Title: Dark Energy, Lorentz Violation and Ghosts

Date: May 20, 2007 02:00 PM

URL: http://pirsa.org/07050042

Abstract: I describe how vacuum energy can be controlled by a symmetry principle that necessitates a ghost sector. I argue that the implied instability of Minkowski spacetime is natural and consistent with experience if gravity is fundamentally Lorentz-violating, and describe attempts to construct such exotic dynamics. I briefly discuss the more robust experimental/observational signatures of such a scenario.

DARK ENERGY,

LORENTZ VIOLATION,

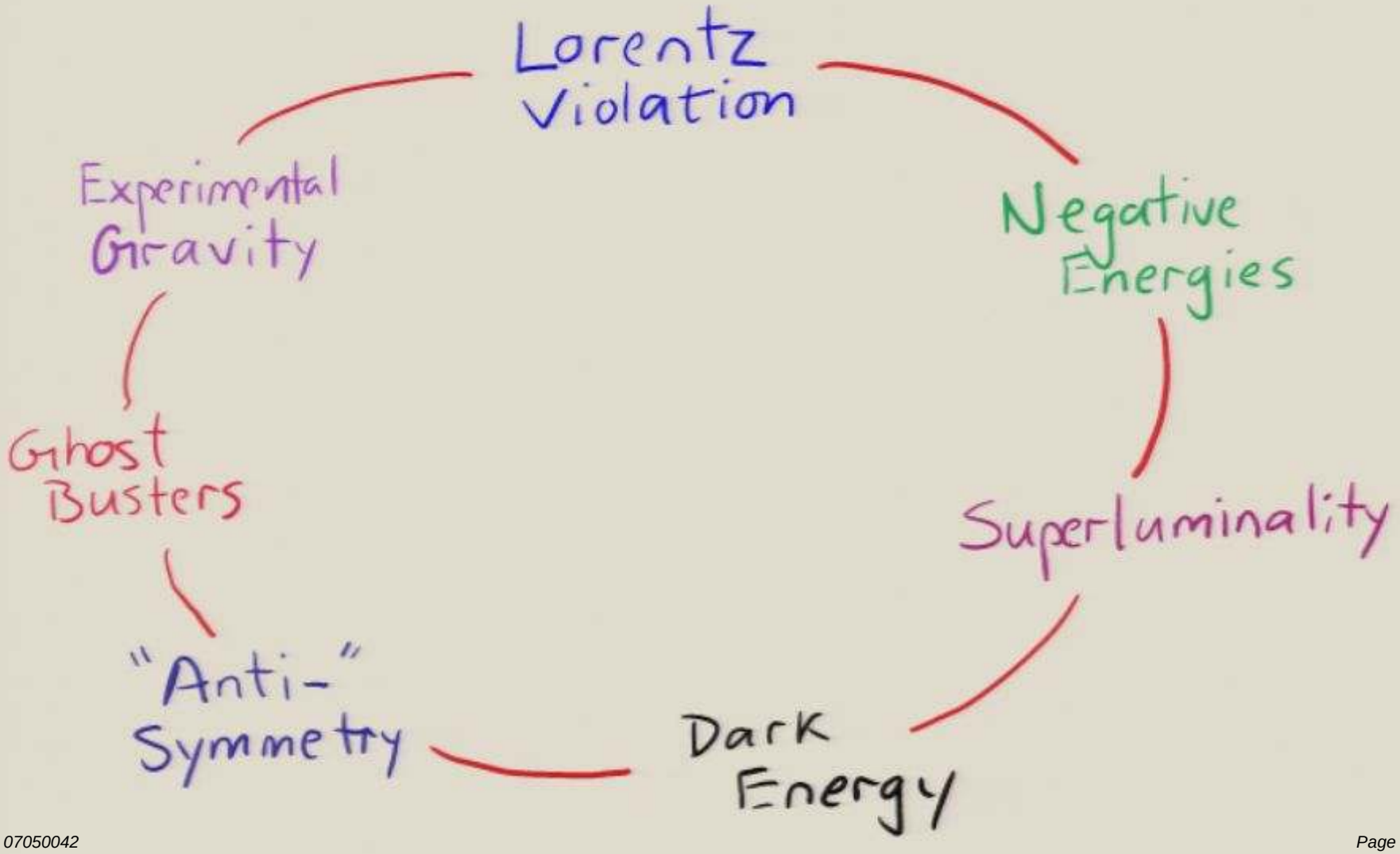
& GHOSTS

Raman Sundrum
Johns Hopkins University

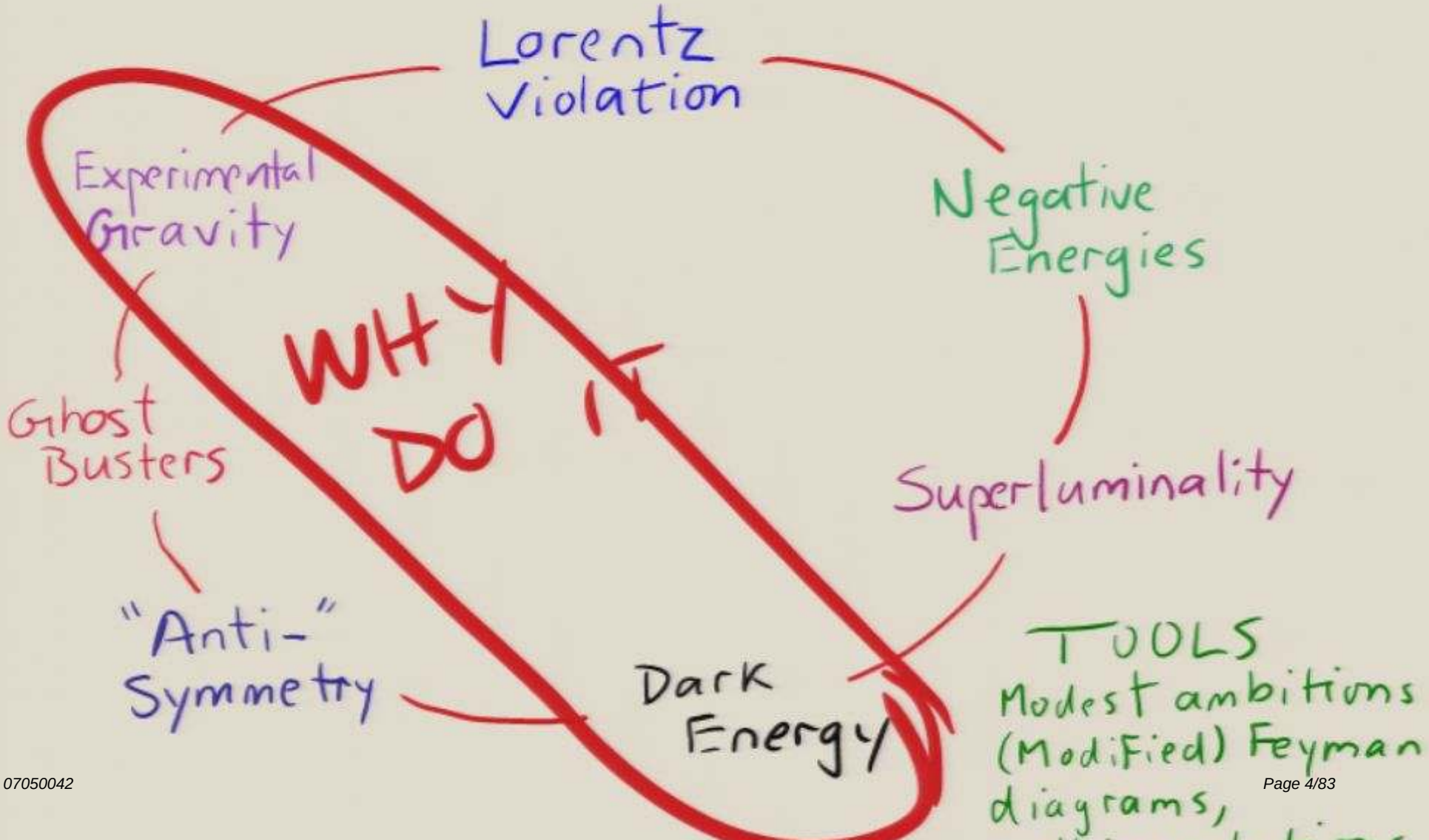
Pirsa: 07050042

Collaborators: David E. Kaplan, Matthew Schwartz

OUTLINE


Lorentz Violation
Negative Energies
Superluminality
Dark Energy
"Anti-" Symmetry
Ghost Busters
Experimental Gravity

OUTLINE


Lorentz Violation
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TOOLS
Modest ambitions
(Modified) Feyman
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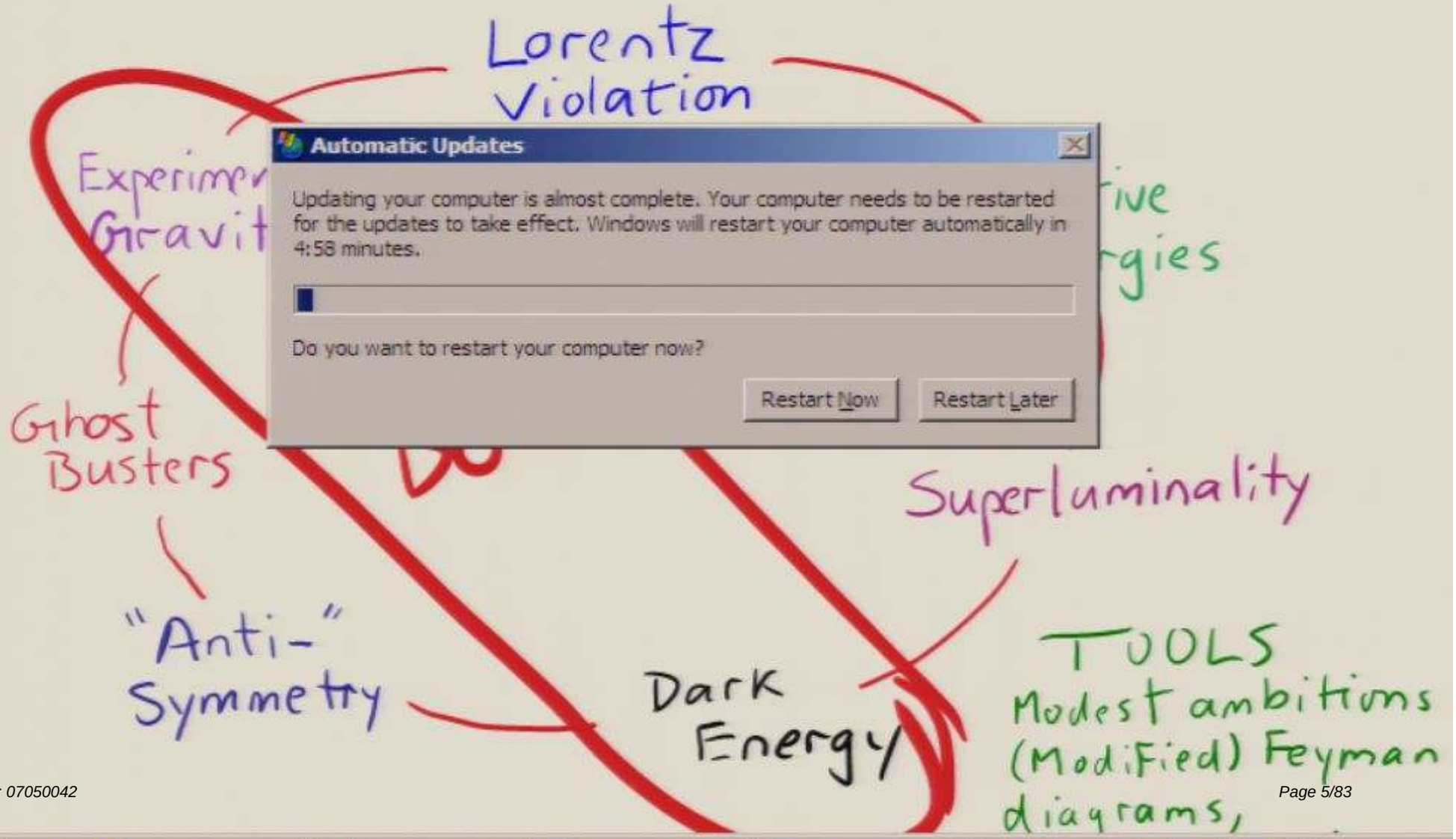
Lorentz Violation
Automatic Updates
Updating your computer is almost complete. Your computer needs to be restarted for the updates to take effect. Windows will restart your computer automatically in 4:58 minutes.
Do you want to restart your computer now?
Restart Now
Restart Later
Superluminality
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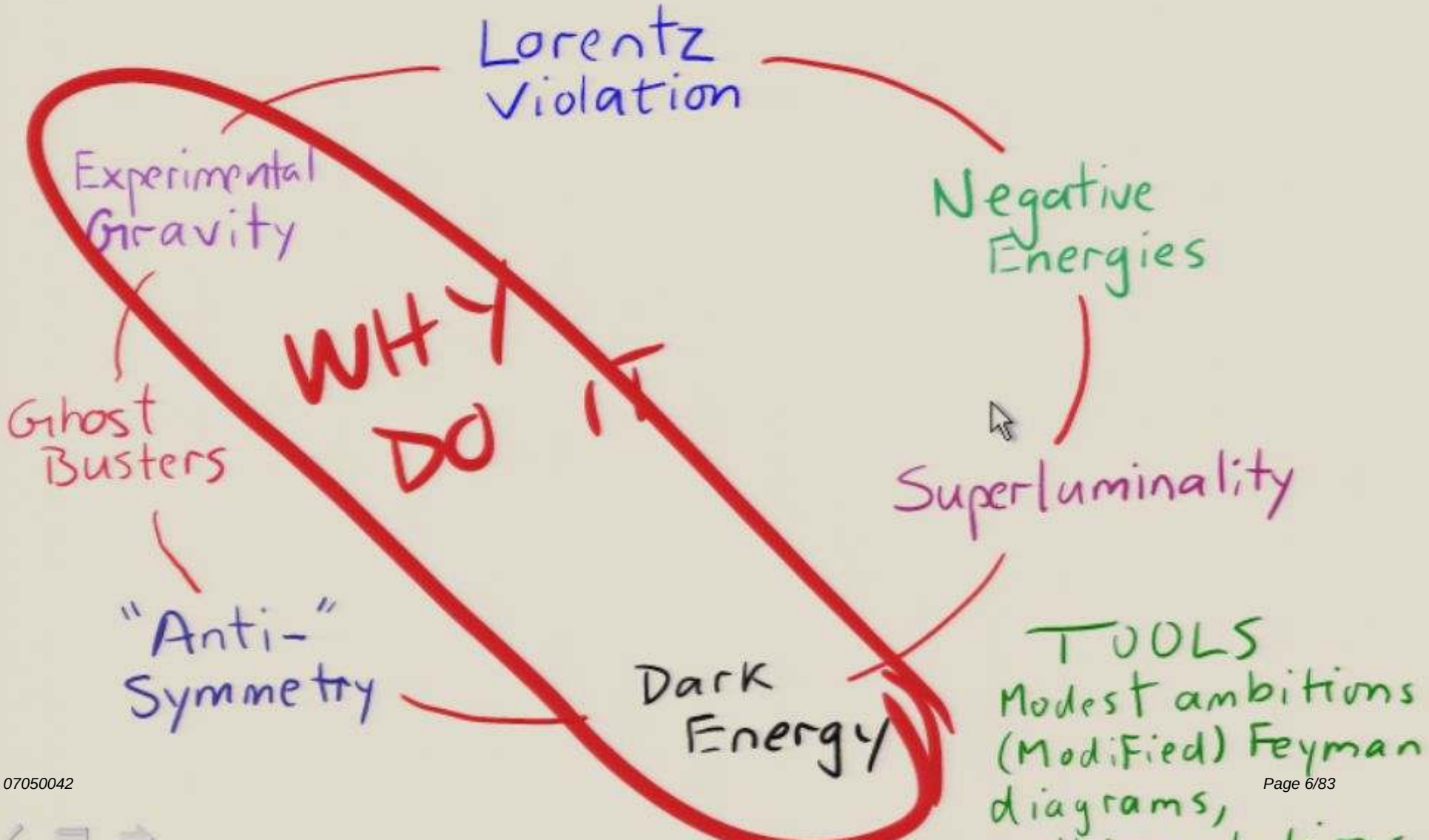
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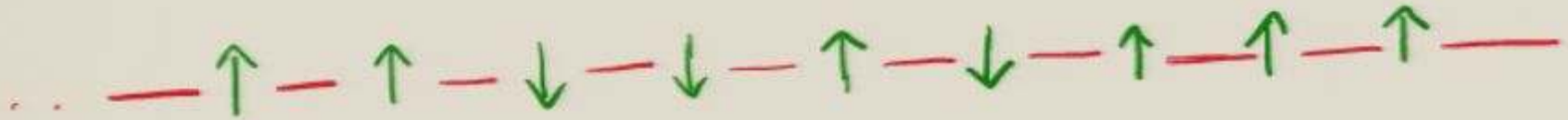
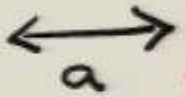
EMERGENT RELATIVITY

