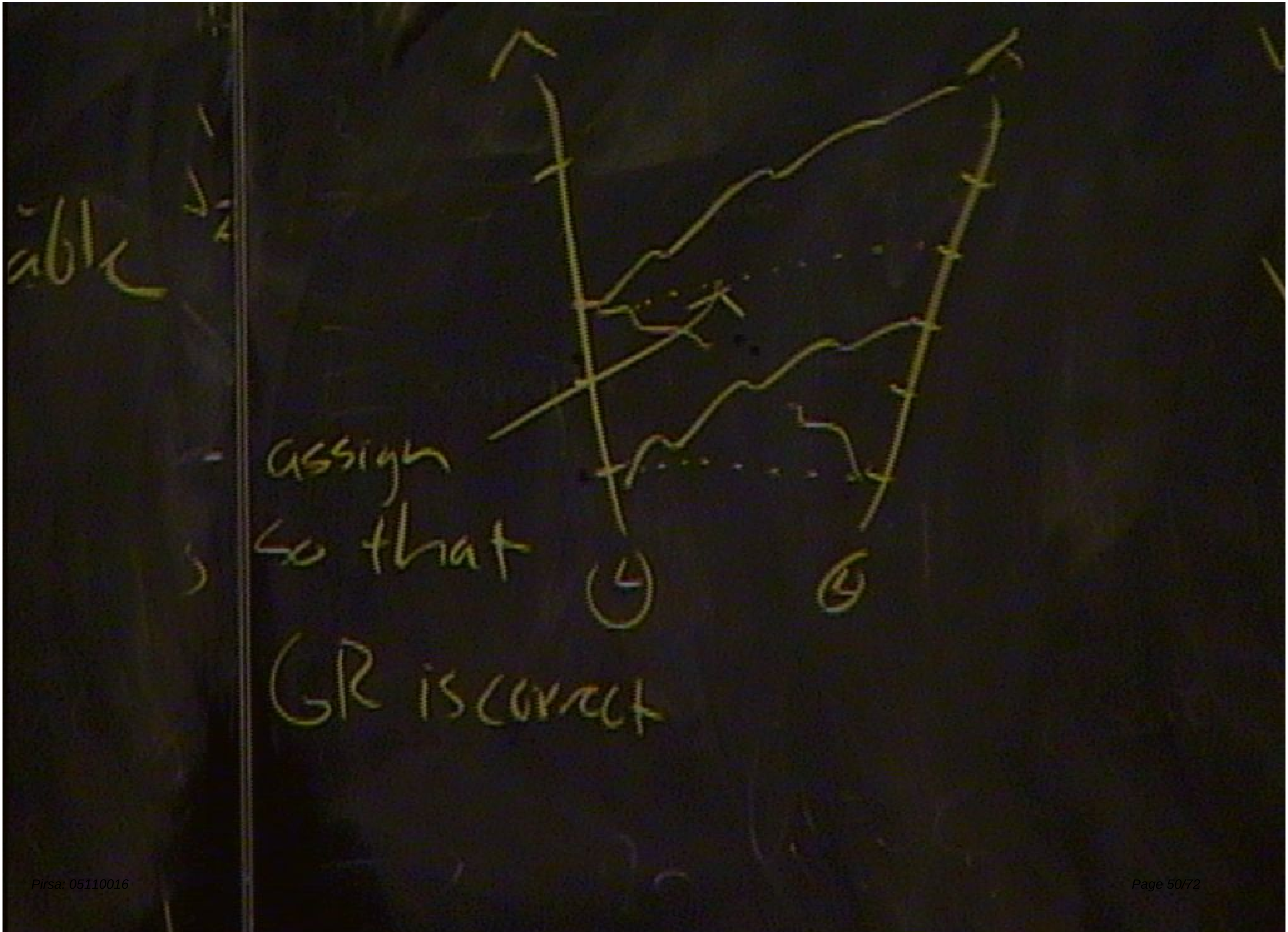
Nature + Sci Am

Nov 1994

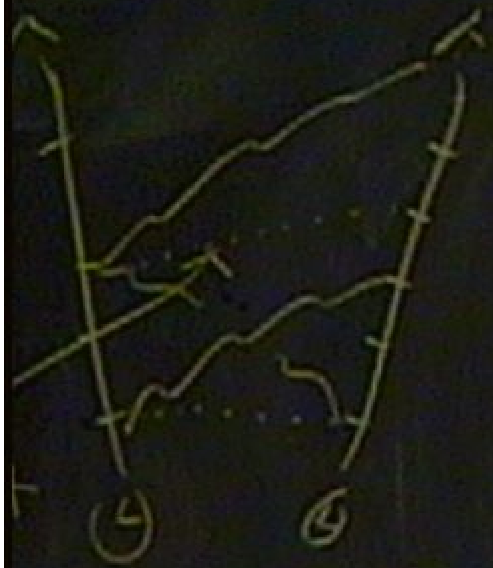

a spacetime
ion of spacetimes)
C. — should
nstein eqs. in suitable
inal states
structure (wires)
ynamics (gates
GPS —
can reconstruc
version o