(without gravity)

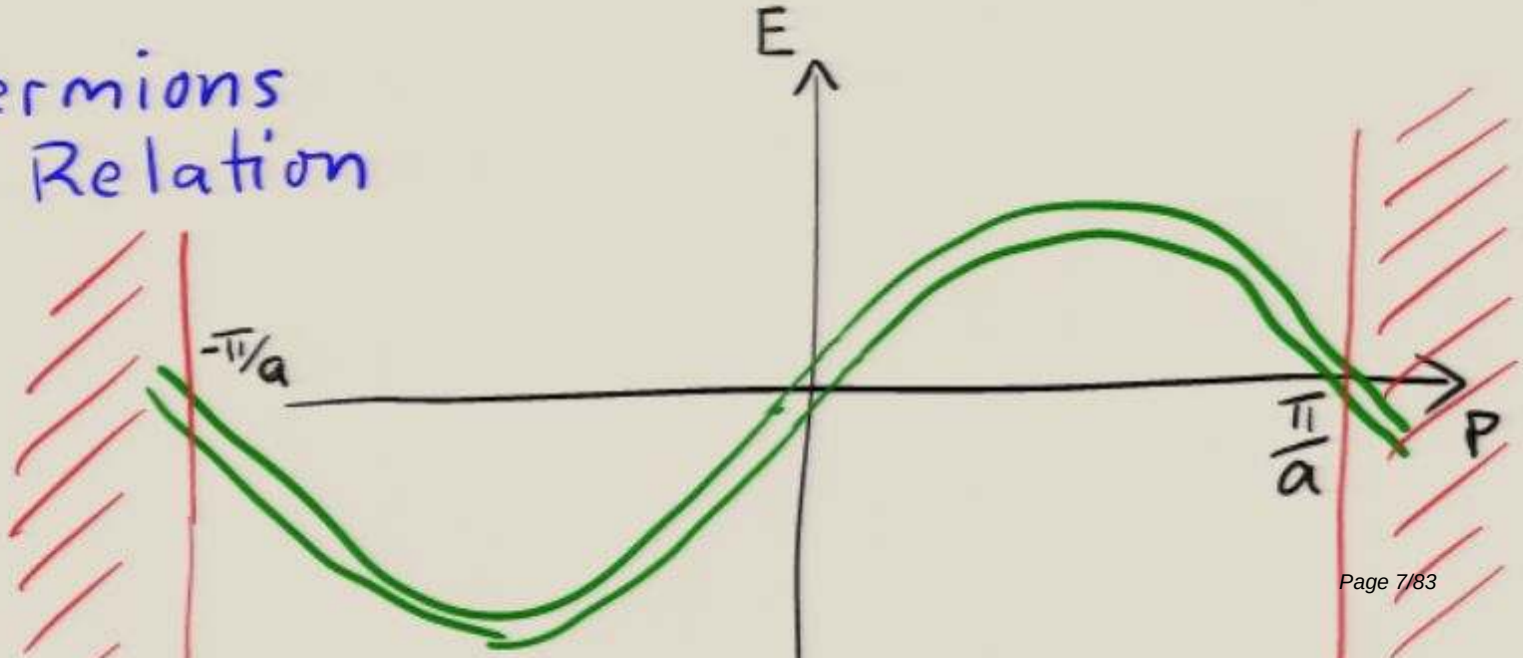
Quantum Spin Chain:





not boost-invariant

Lattice Fermions Dispersion Relation



EMERGENT RELATIVITY

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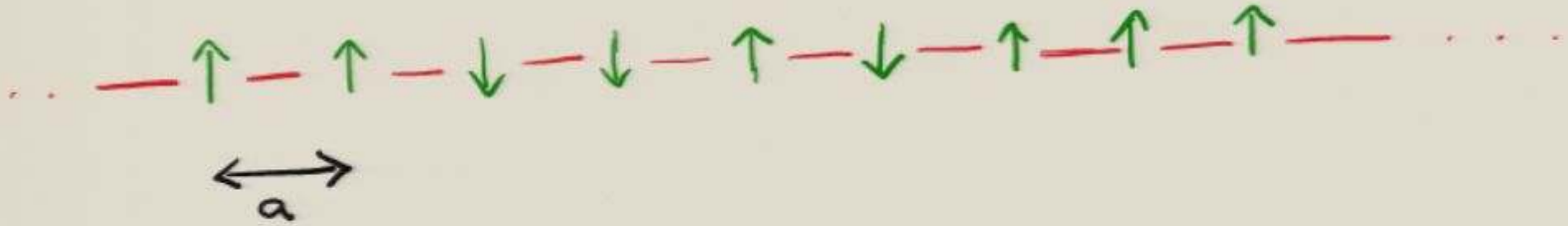

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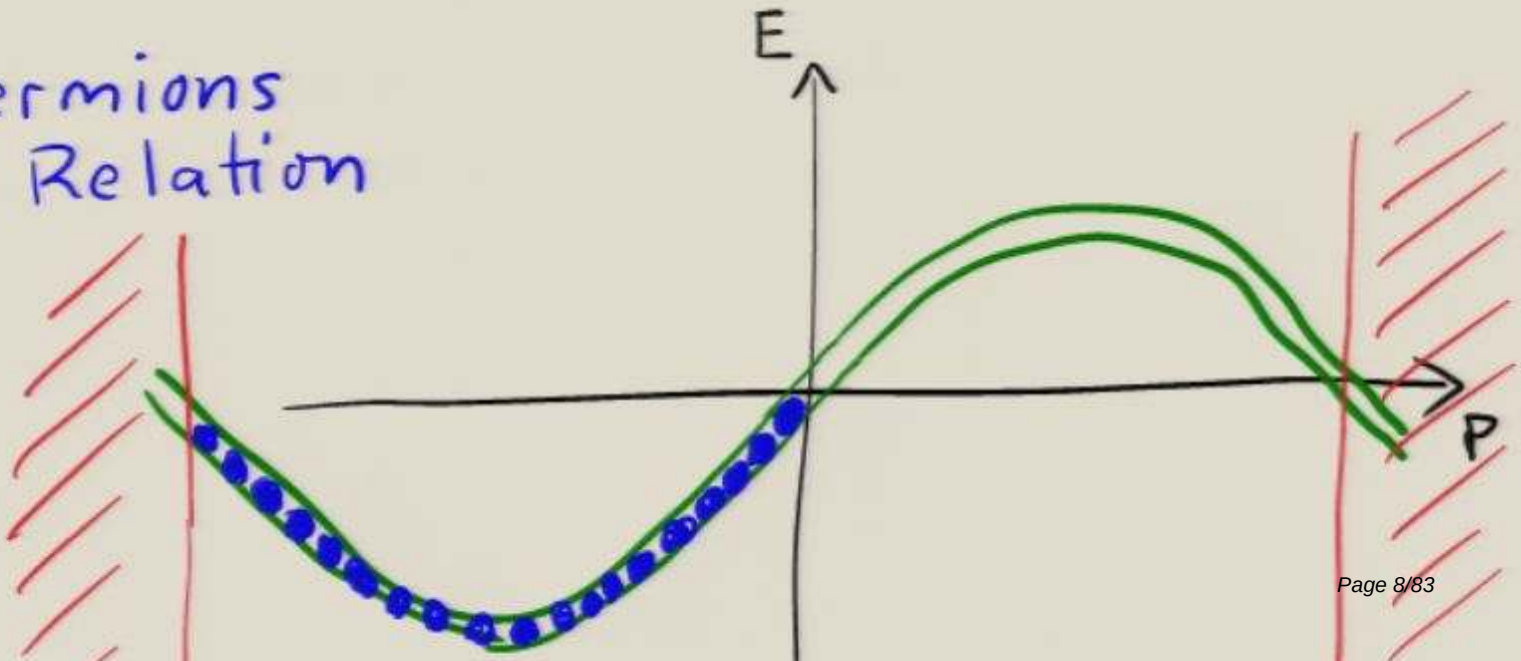
Dispersion Relation



$|0\rangle$ "Minkowski"

EMERGENT RELATIVITY

(without gravity)

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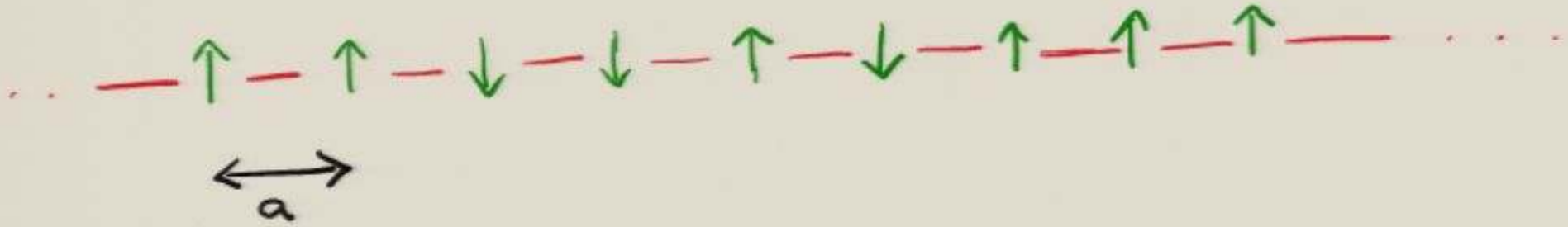