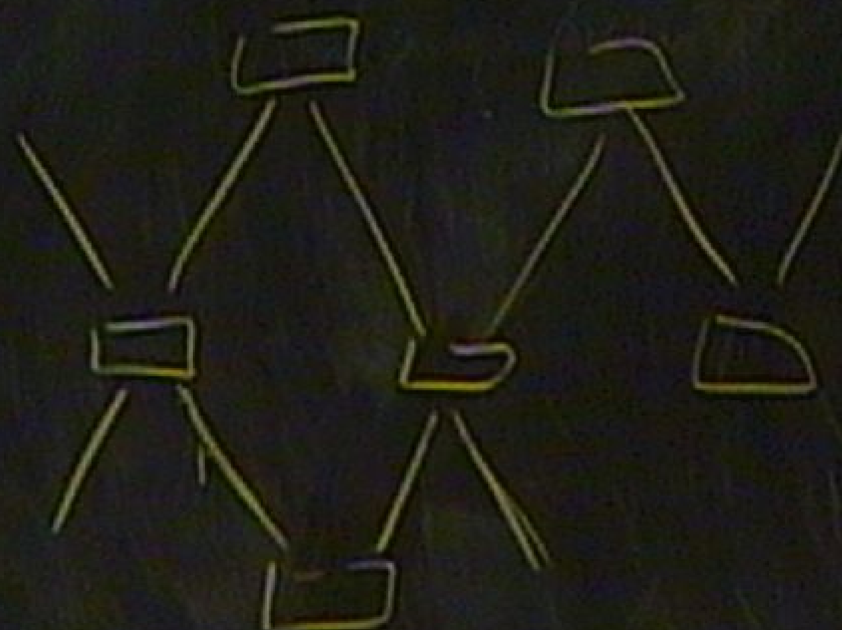
assign
so that
GR is correct

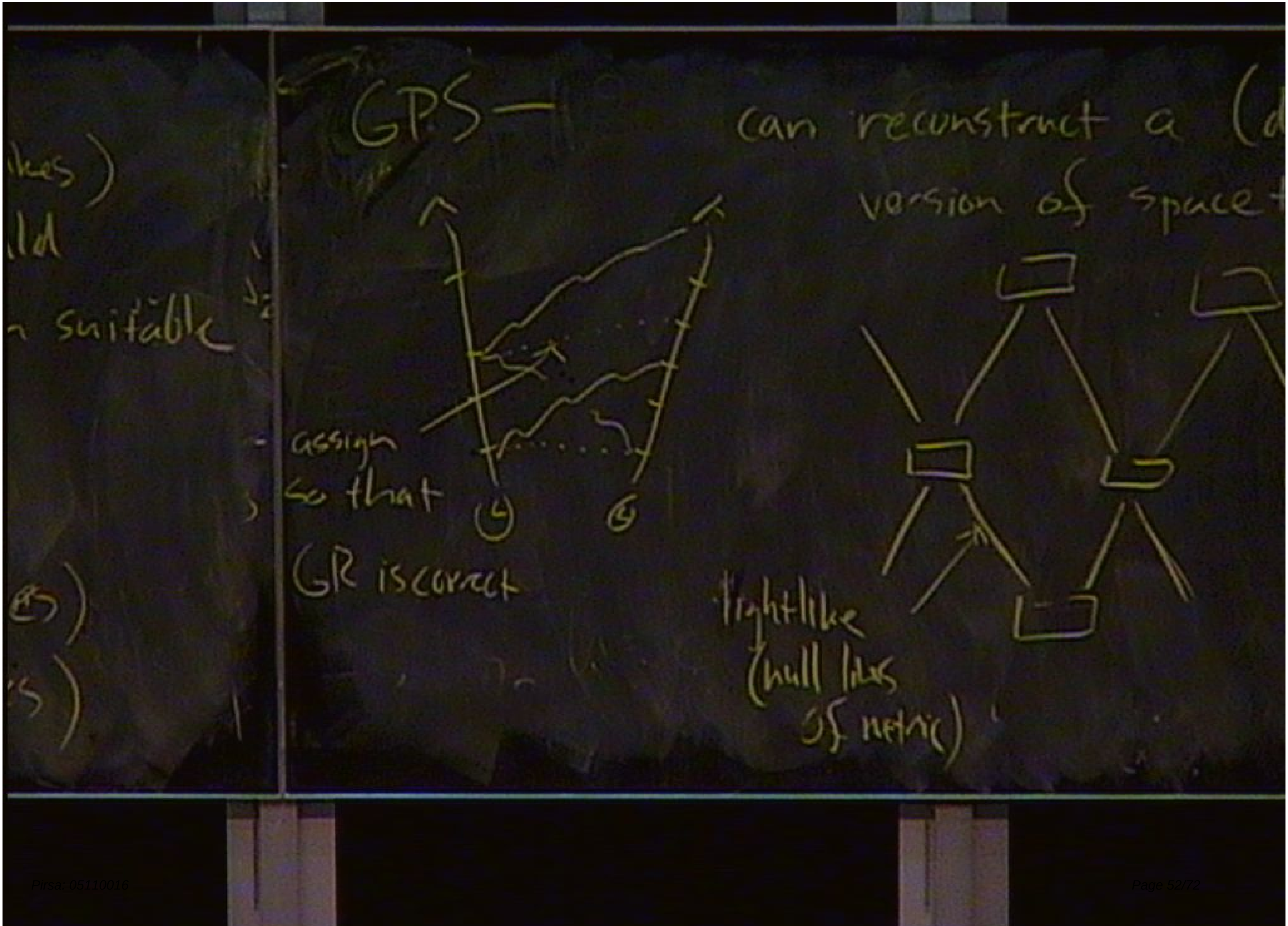
ps —

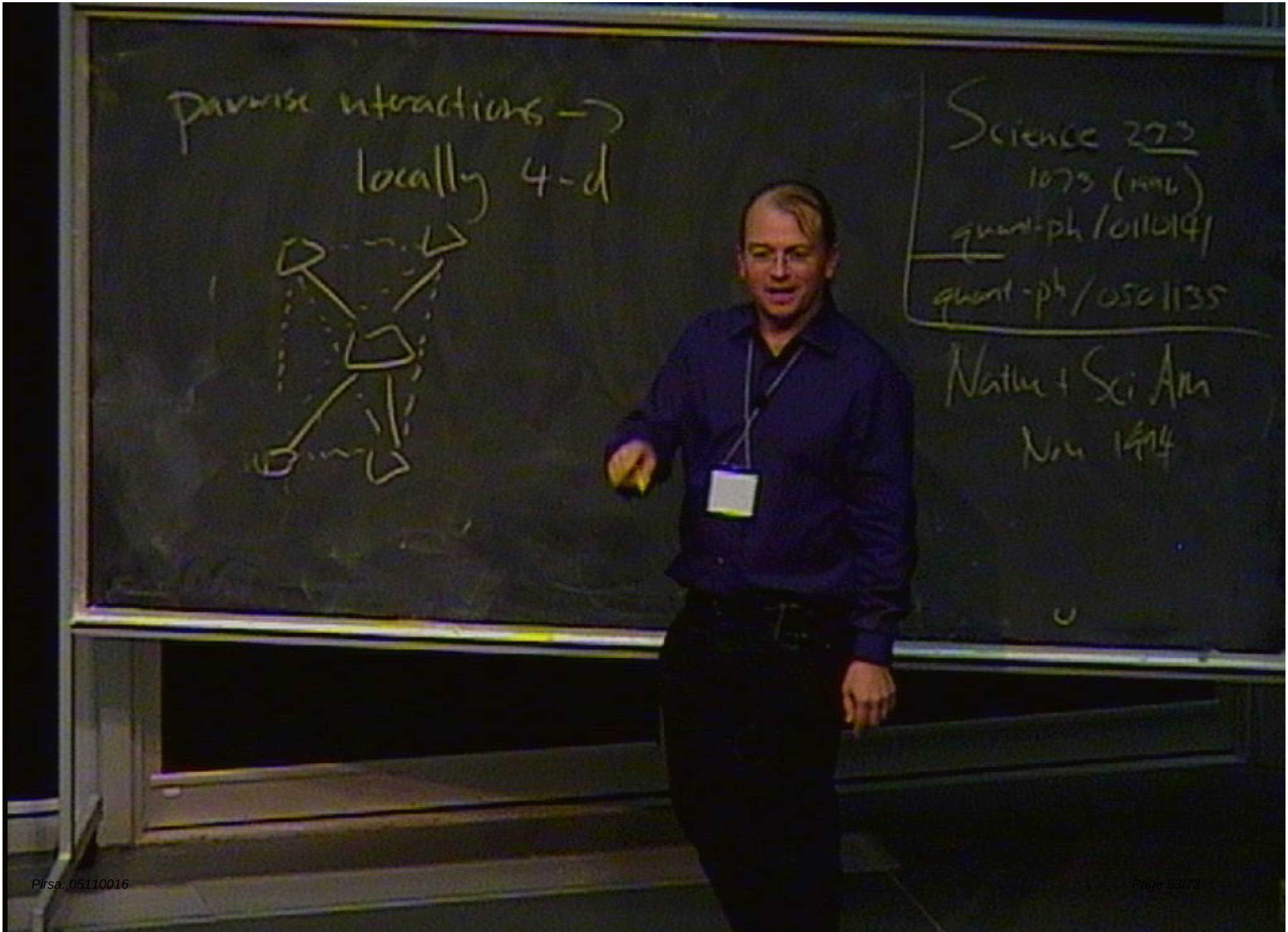
can reconstruct a (discretized) version of spacetime metric.



correct




GPS —
can reconstruct a (d
version of space
suitable
assign
so that
GR is correct
lightlike
(null lines
of metric)


pairwise interactions →
locally 4-d
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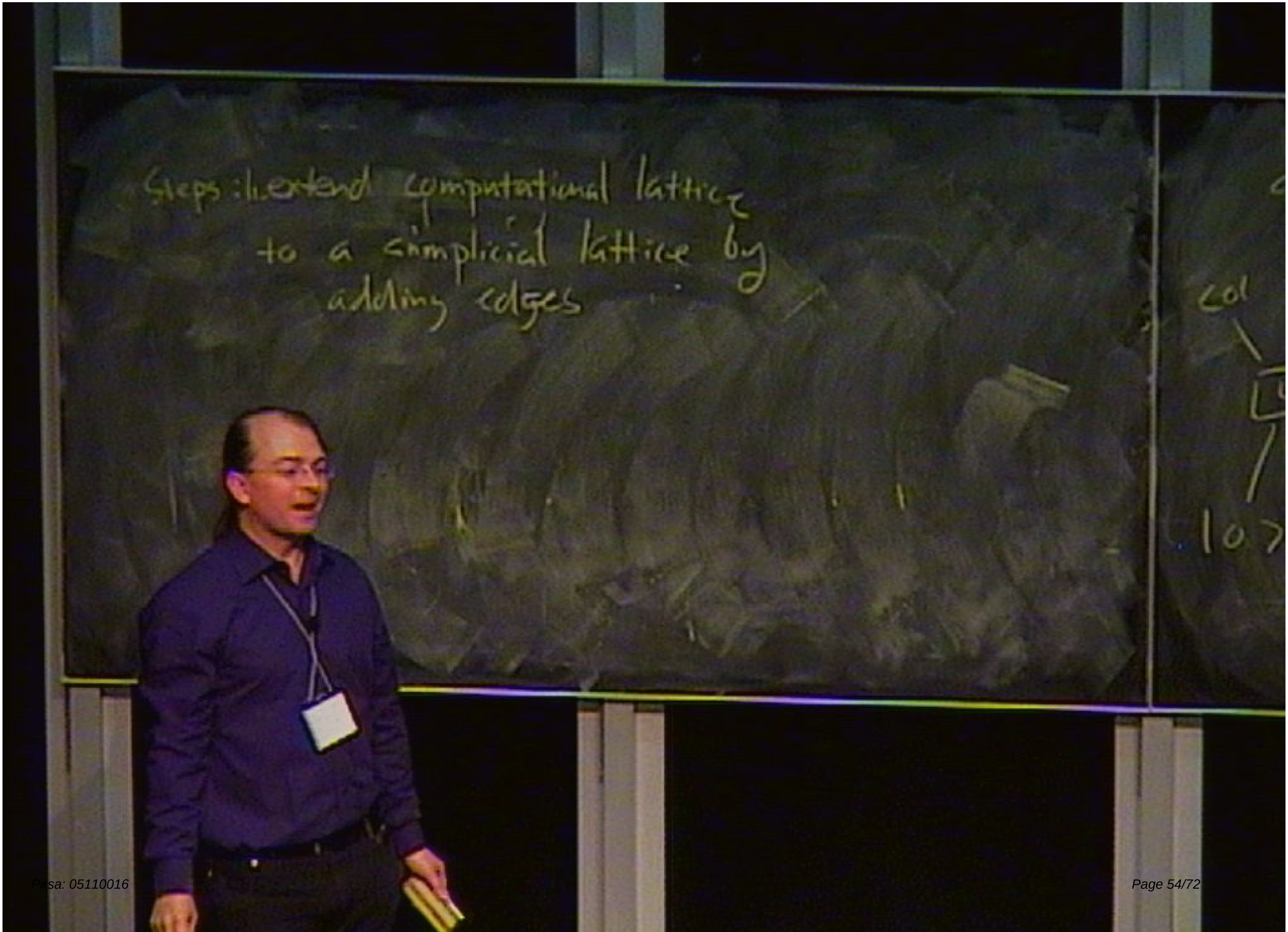
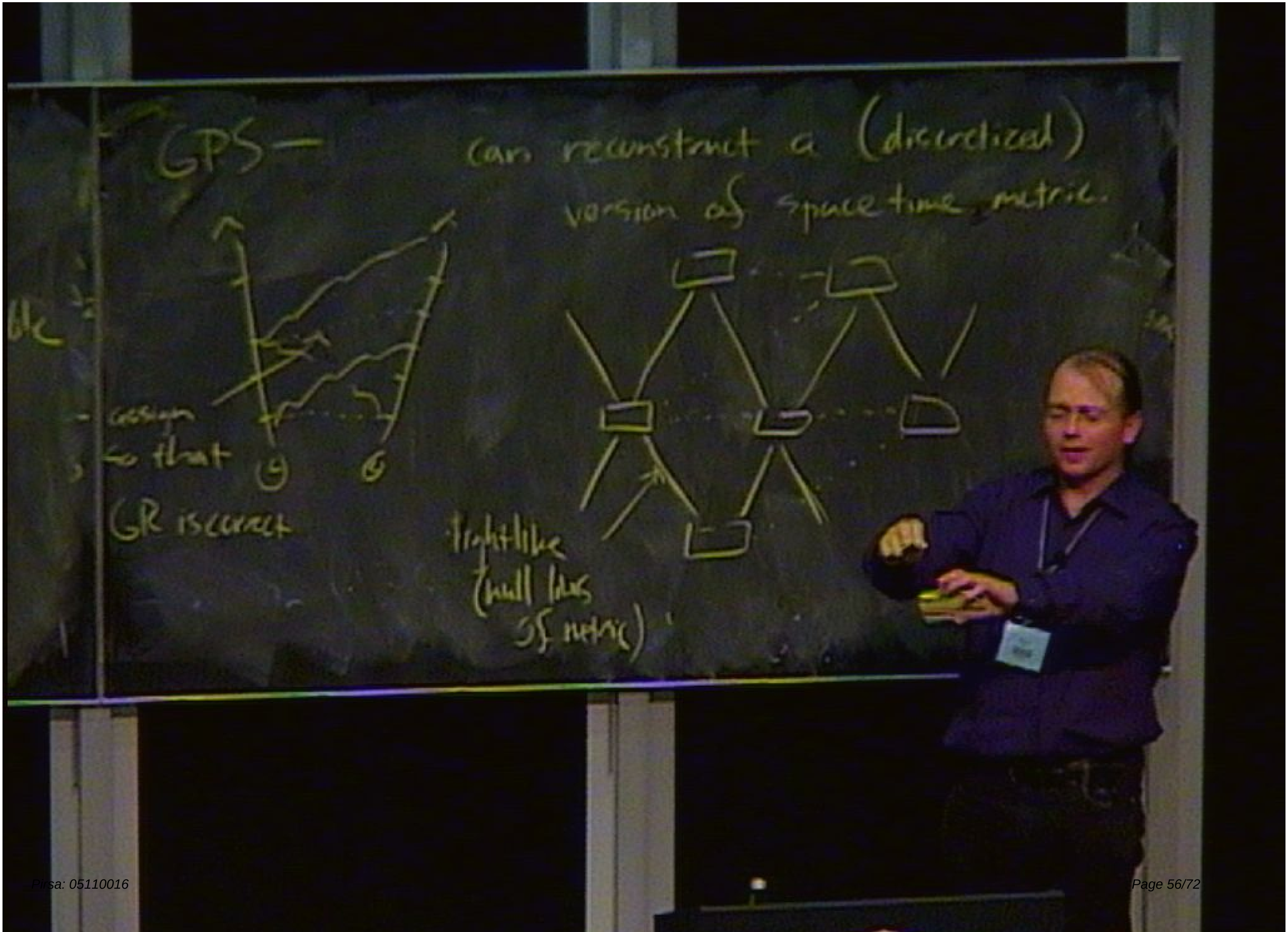
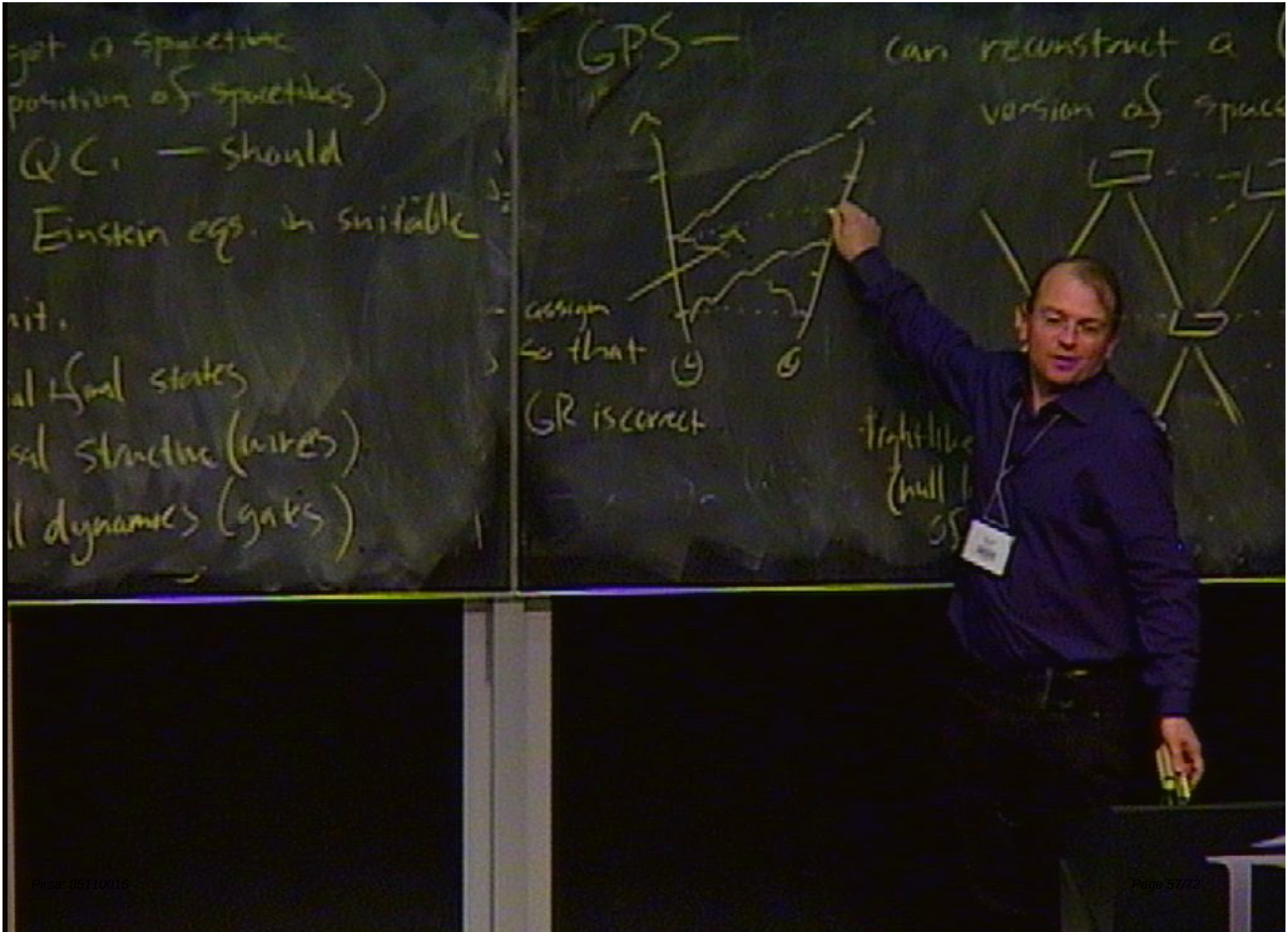
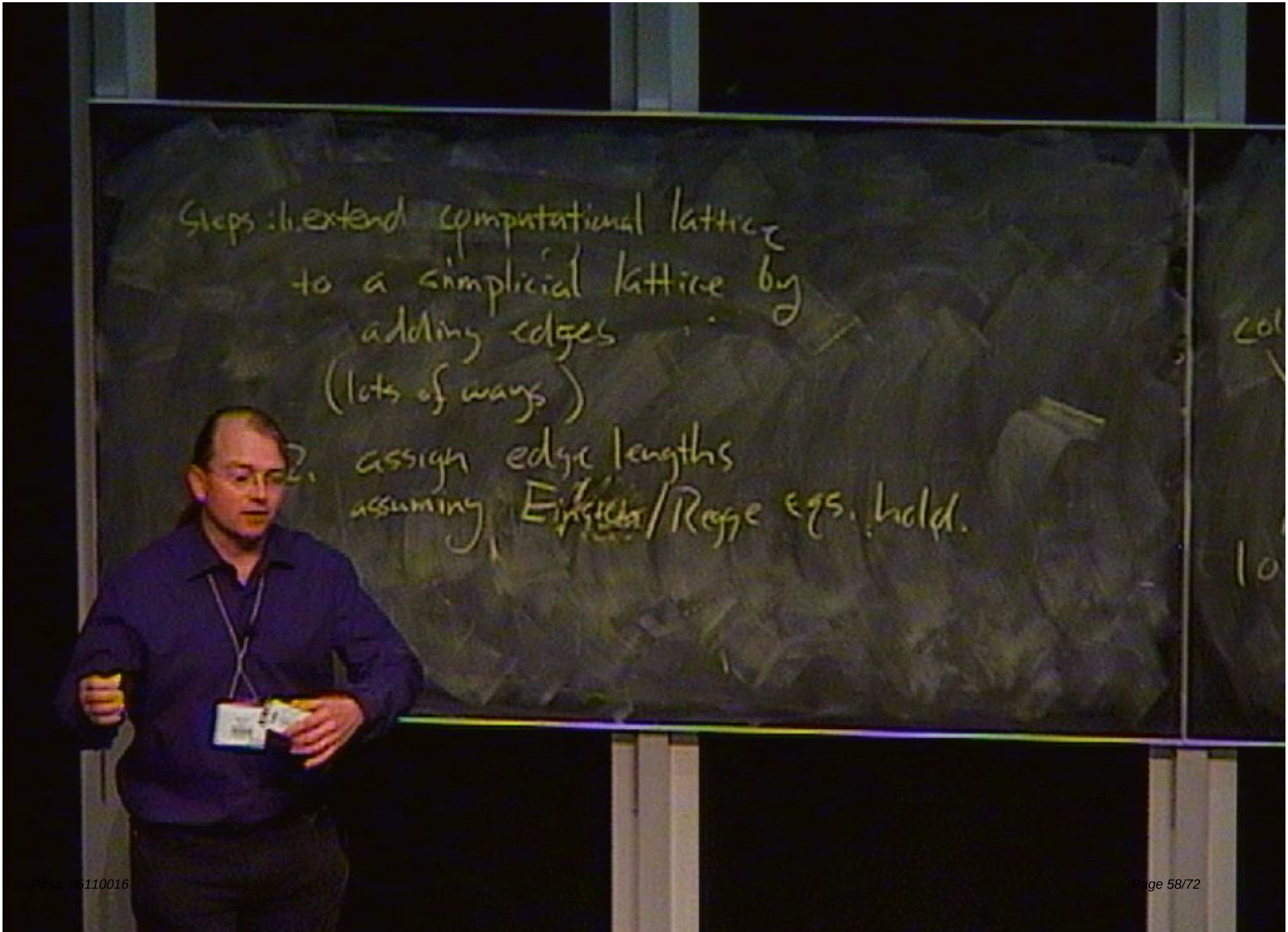
quant-ph/0110141
quant-ph/0501135
Nature + Sci Am
Nov 1994


Steps: 1. extend computational lattice
to a simplicial lattice by
adding edges

Steps: 1. extend computational lattice
to a simplicial lattice by
adding edges
(lots of ways)