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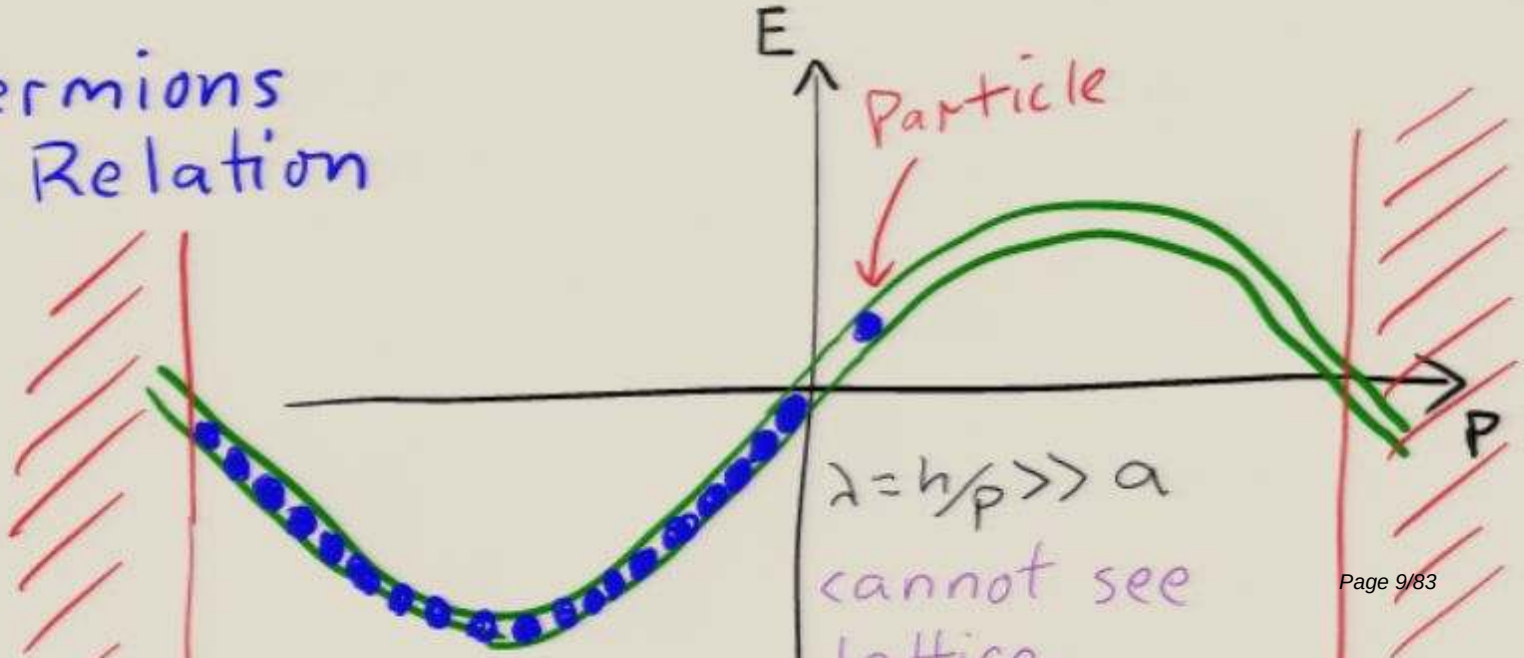

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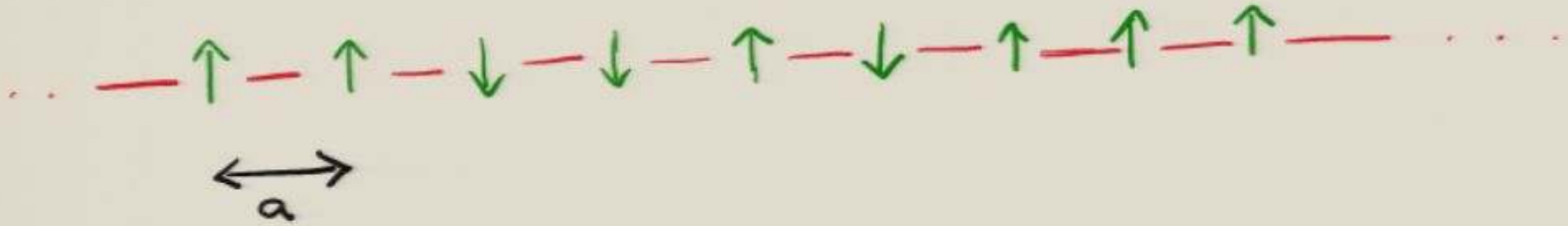

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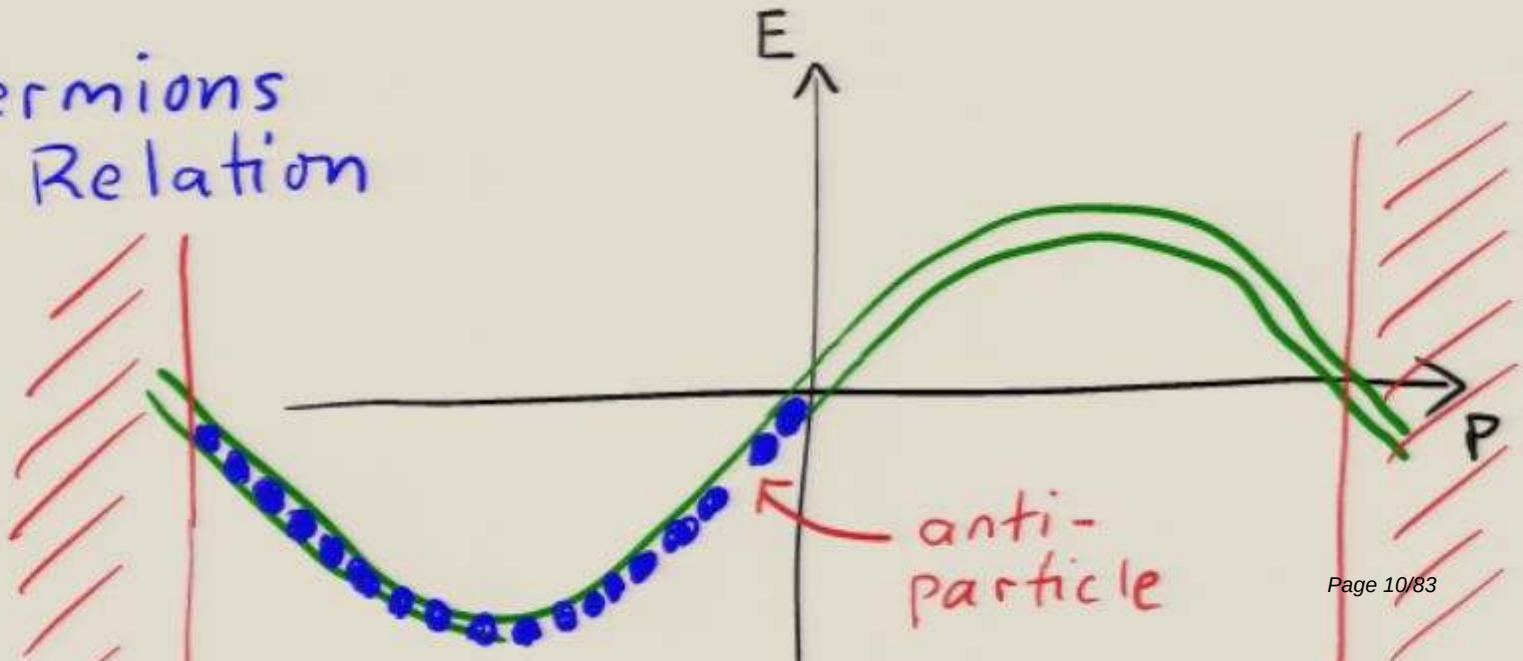
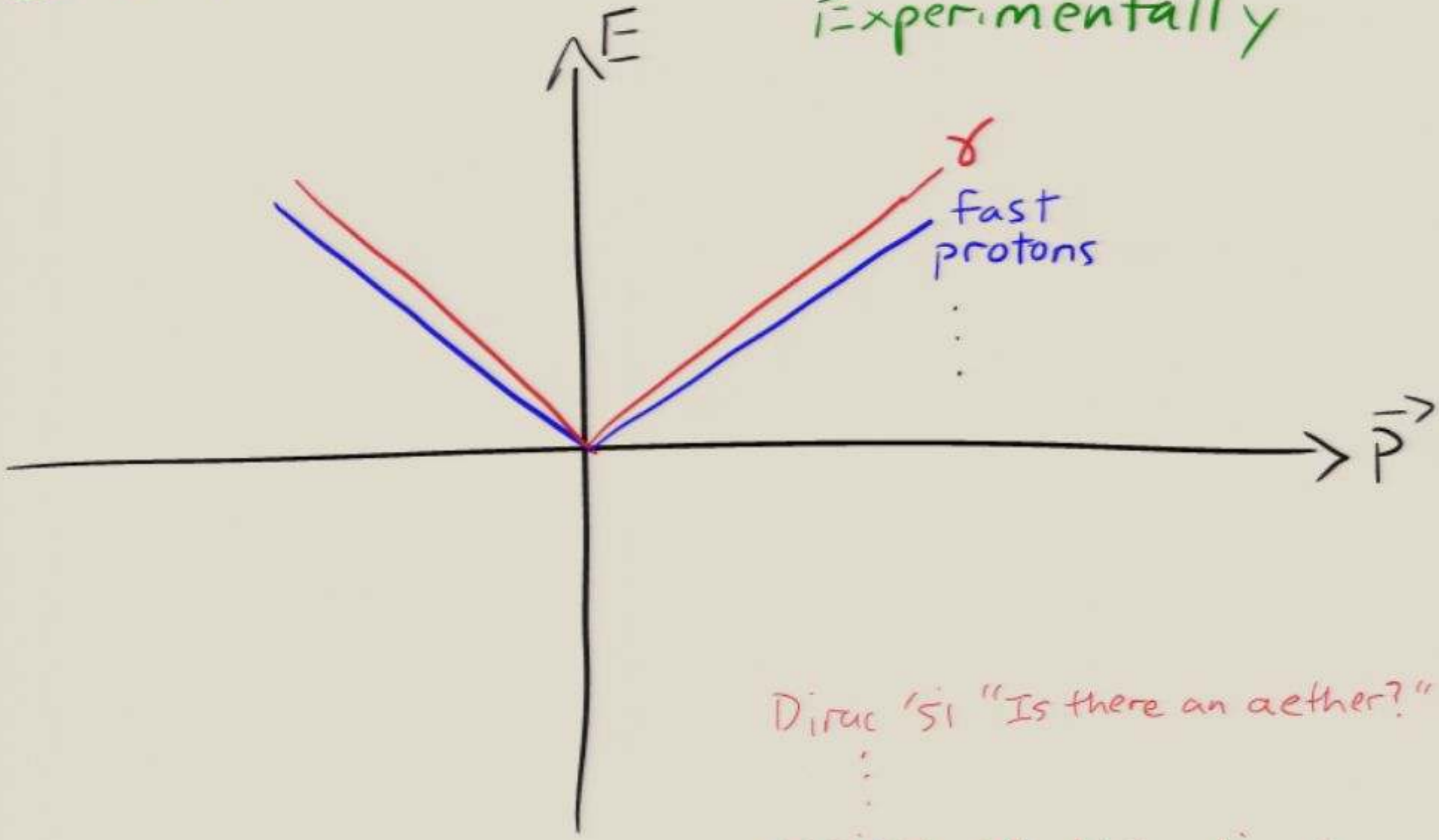


BUT TIGHTLY CONSTRAINED

Experimentally



Dirac '51 "Is there an aether?"

review: Mattingly '05

EMERGENT RELATIVITY

(without gravity)

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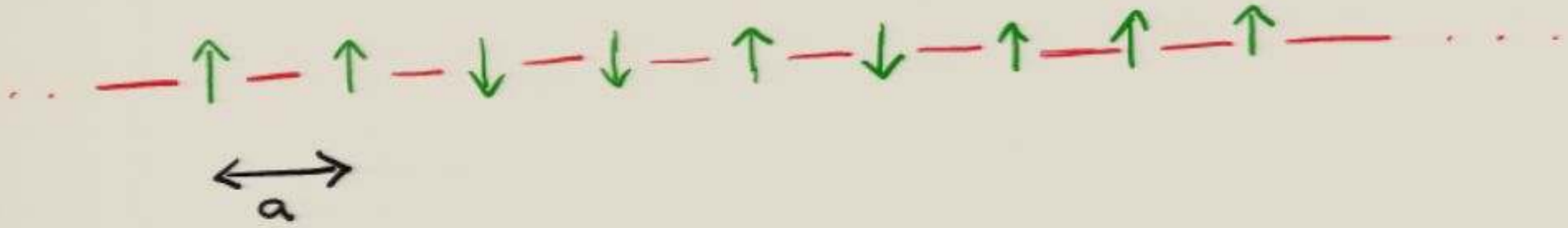