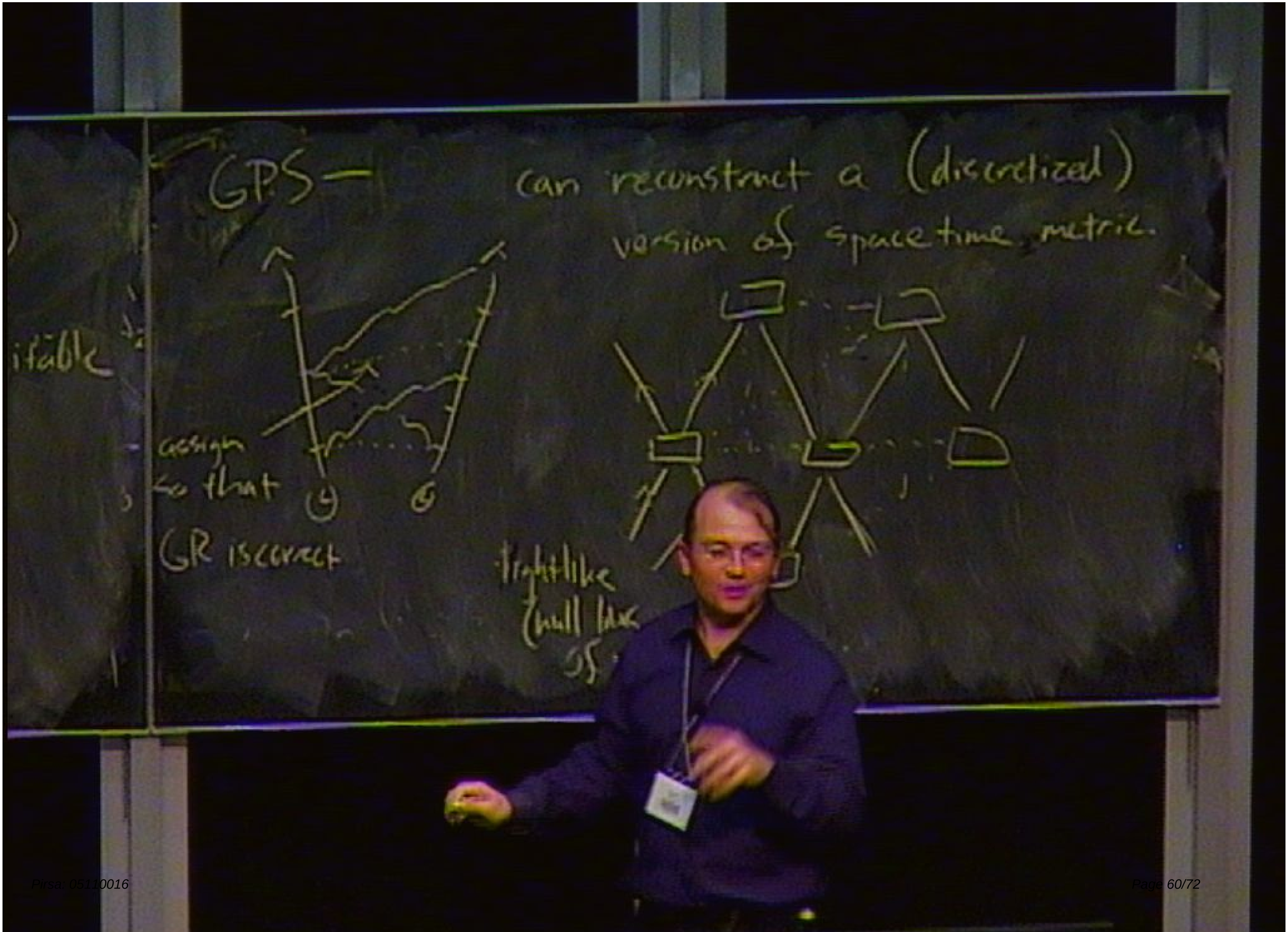

GPS —
can reconstruct a (discretized) version of space-time metric.
design so that
GR is correct
lightlike
(null lines of metric)

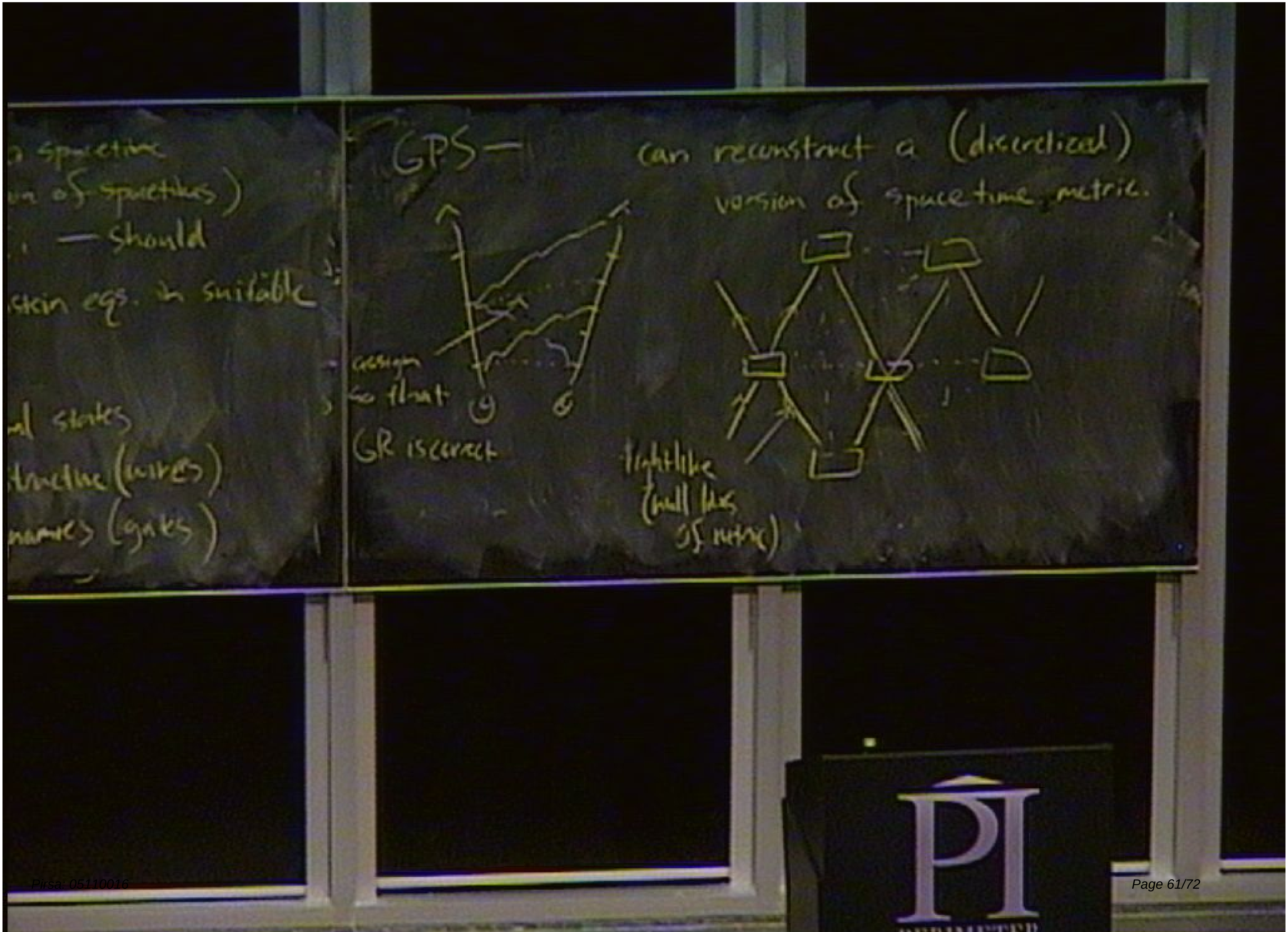

get a spacetime
position of spacetimes)
QC. — should
Einstein eqs. in suitable
GPS —
can reconstruct a
version of space
assign
so that
GR is correct

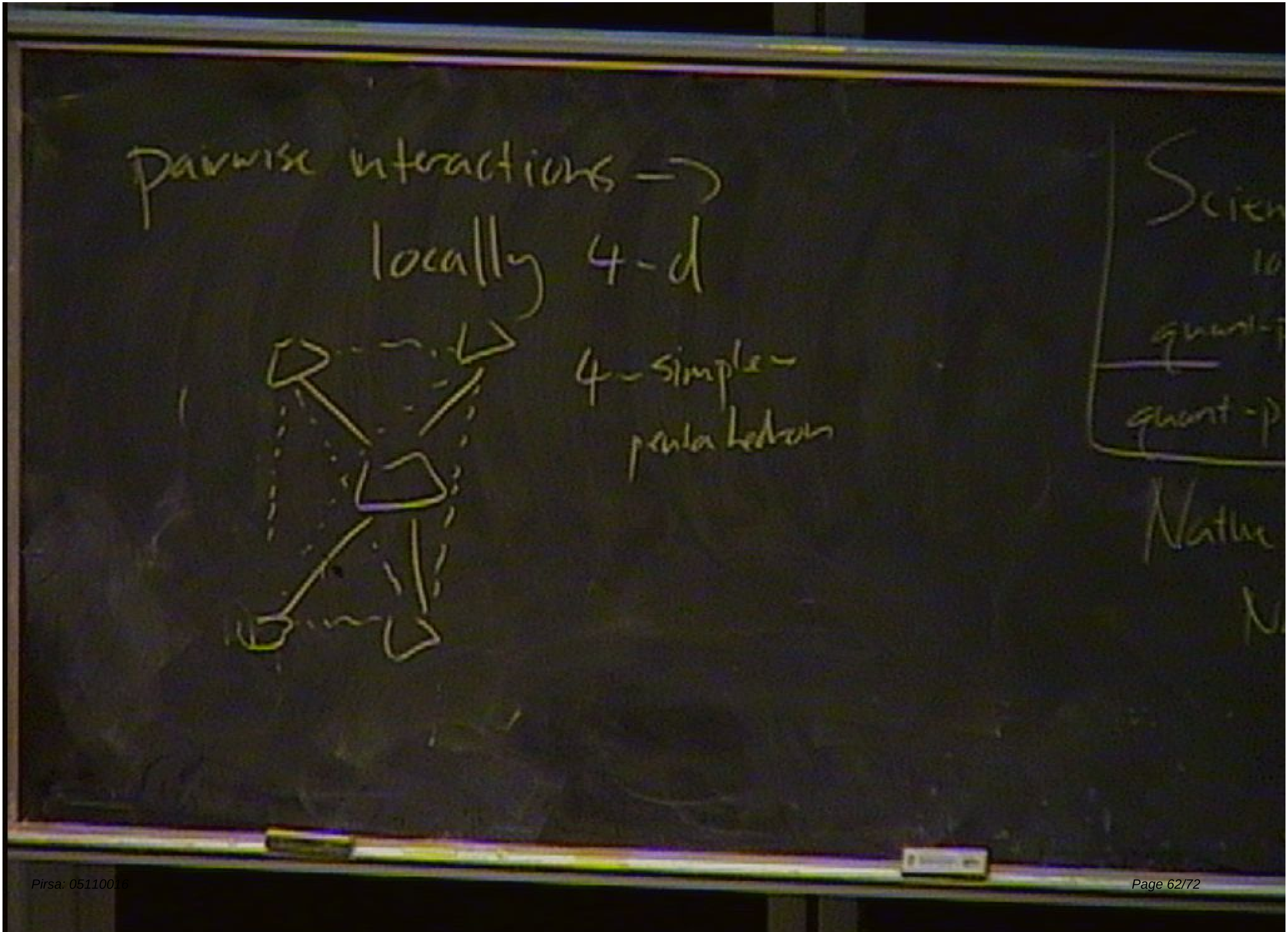

Steps: 1. extend computational lattice
to a simplicial lattice by
adding edges
(lots of ways)
2. assign edge lengths
assuming Einstein/Regge eqs. hold.