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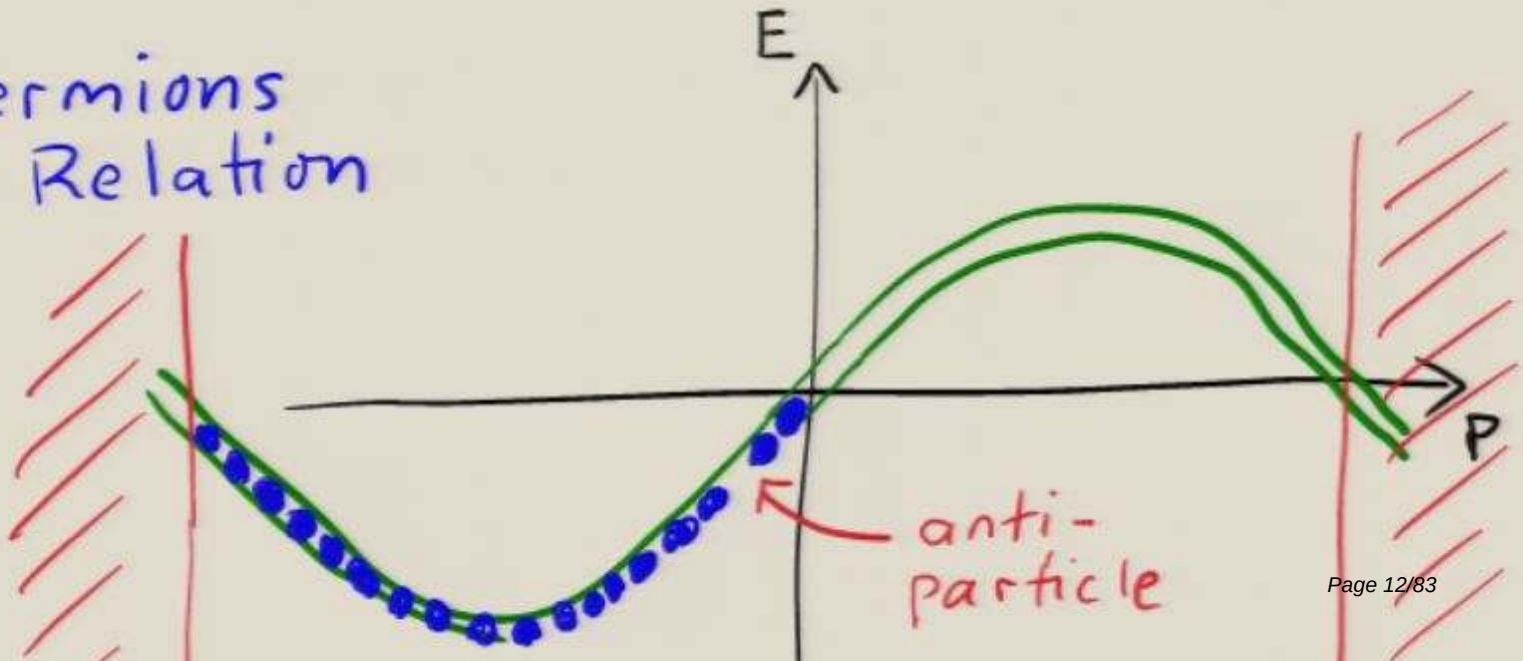

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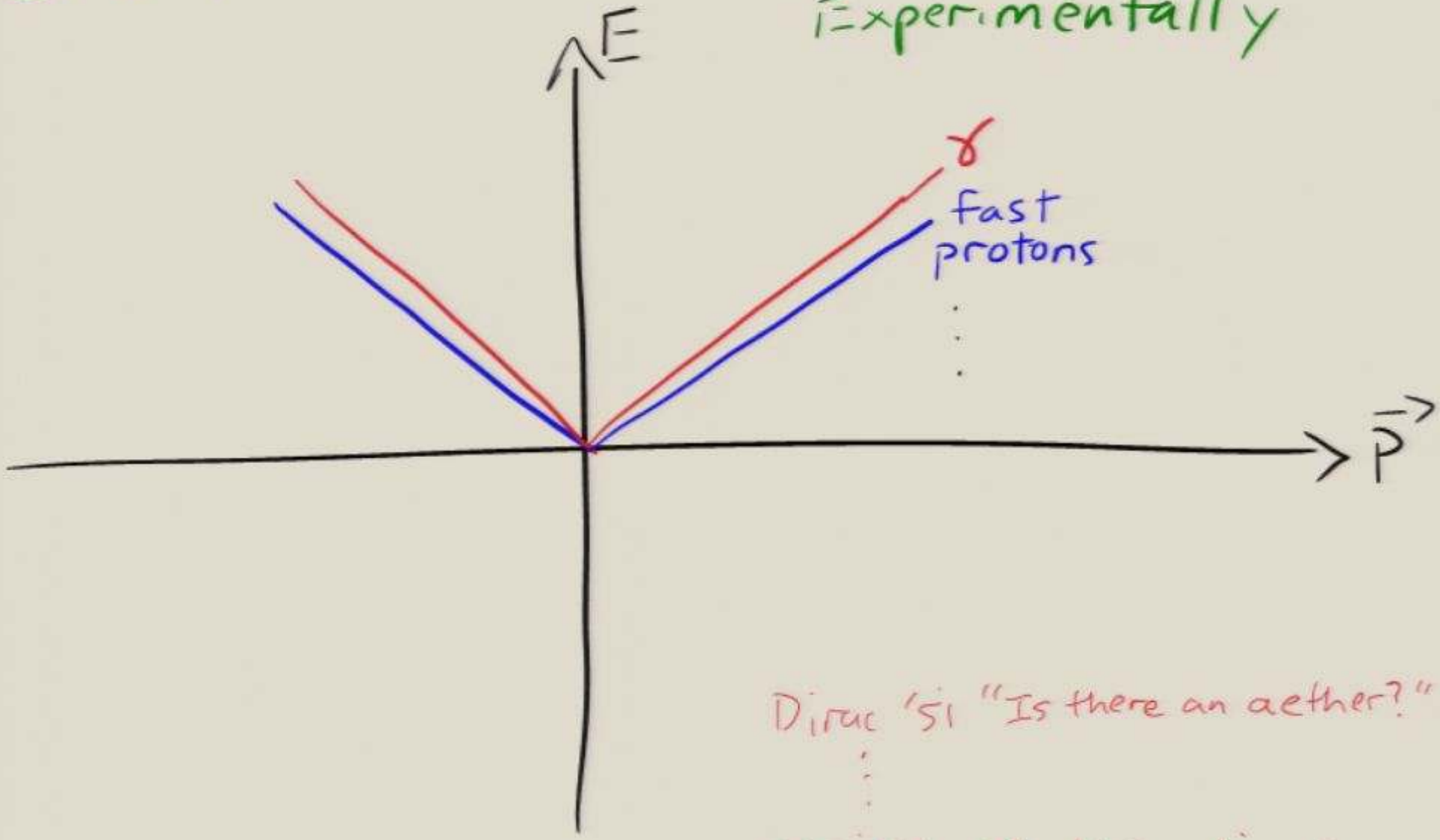

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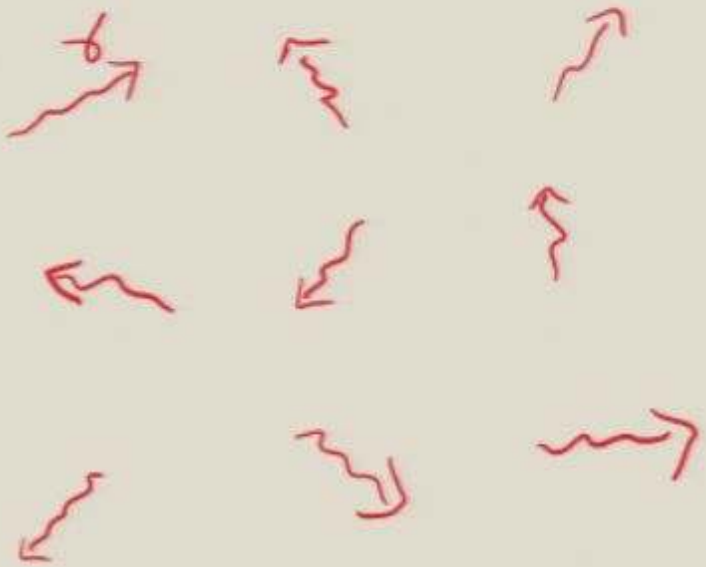
GRAVITATIONAL ~~LORENTZ~~

Precedent for local Lorentz violation:



Cosmic Microwave Background

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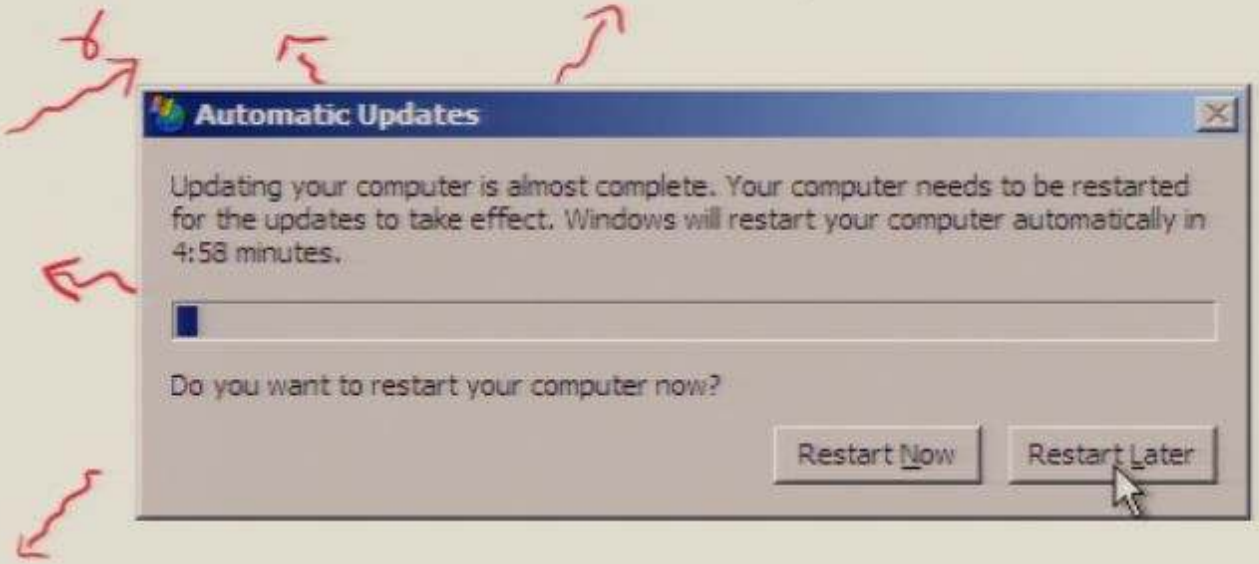

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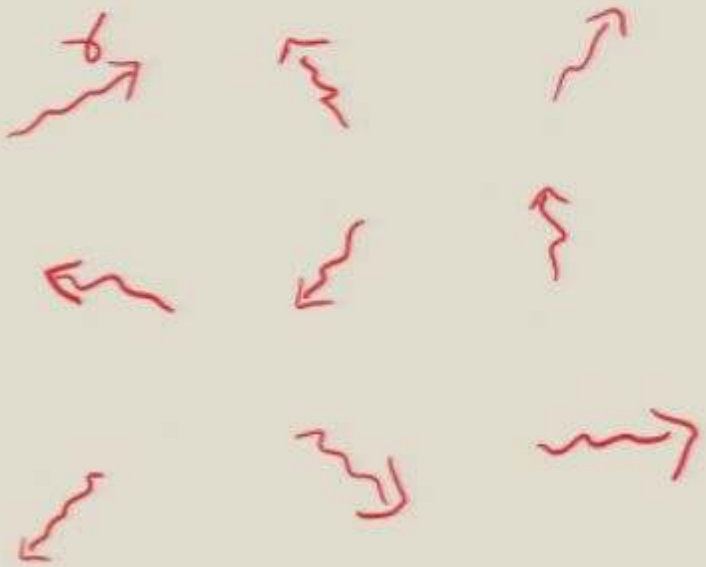


Cosmic Microwave Background

GRAVITATION-L ~~LORENTZ~~

Precedent for local Lorentz violation:

. . .

. . .

. . .

Cosmic Microwave Background

"trivially" gives a preferred coordinate system, breaking general coordinate invariance

OTHER DIRECTION . . .

IF there is a preferred frame,

DYNAMICAL SPACETIME ⇒ DYNAMICAL FRAME

⇒ some type of dynamical AETHER

Jacobson, Mattingly '01

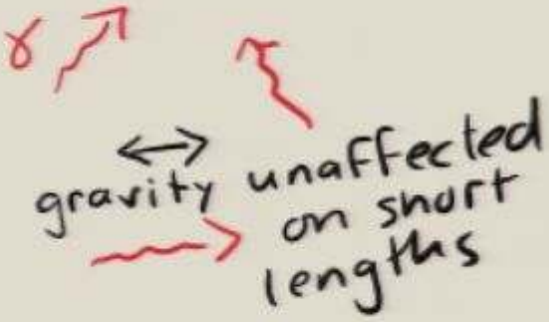
Revolutionary if part of spacetime Fabric :

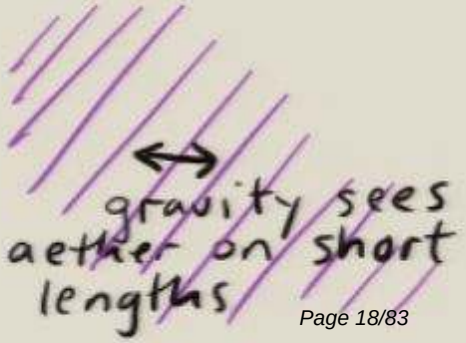
Superluminality or spatial non-locality without acausality, as on lattice

neighbour interactions

↑ ↓ ↑ ↑ ↓ ↑ ↓ ↓ . . .