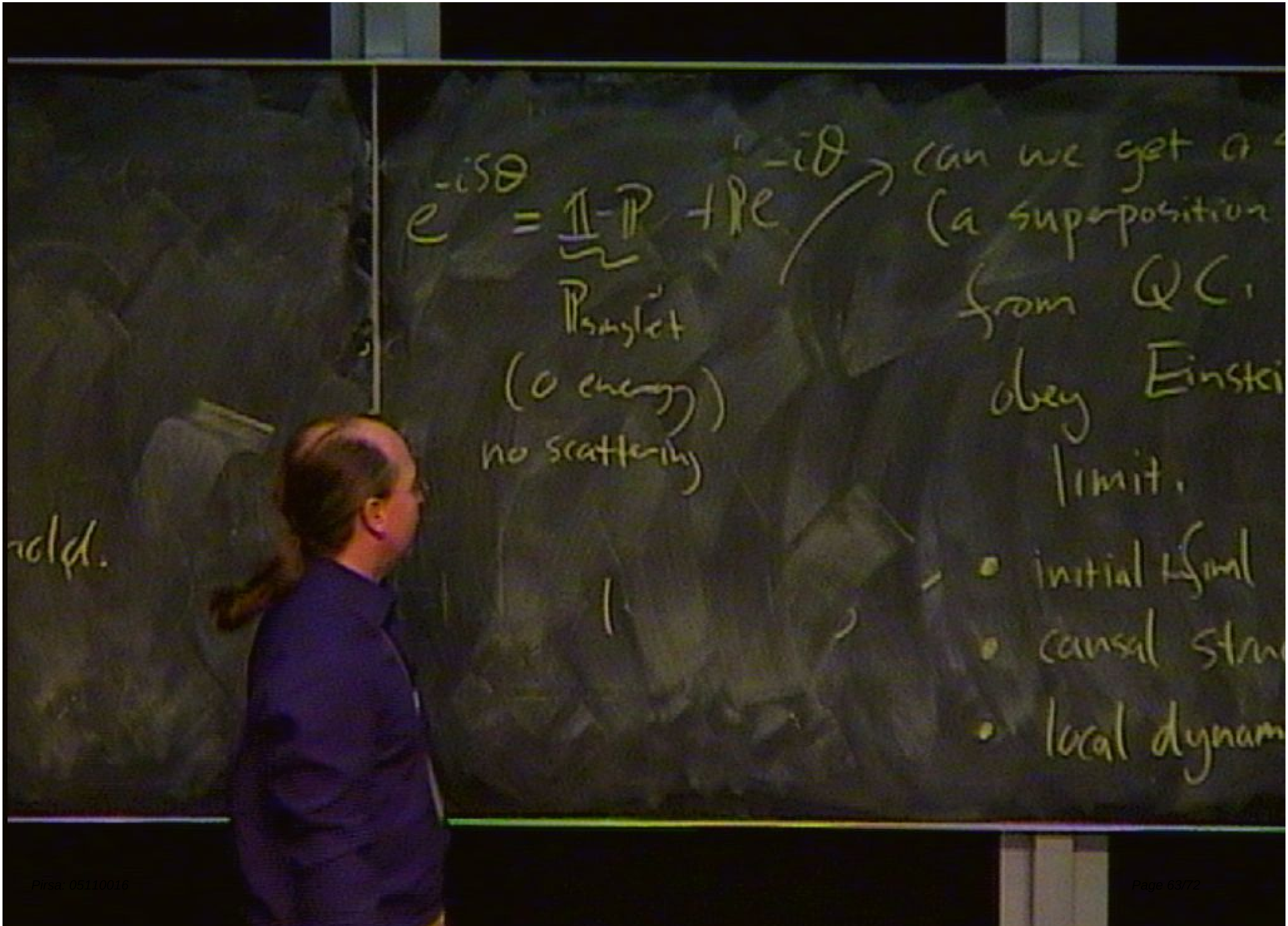
Steps: 1. extend computational lattice
to a simplicial lattice by
adding edges
(lots of ways)

2. assign edge lengths
assuming Einstein/Regge eqs. hold.
with matter


GPS —
can reconstruct a (discretized)
version of spacetime metric.
assign
so that
GR is correct
lightlike
(null like)


spacetime
of spacetimes)
— should
stein eqs. in suitable
al states
structure (wires)
names (gates)
GPS —
can reconstruct a (discretized)
version of space time metric.
design
so that
GR is correct
lightlike
(null lines
of metric)


pairwise interactions →
locally 4-d
4-simplex
pentahedron


e^{-iSθ} = 1 - P + Pe^{-iθ}
P singlet
(0 energy)
no scattering
can we get a
(a superposition
from QC,
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• initial & final
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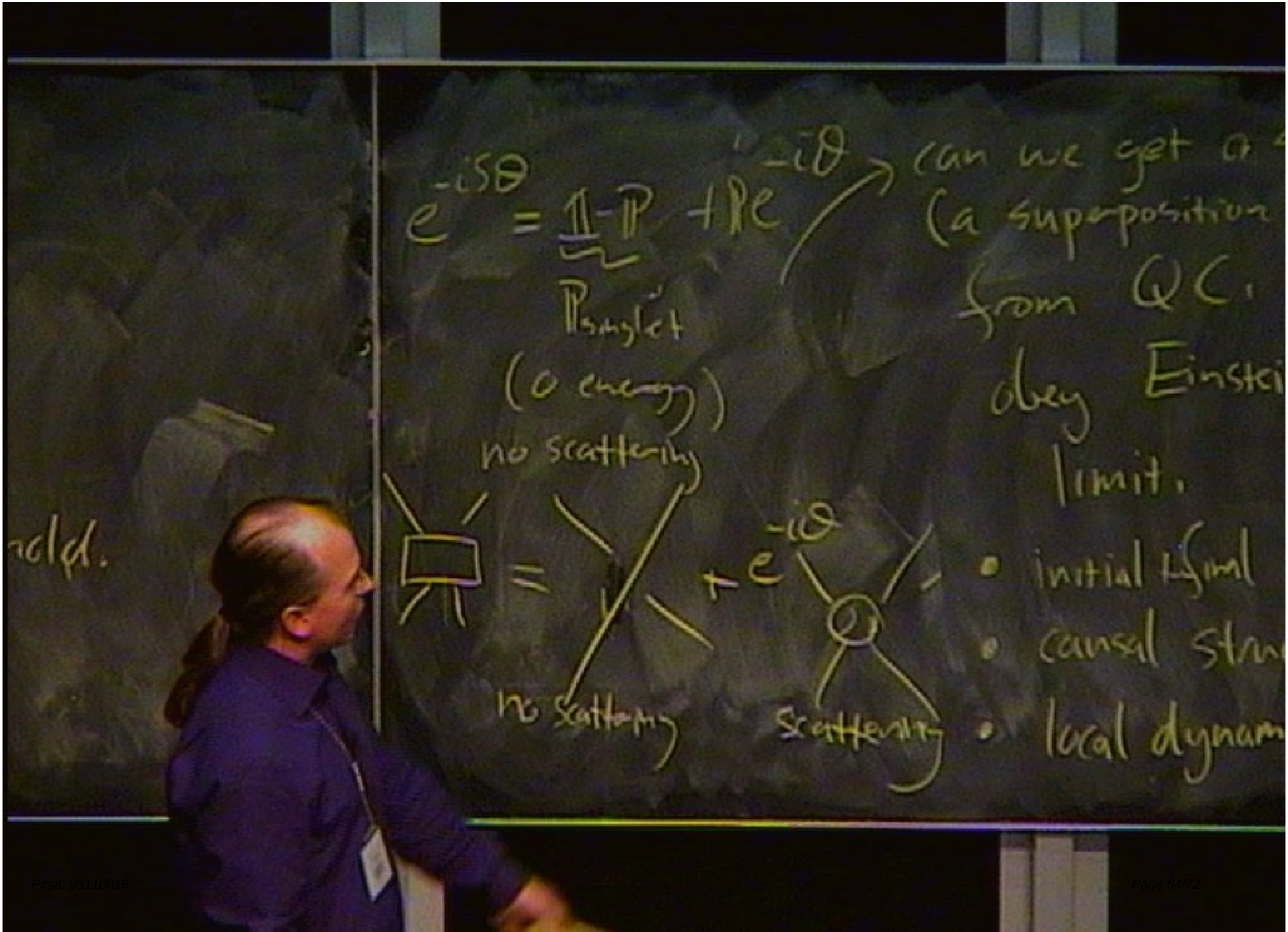

e^{-iSθ} = 1 - P + Pe^{-iθ}
Psinglet
(0 energy)
no scattering
no scattering
scattering
can we get a
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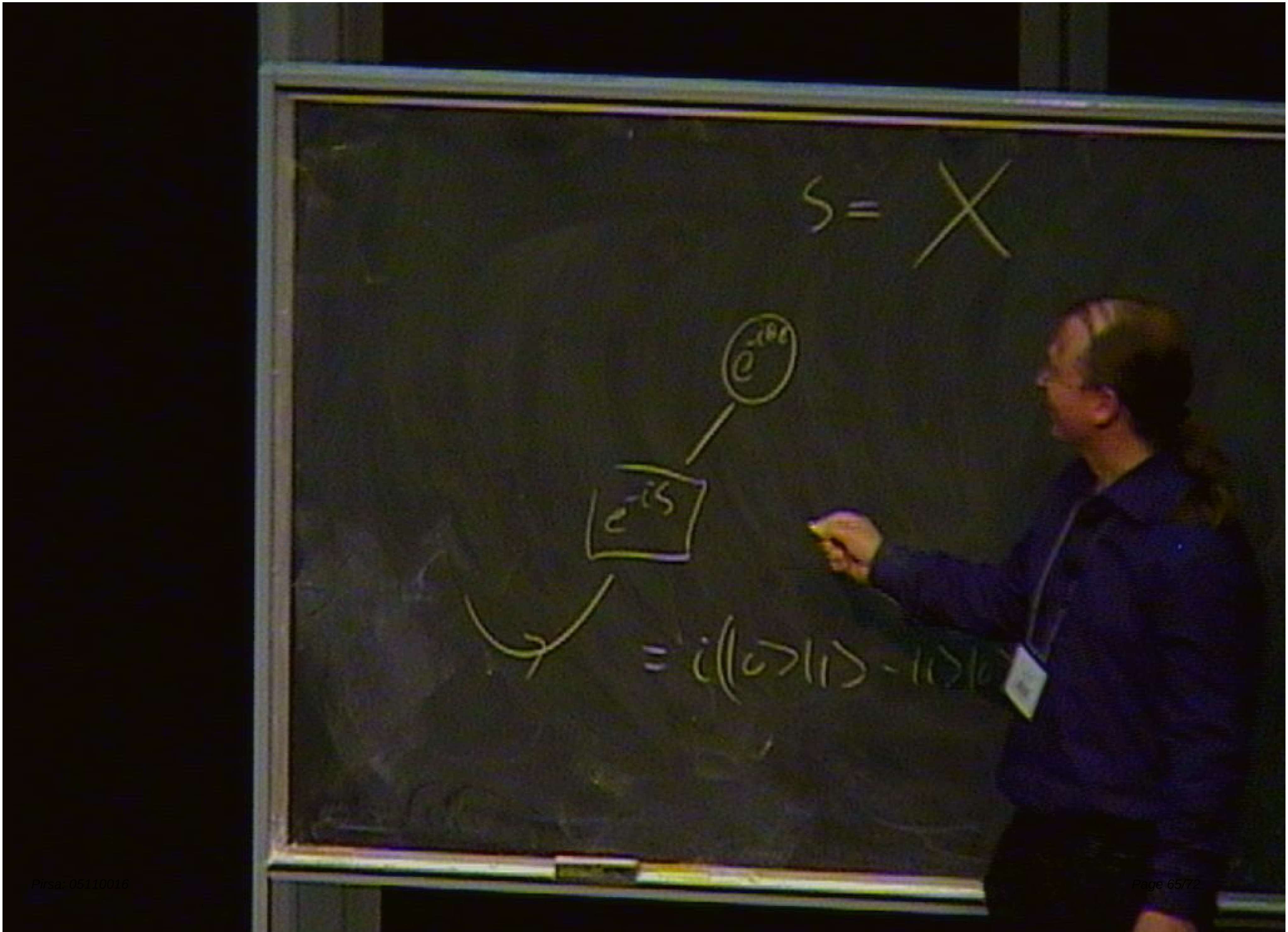
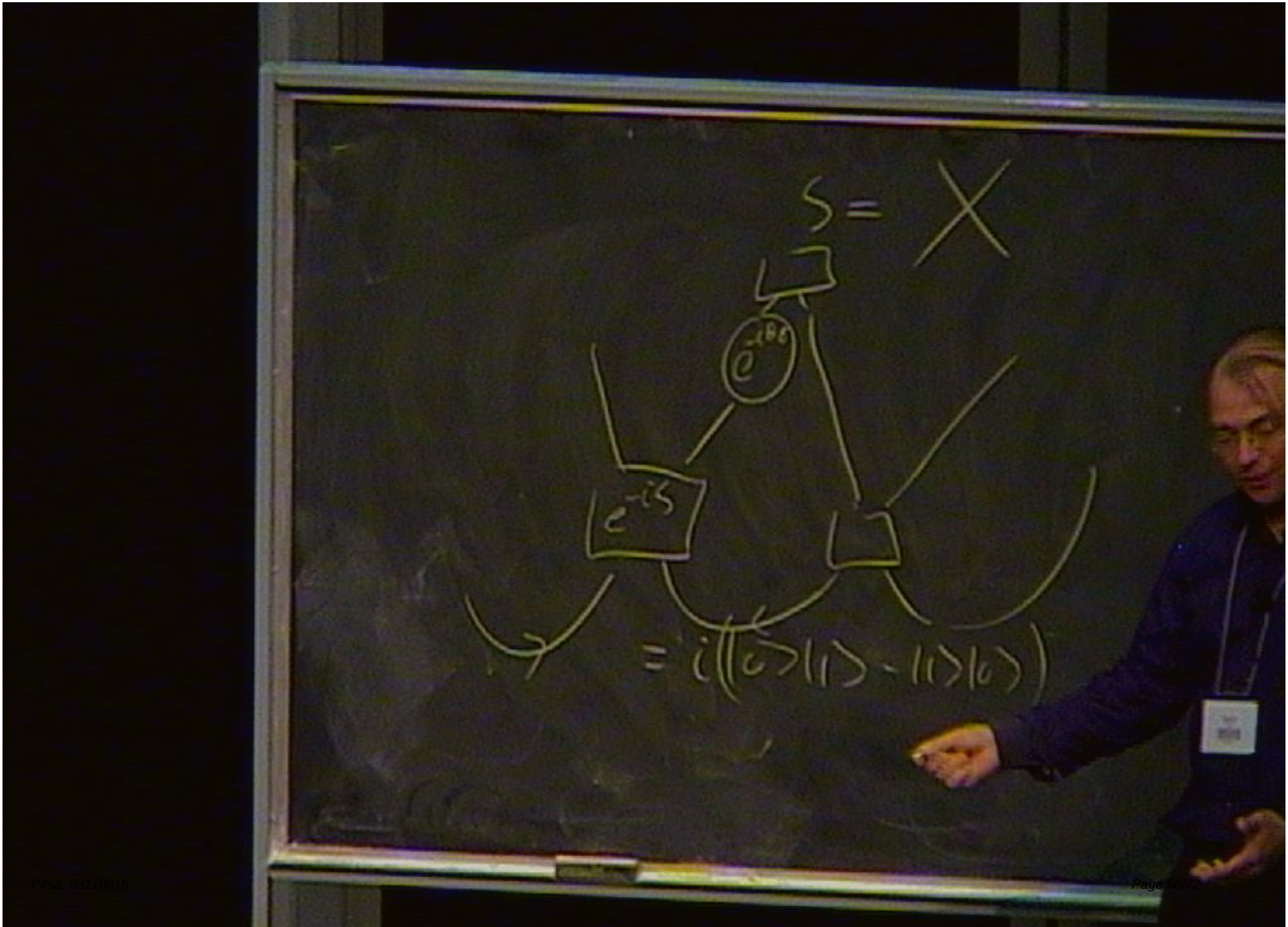
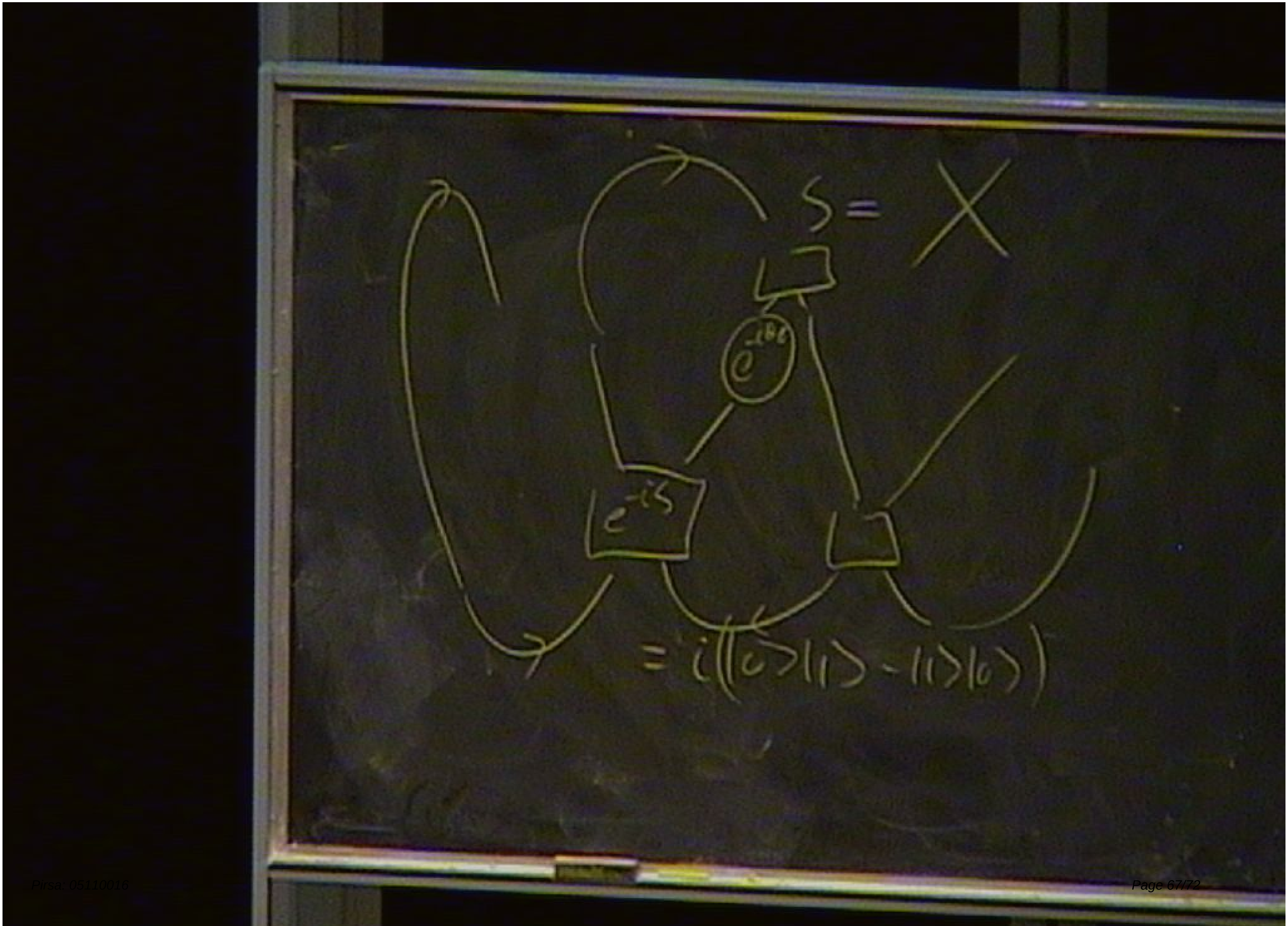
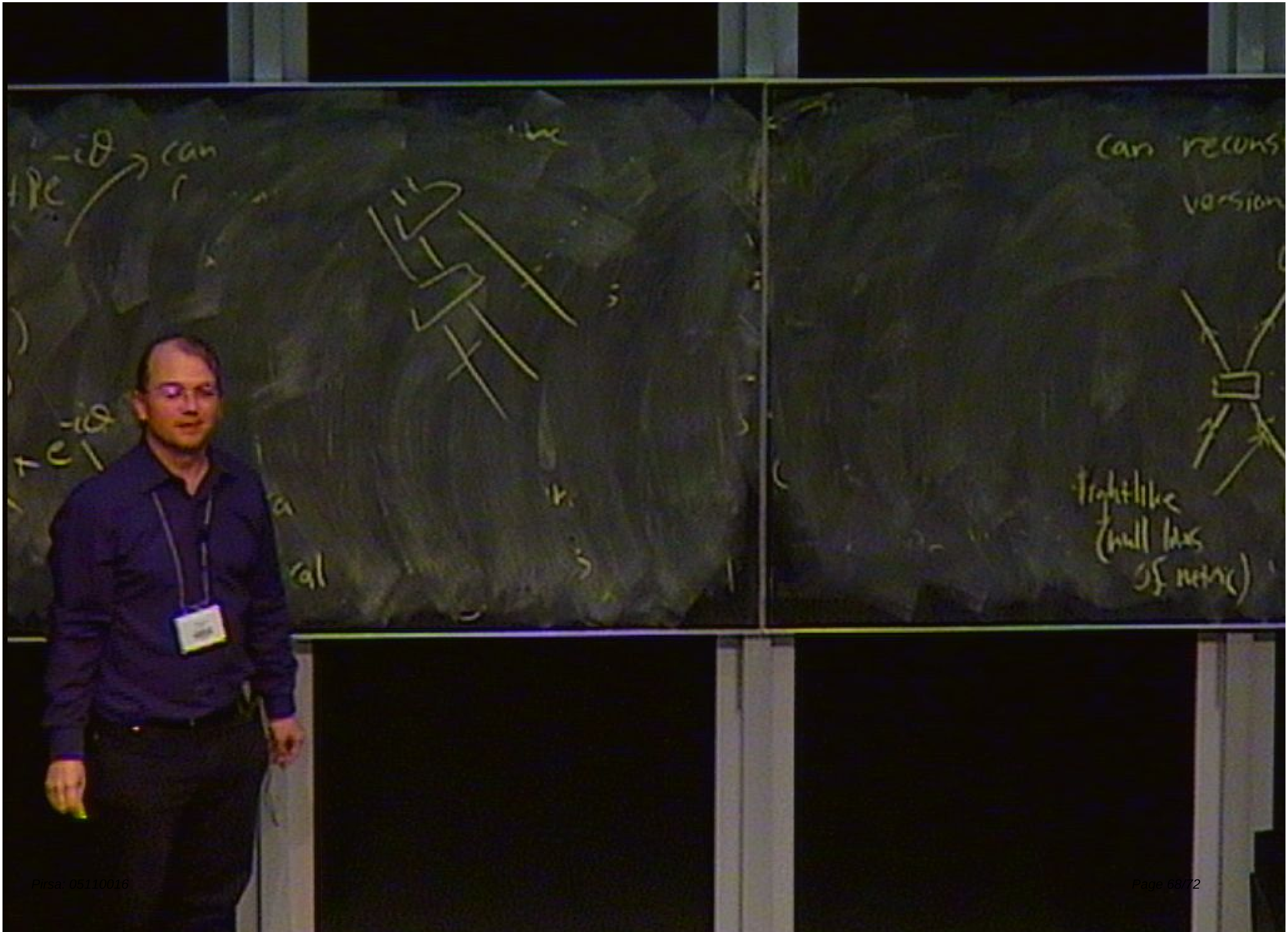