Can affect gravity at arbitrarily short distance



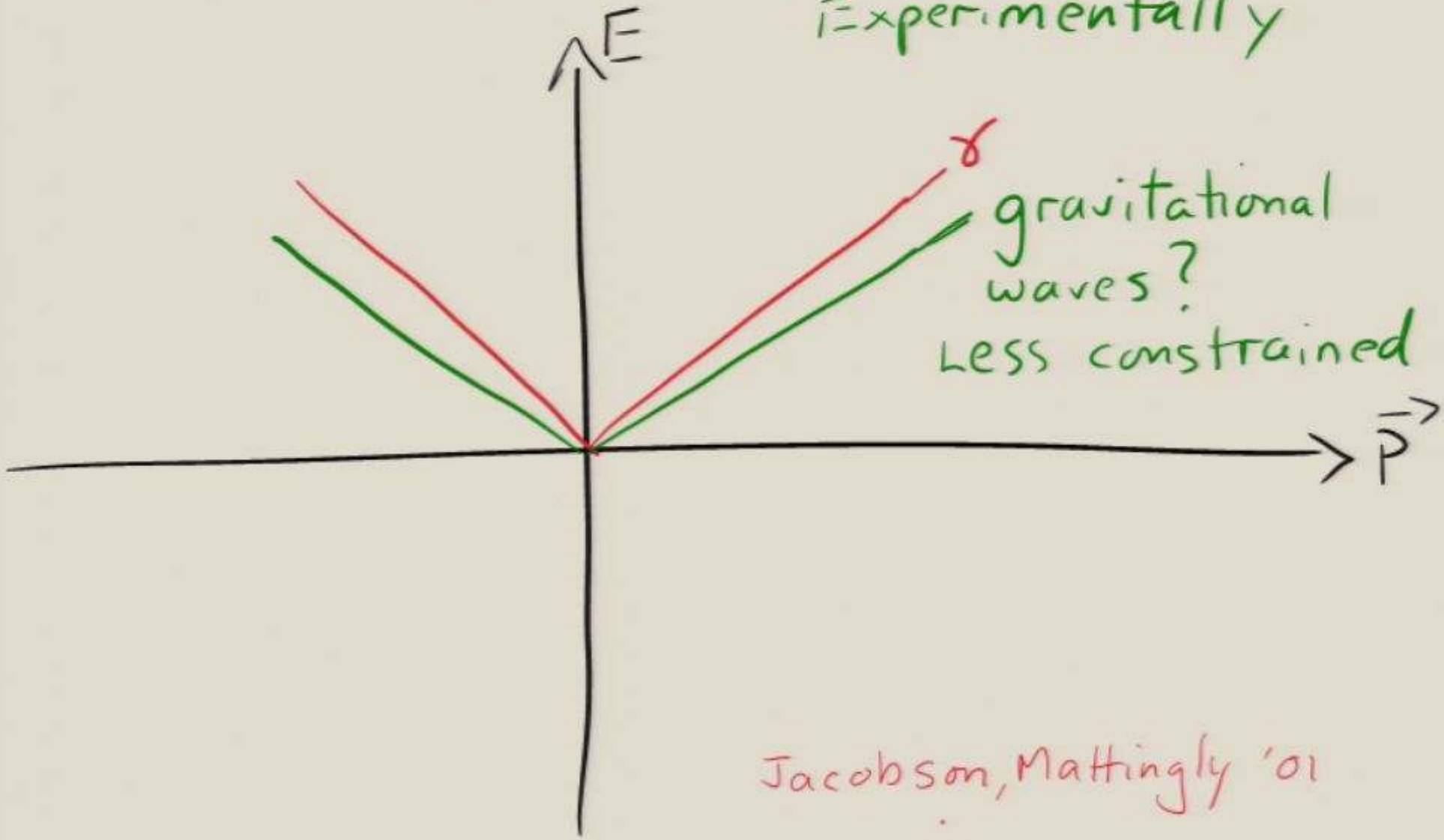


CMBR

AETHER

LESS TIGHTLY CONSTRAINED

Experimentally



Jacobson, Mattingly '01

⋮

~~LORENTZ~~ ⇒ NEGATIVE E ?

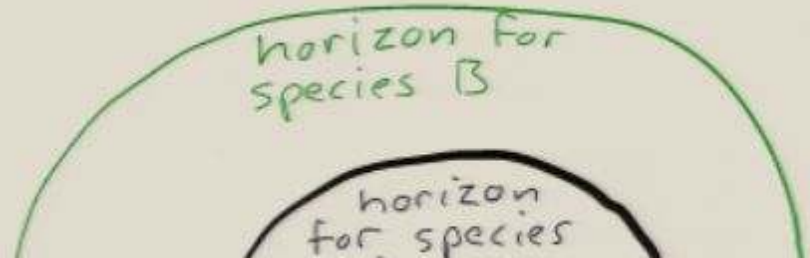
CMB ANALOG:

CMB hole would have E<0 relative to uniform CMB

~~Lorentz~~ aethers exhibit "pathologies" with similar flavor, near black holes:

DubovsKy, Sibiryakov '06

Eling, Foster, Jacobson, Wall '07

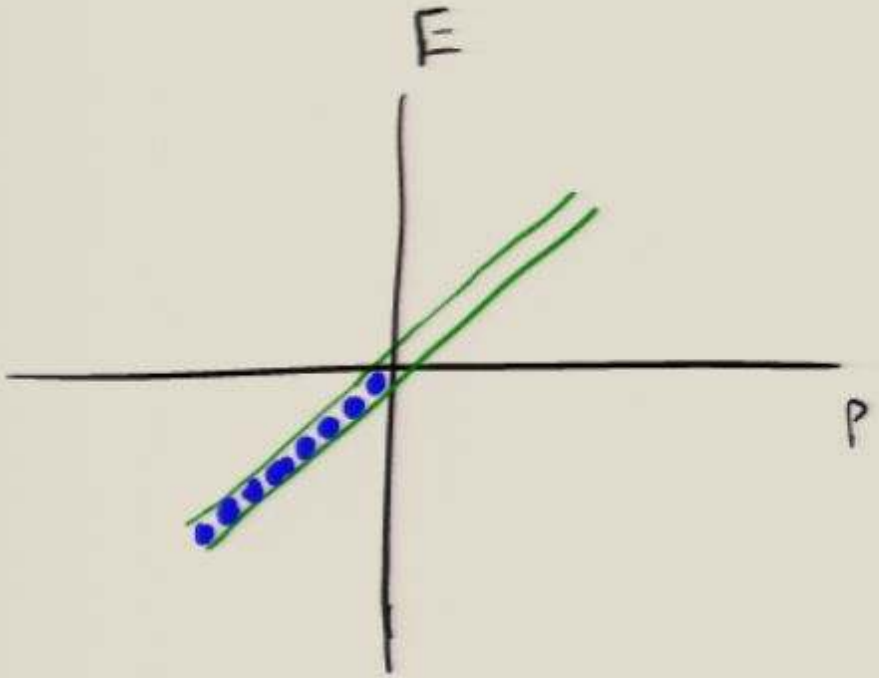


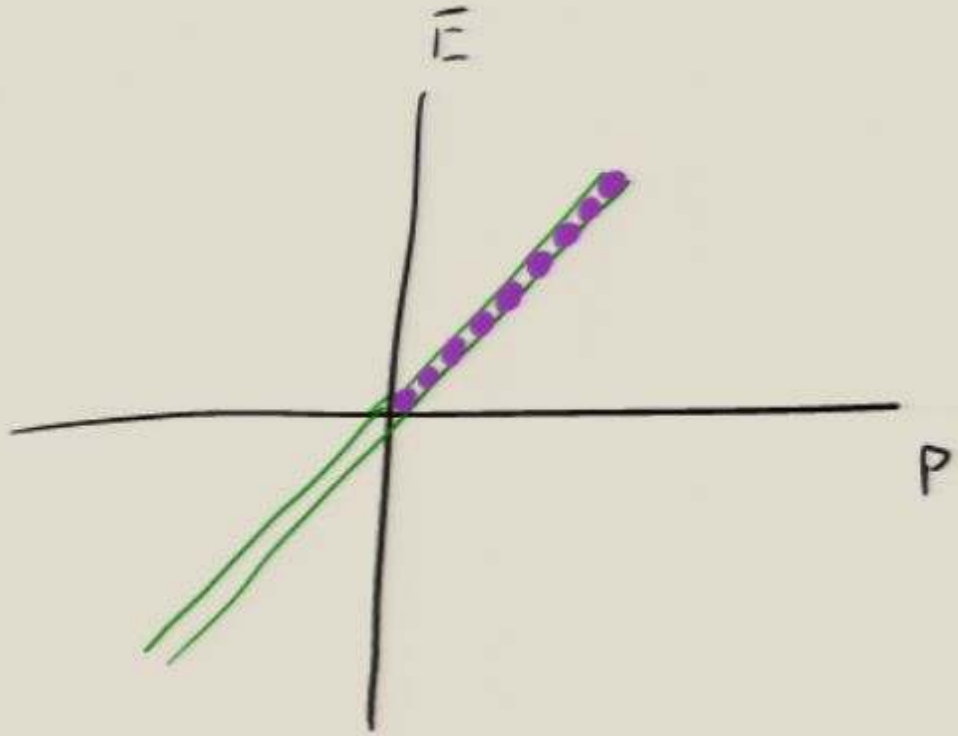
$C_A > C_B$

$T_A > T_B$

despite $\mp$

NEGATIVE ENERGIES ⇒ LORENTZ





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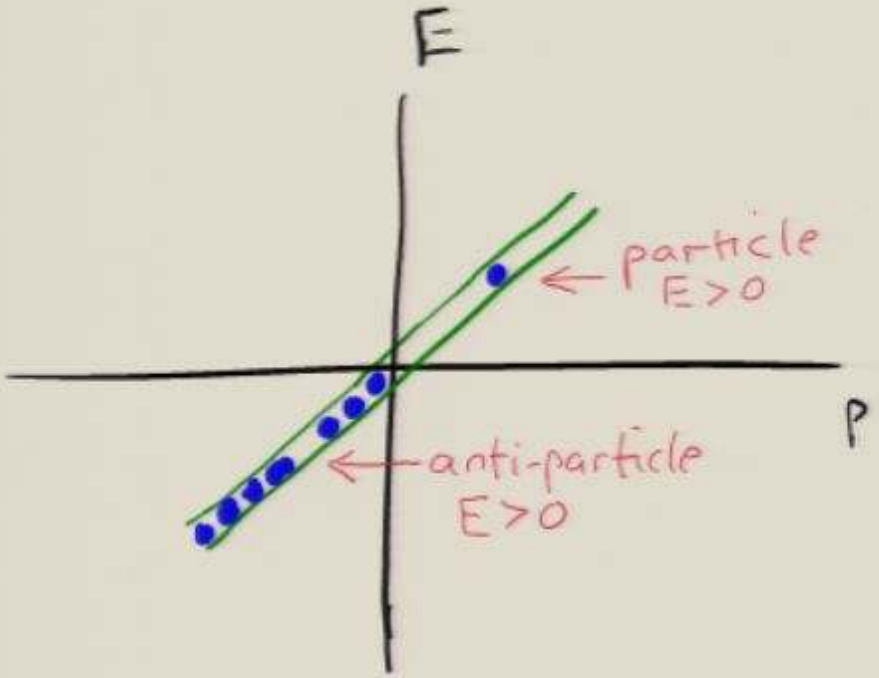

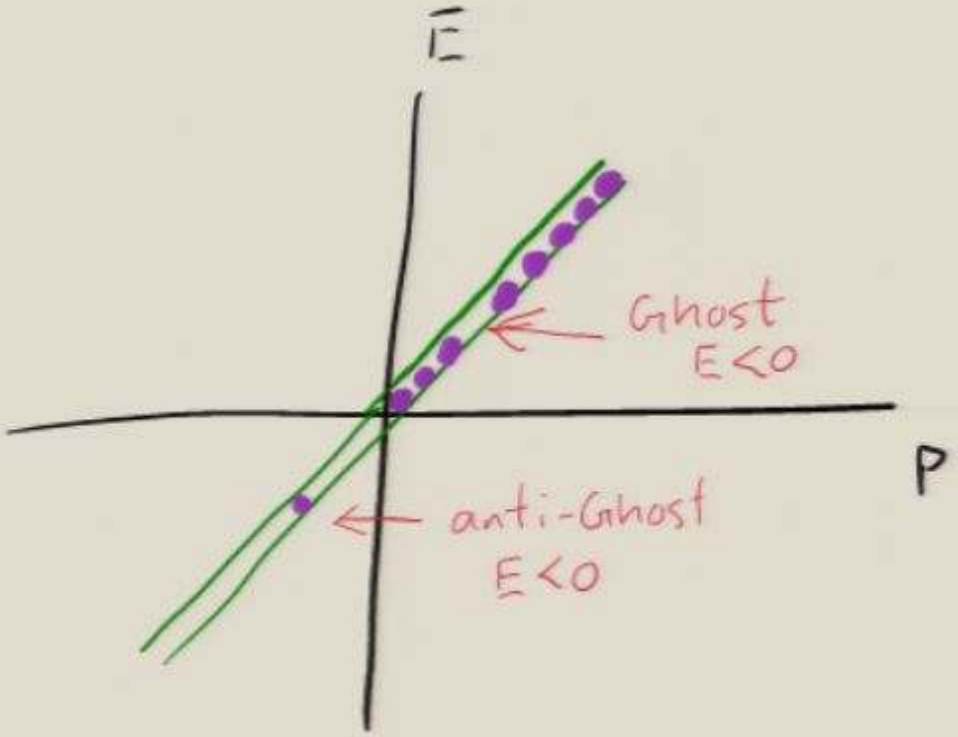

$$\frac{1}{\tau_{10\rangle}} = \int d\,\text{boost} = \infty, \quad \tau_{10\rangle} = 0$$