S = X
e^{-iS}


S =
e^{-iS}
$= i(|0\rangle|1\rangle - |1\rangle|0\rangle)$


S =
e^{-iS}
= i(|0>|1> - |1>|0>)


can
can reconst
version
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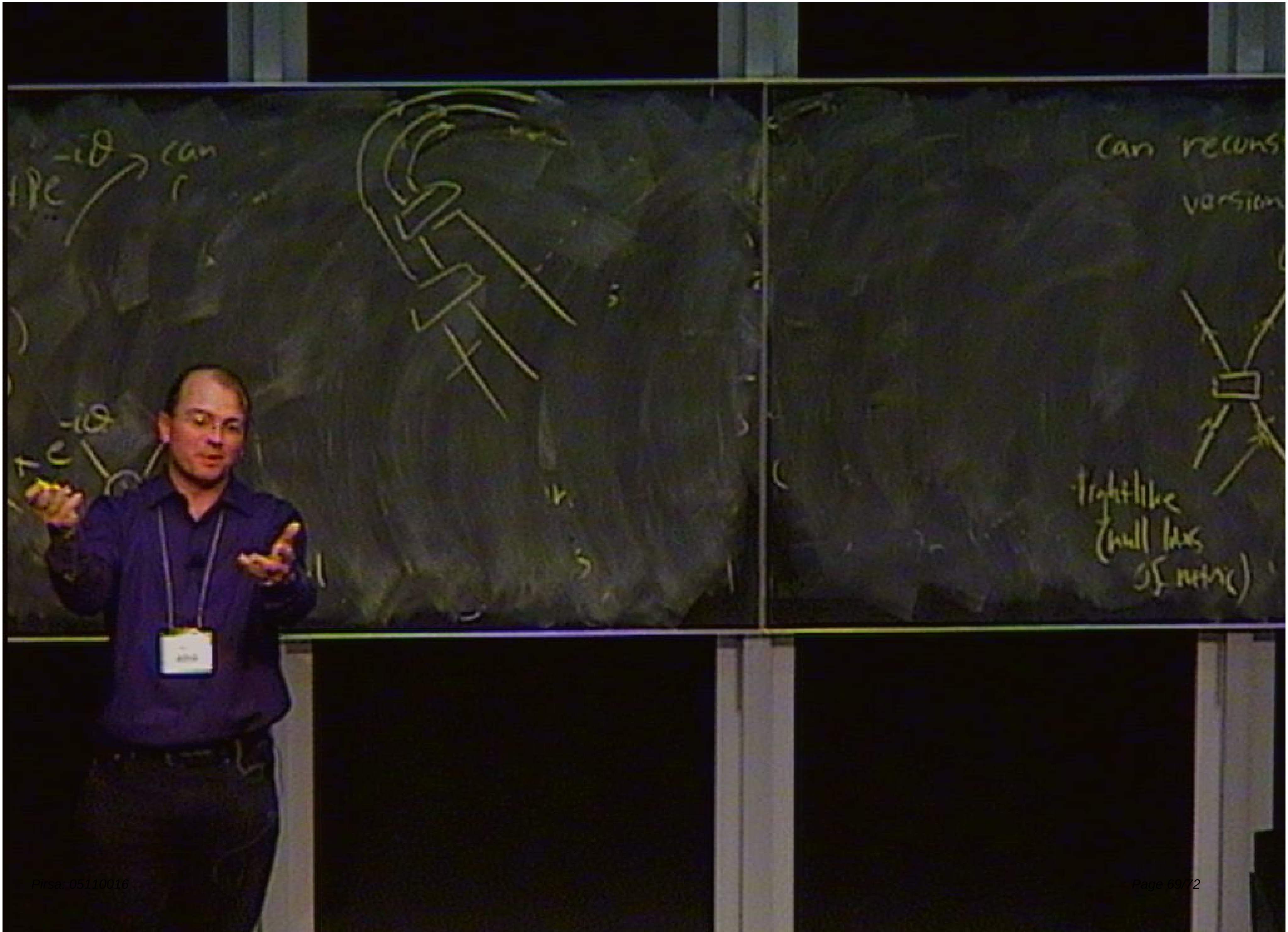
(null lines
of metric)