Lorentz invariance

Caroll, Hoffman, Trodden '03
Cline, Jeon, Moore '04

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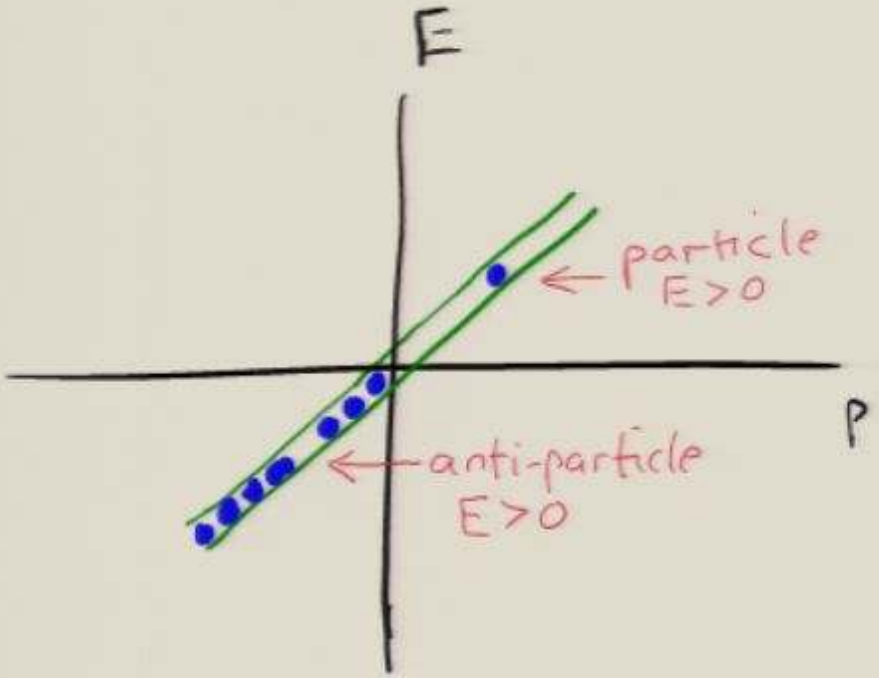

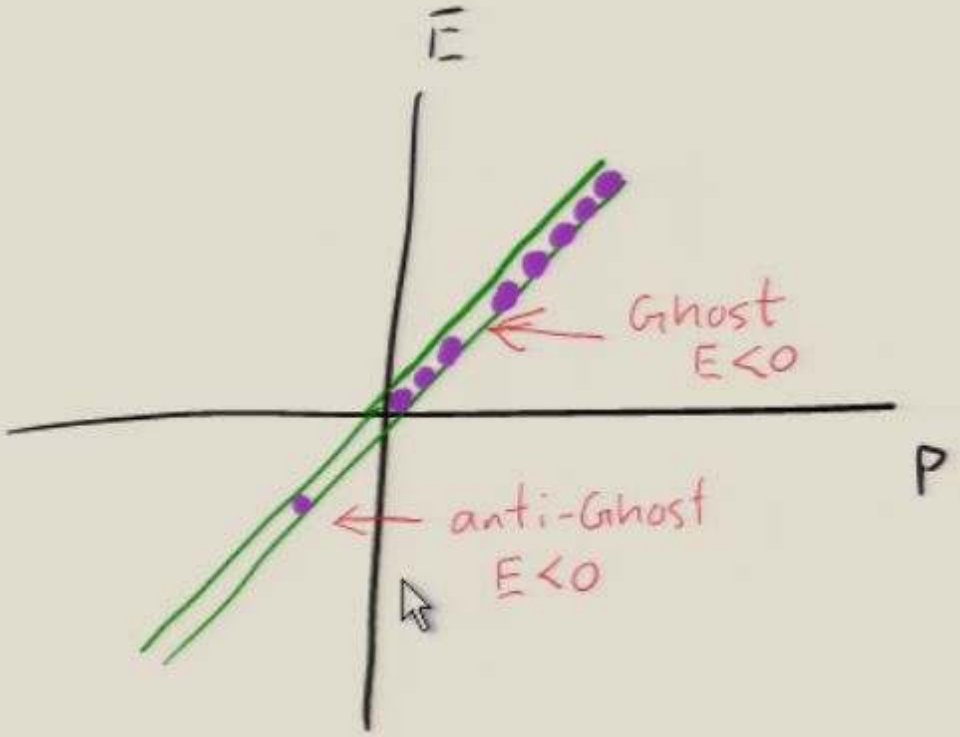

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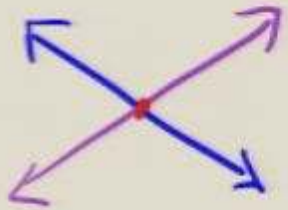

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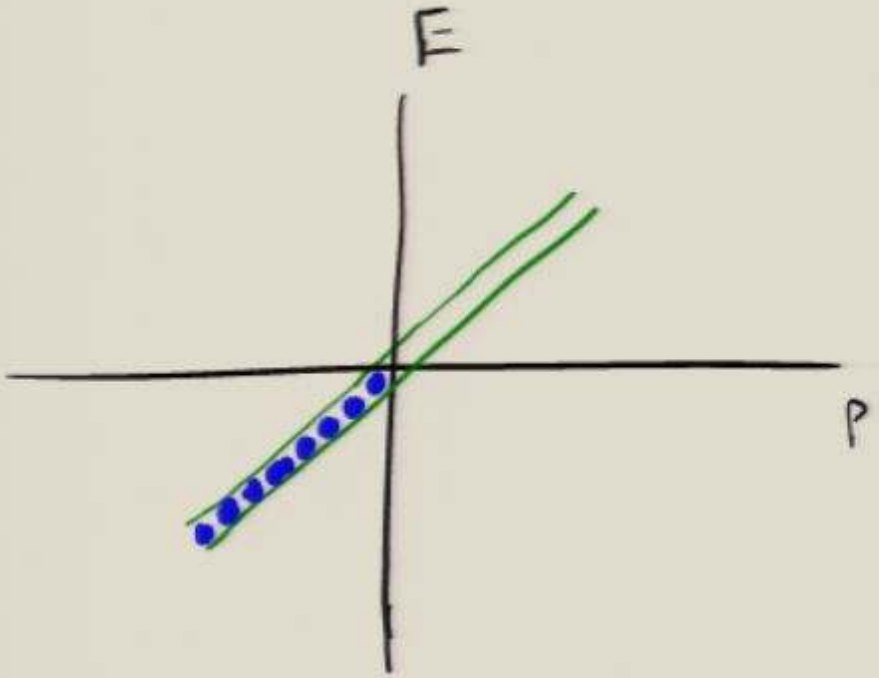

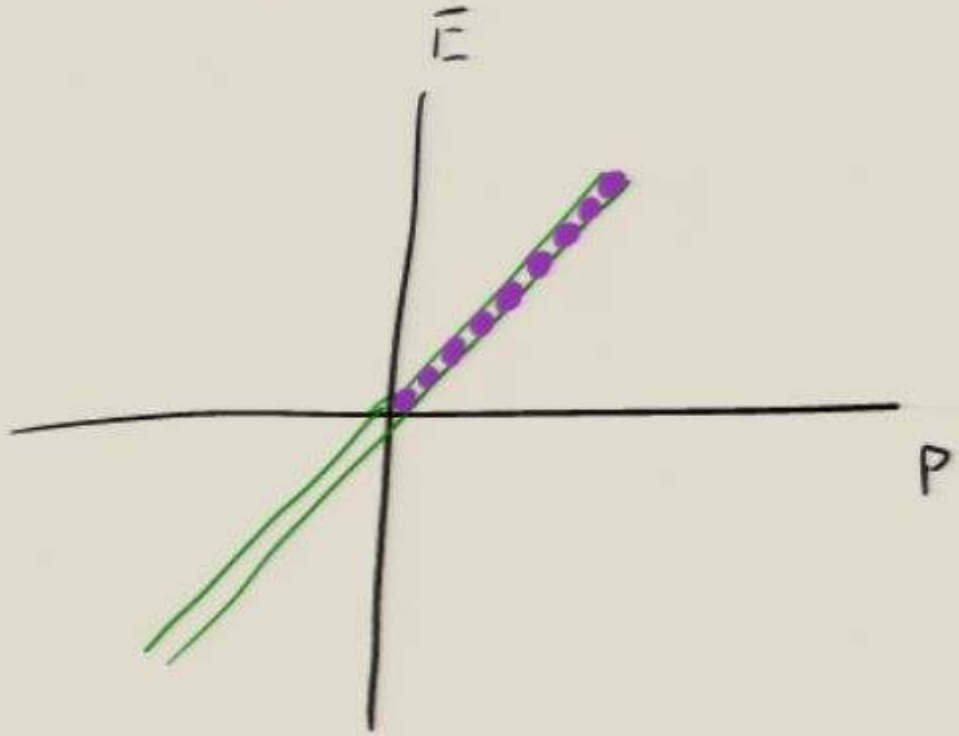

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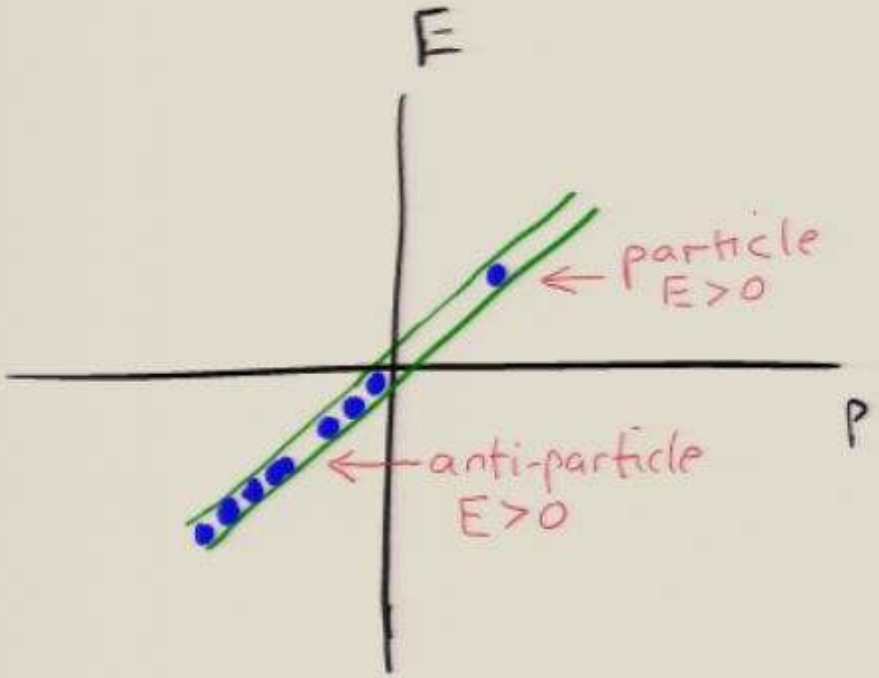

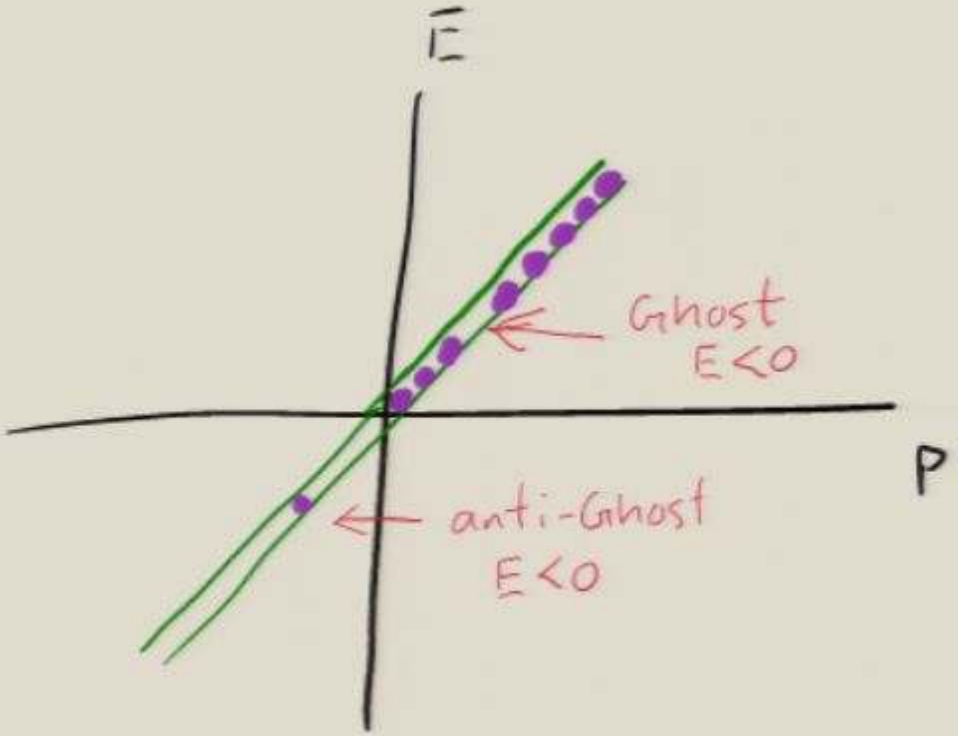

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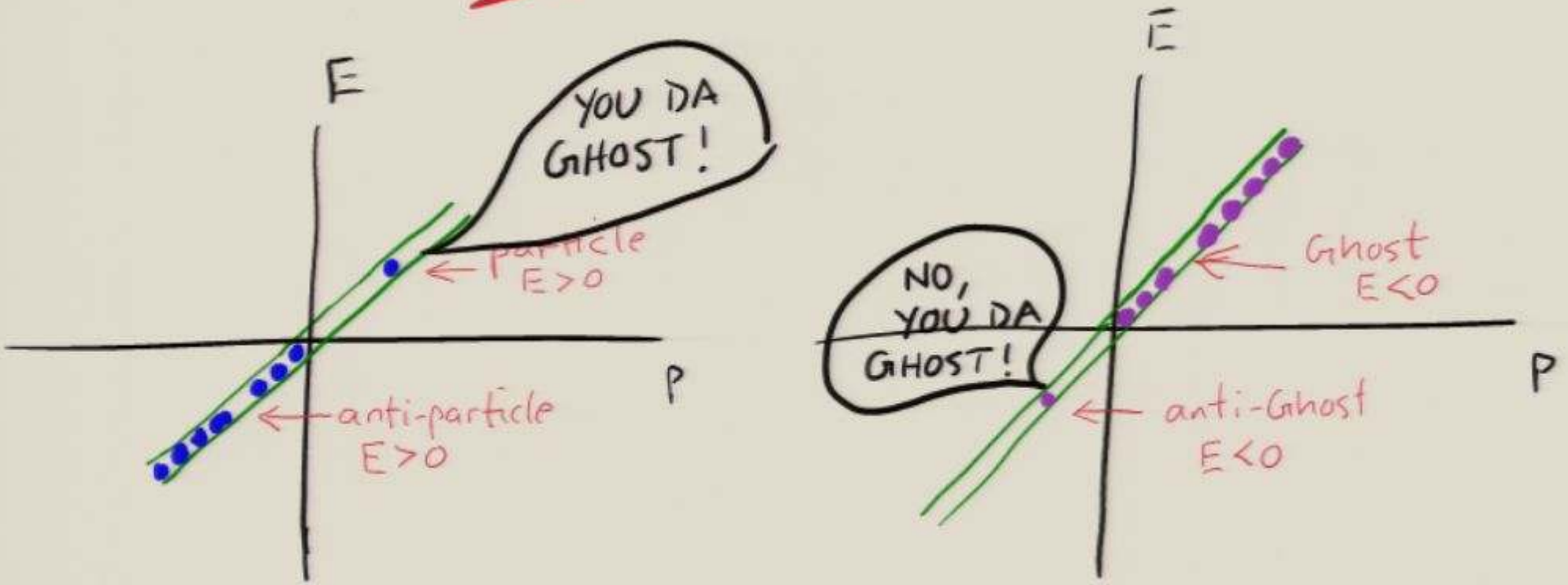


"Ghost" is a relative word.