can
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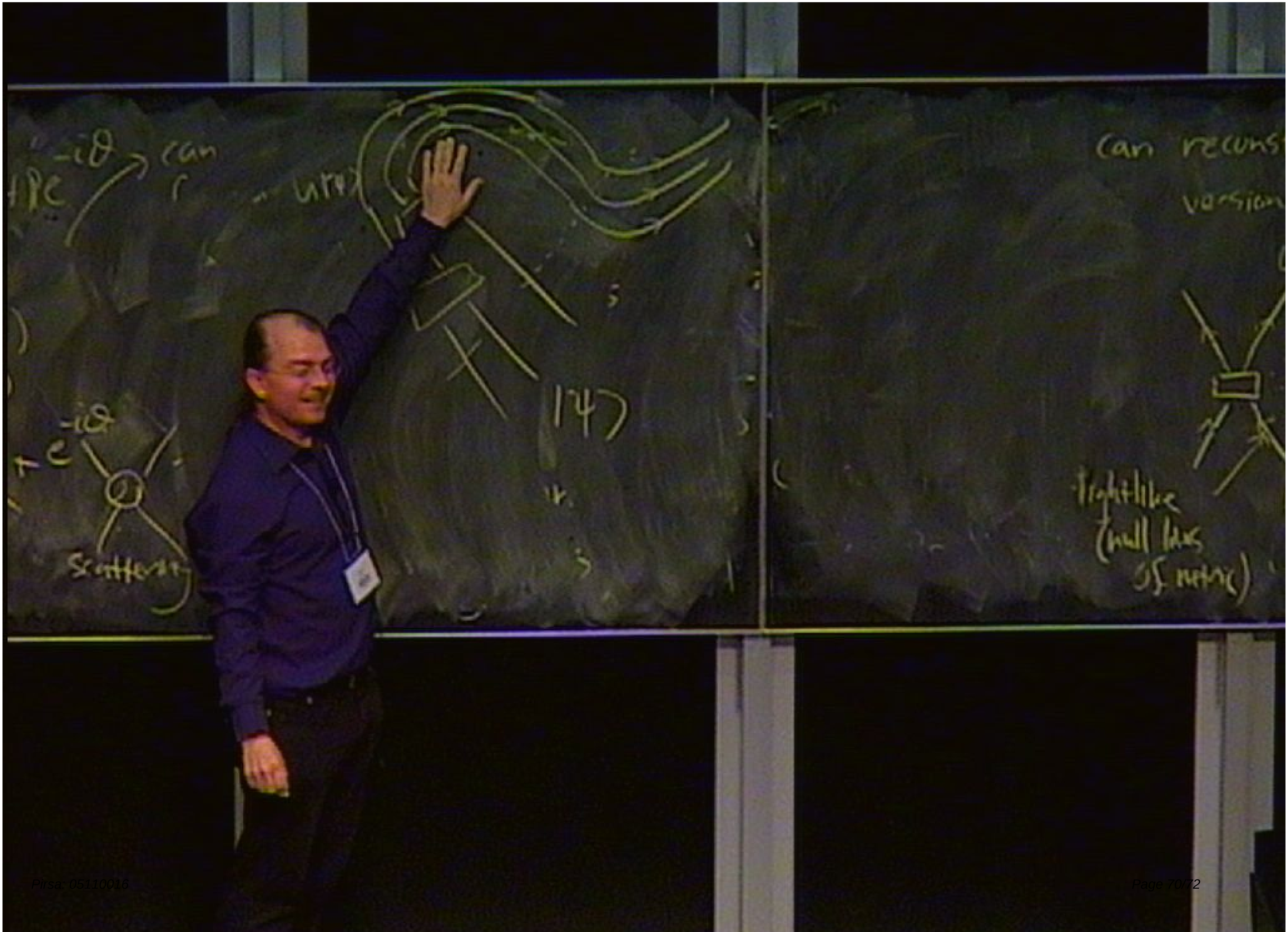
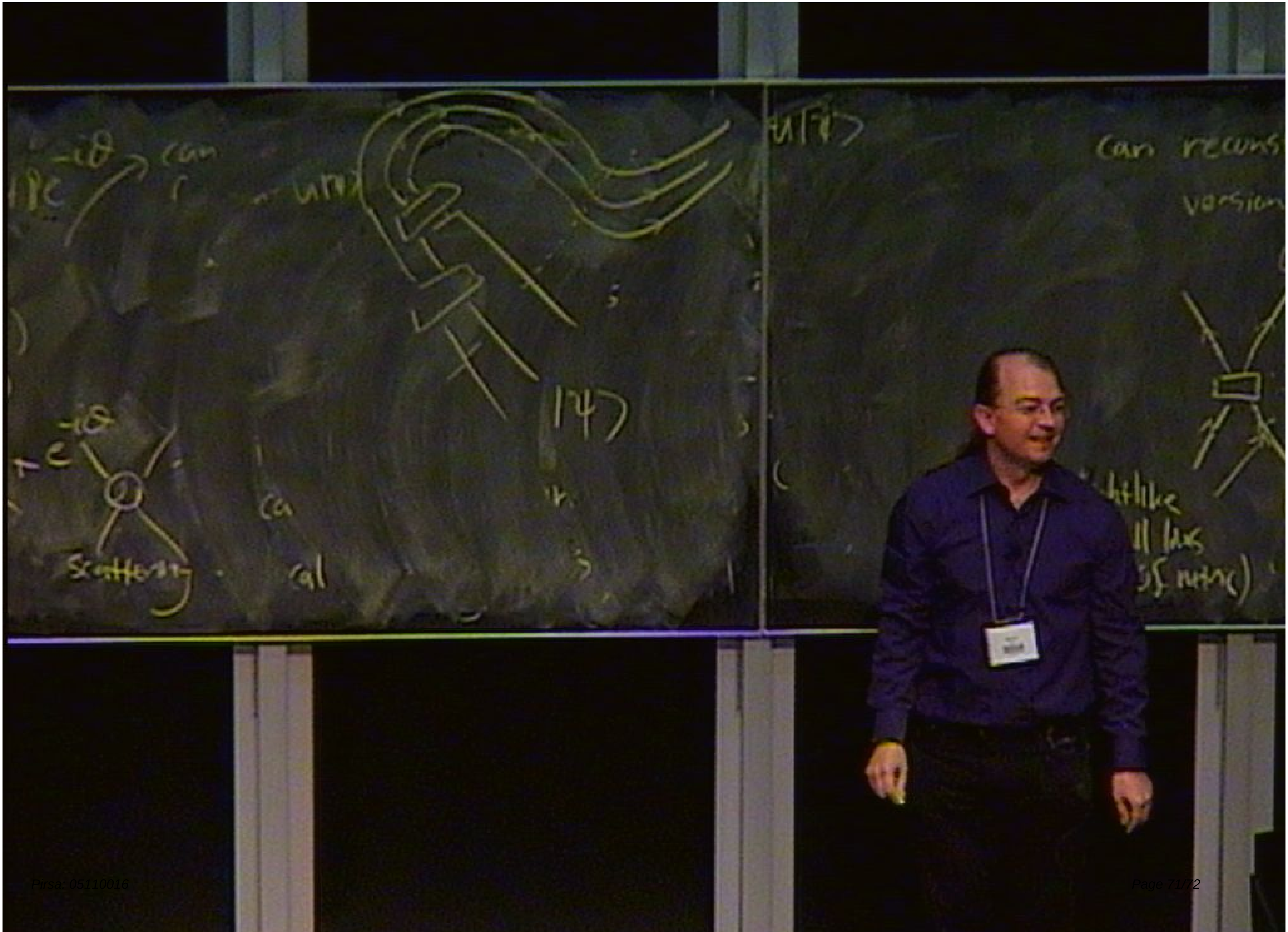
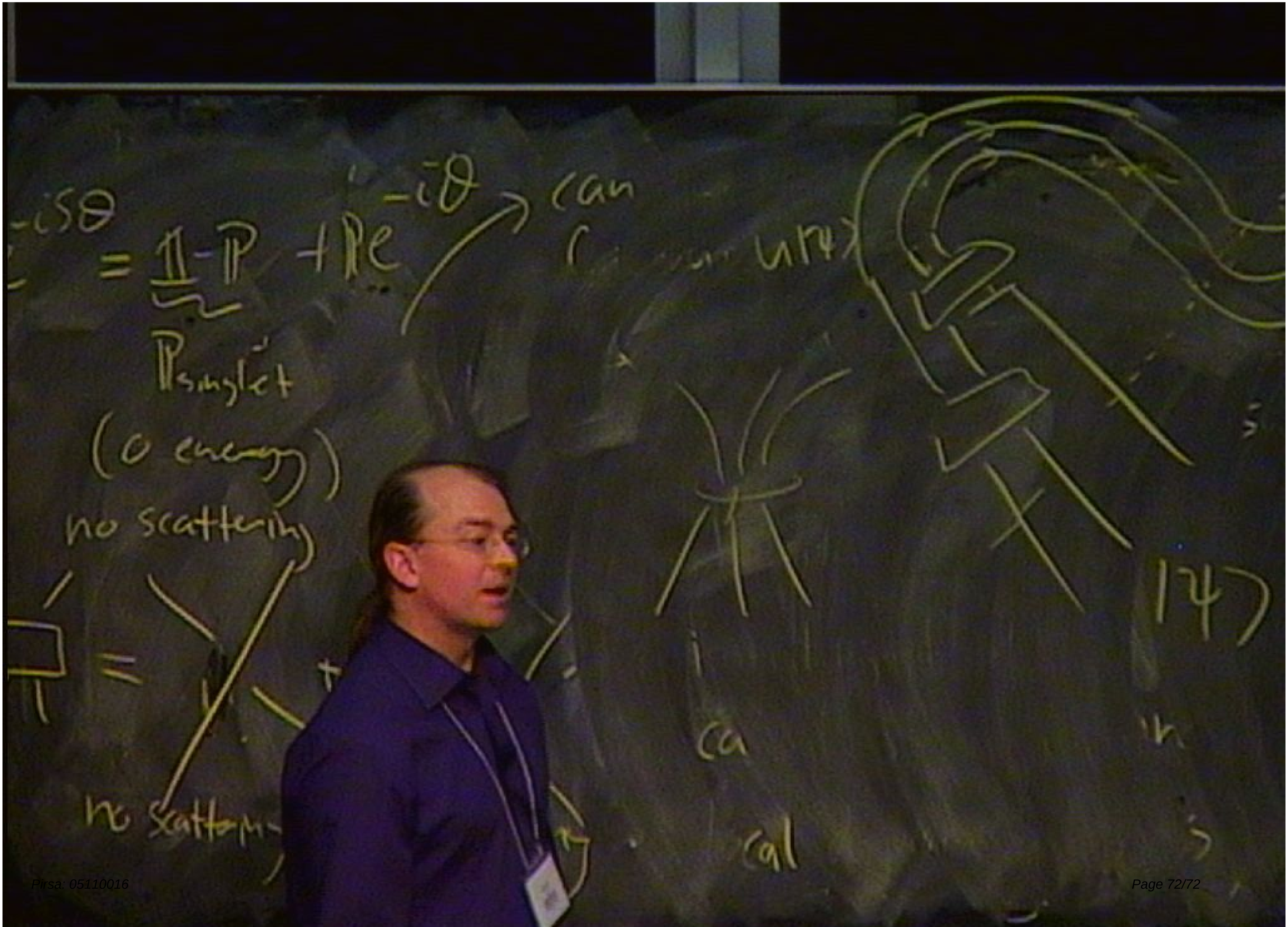
of metric)




can
can recons
version
scattering


can
$\mathbb{P}_{singlet}$
(0 energy)
no scattering
no scattering
$|\psi\rangle$