GHOSTS IN FIELD THEORY

Classically,

$$\mathcal{L} = \sqrt{-g}\left\{ M_{Pl}^2 R - \rho + \mathcal{L}_{matter}(\Psi, D_\mu) - \mathcal{L}_{matter}(\hat{\Psi}, D_\mu) \right\}$$

Ghosts

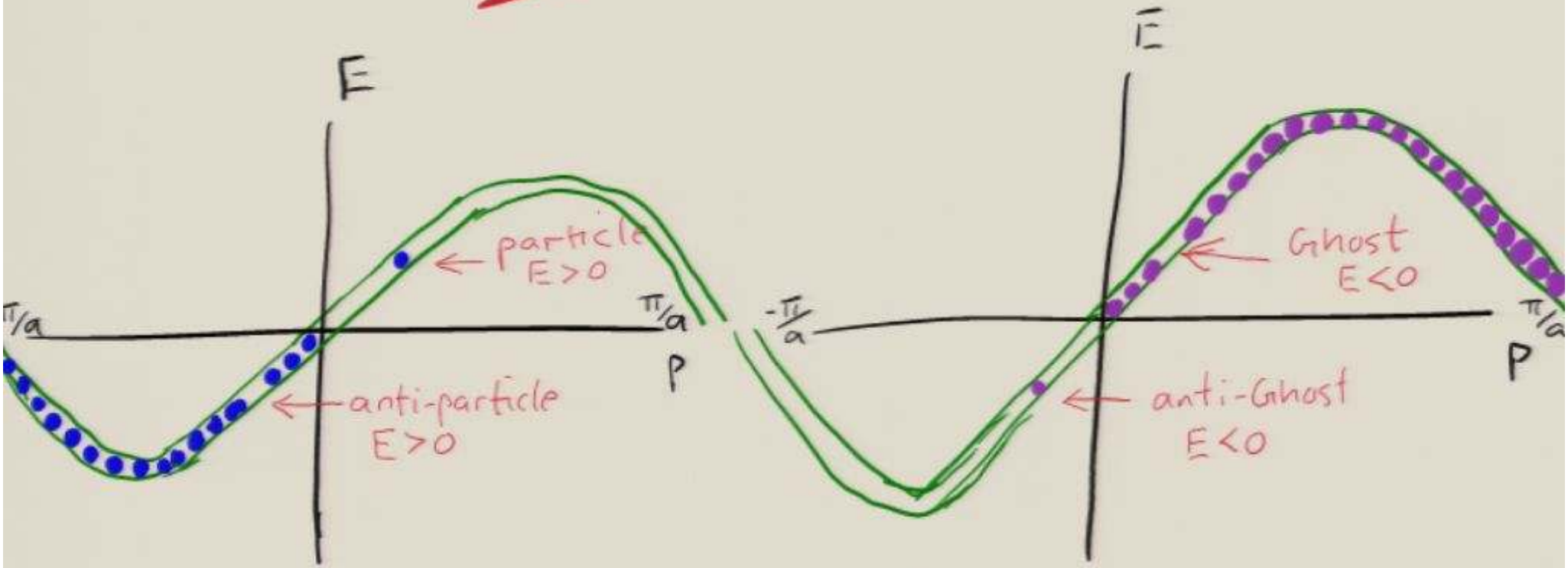
as proposed by Linde '84

Perturbative Quantization:

Non-Ghosts $\quad \dfrac{i}{p^2 - m^2 + i\varepsilon}$

Ghosts $\quad \dfrac{-i}{p^2 - m^2 - i\varepsilon}$ $\quad (i \to -i)$

NEGATIVE ENERGIES ⇒ ~~LORENTZ~~



"Minkowski vacuum" is an excited state . . .

Spin Chain analog:
Sundrum ?

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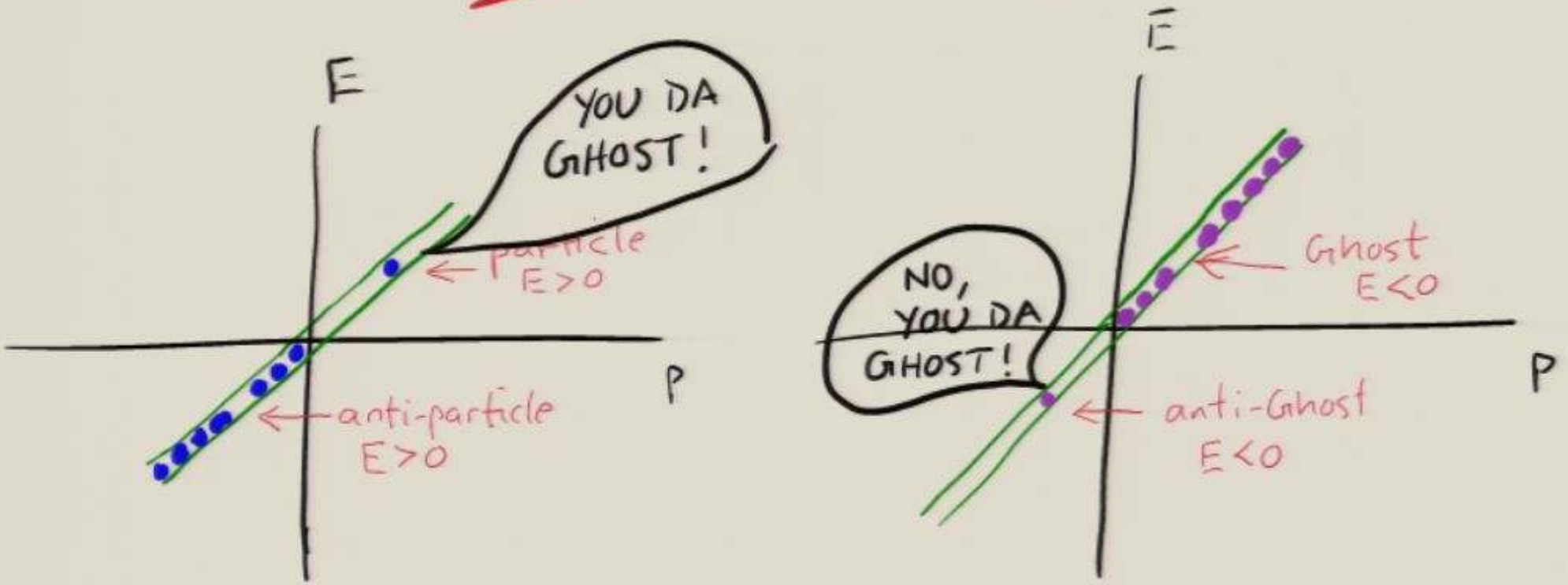

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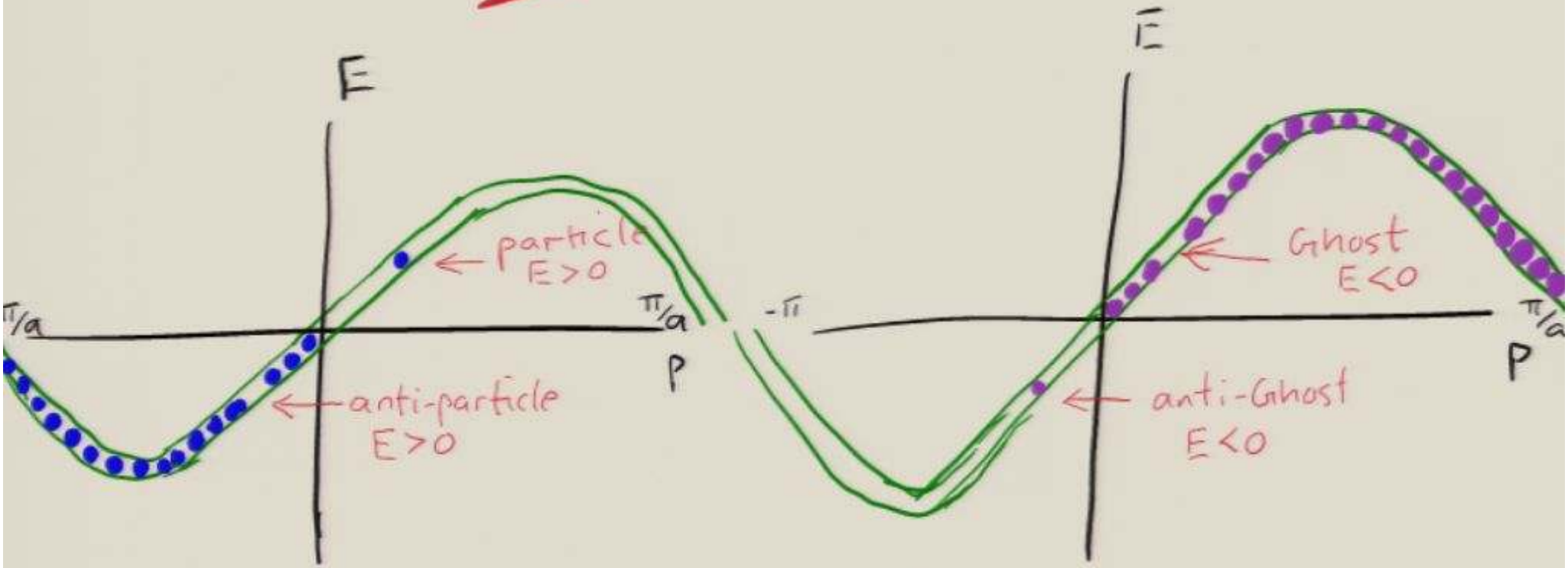

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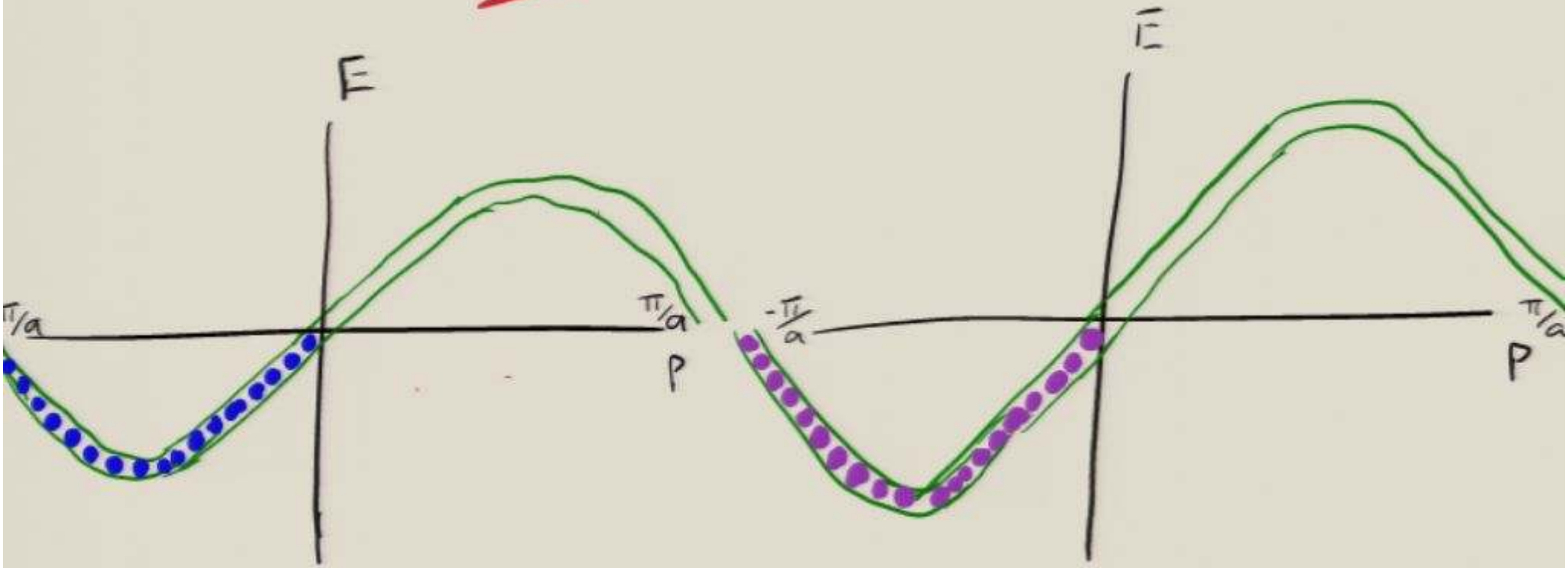
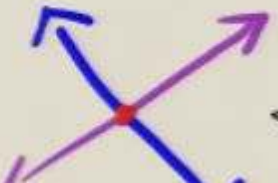


"Minkowski vacuum" is an excited state . . .

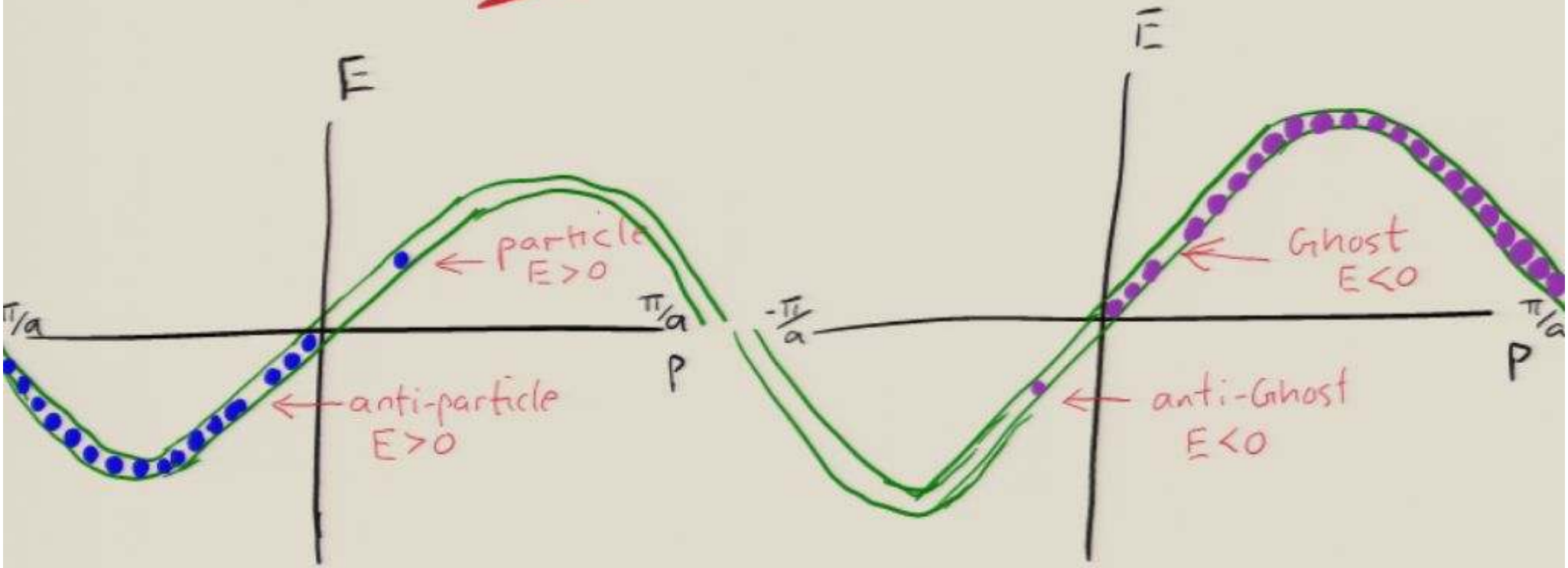
of a non-relativistic true $|0\rangle$.

$$\frac{1}{\int_{|p|<\pi/a} d\,\text{boost}} \sim \text{Lorentz} \quad < \infty$$



Carroll, Hoffman ≒ Trodden '03; Cline, Jean, Moore

NEGATIVE ENERGIES ⇒ LORENTZ



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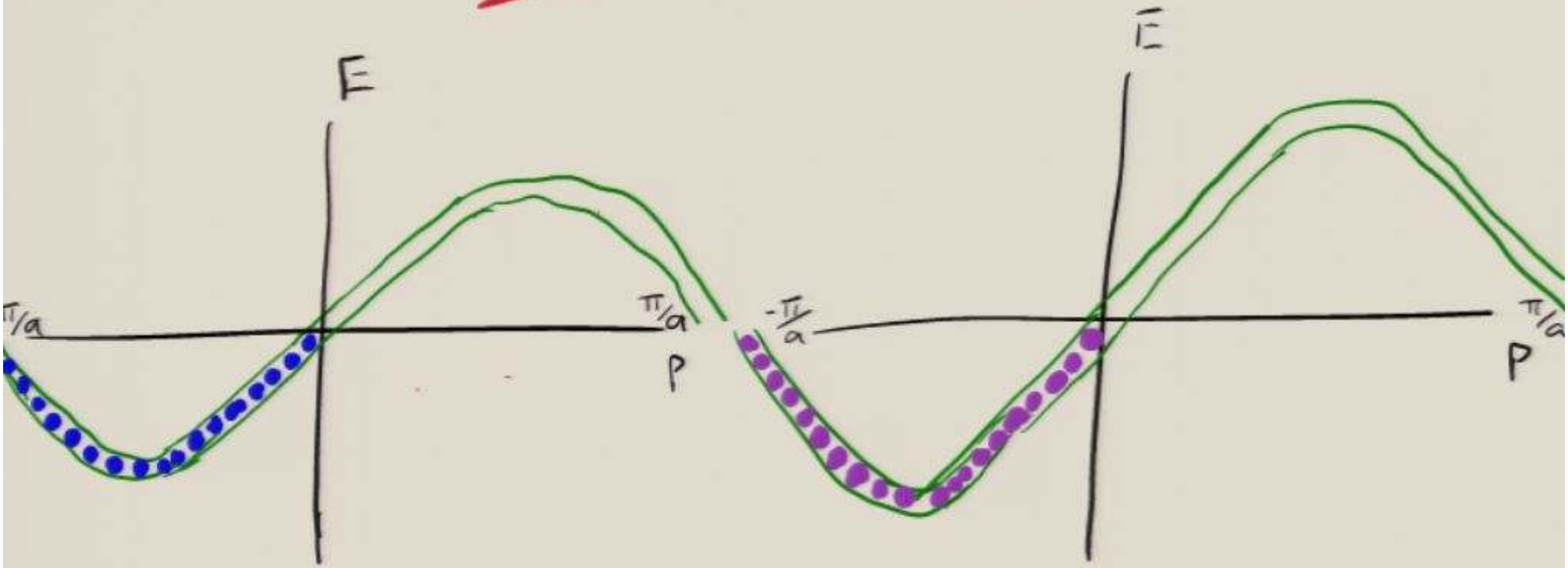

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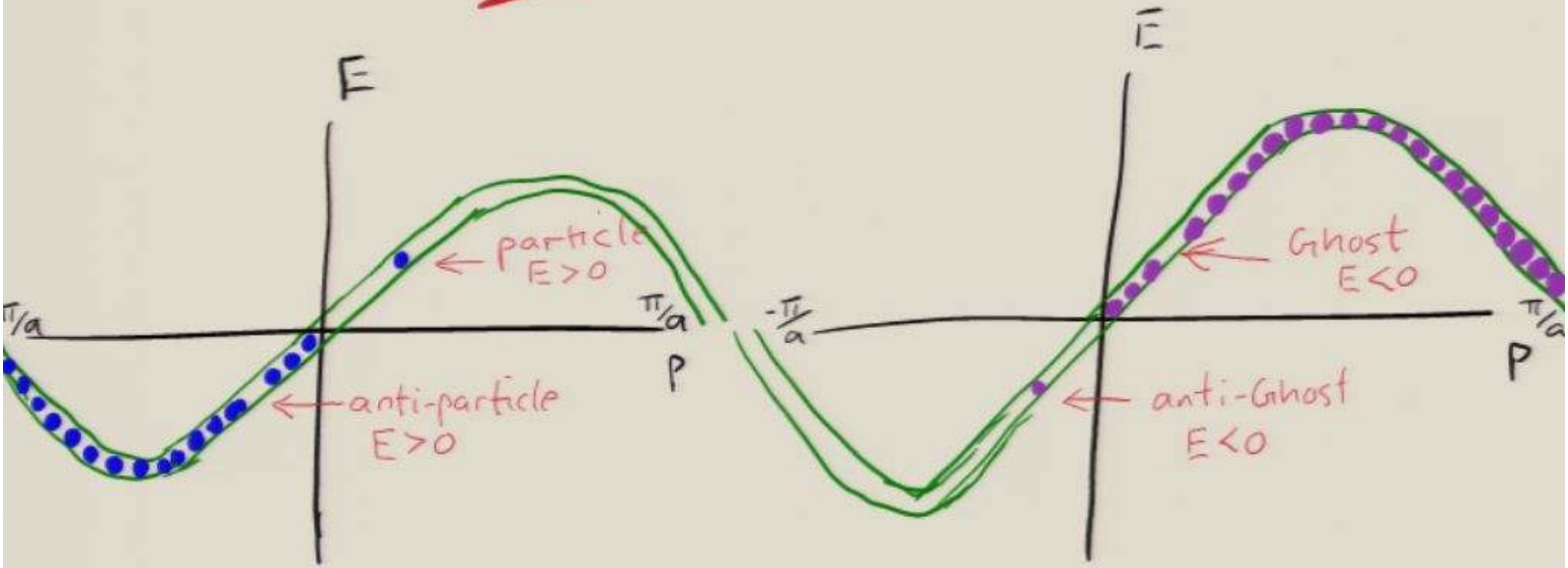
Carroll, Hoffman & Trodden '03; Cline, Jeon, Moore

NEGATIVE ENERGIES ⇒ LORENTZ



"Minkowski vacuum" is an excited state . . .

Spin Chain analog:
Sundrum ?

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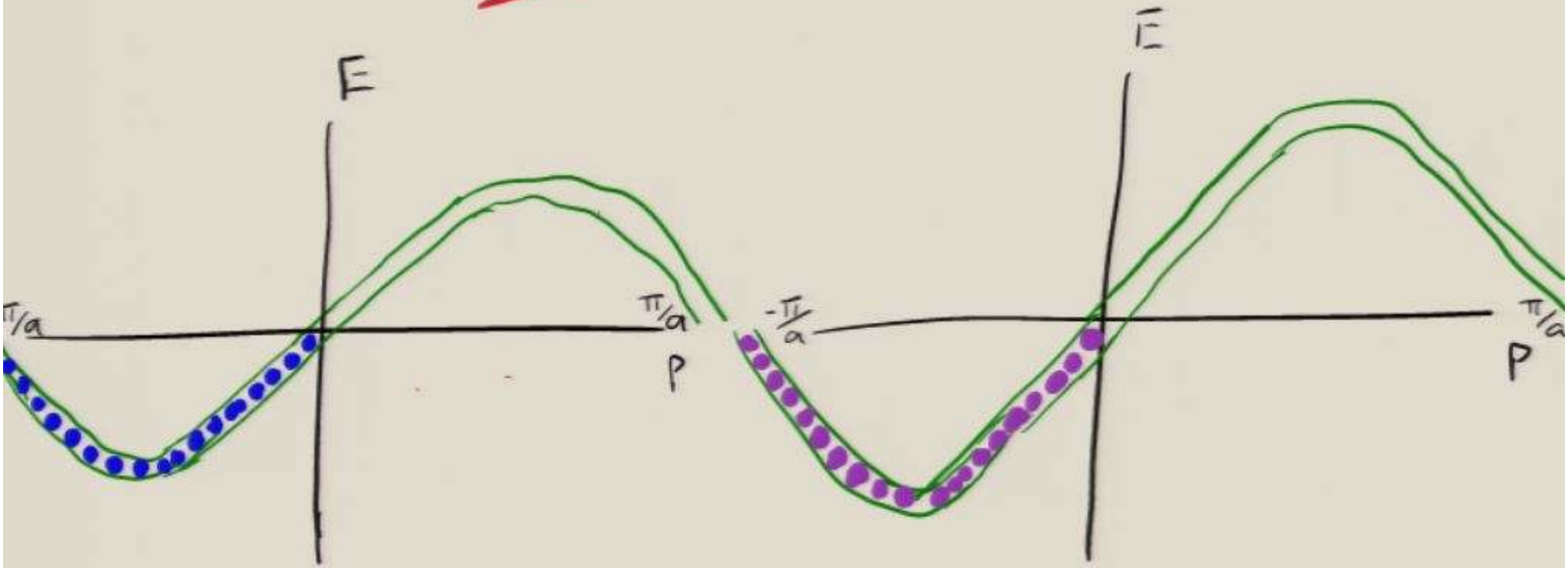

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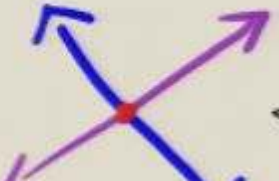

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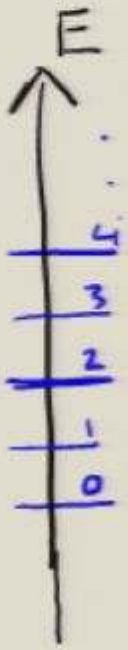
(ANTI-) SYMMETRY FOR $E_{|0\rangle}$

Kaplan, Sundrum '05

→ Dark Energy



Particles of momentum $\vec{p}$

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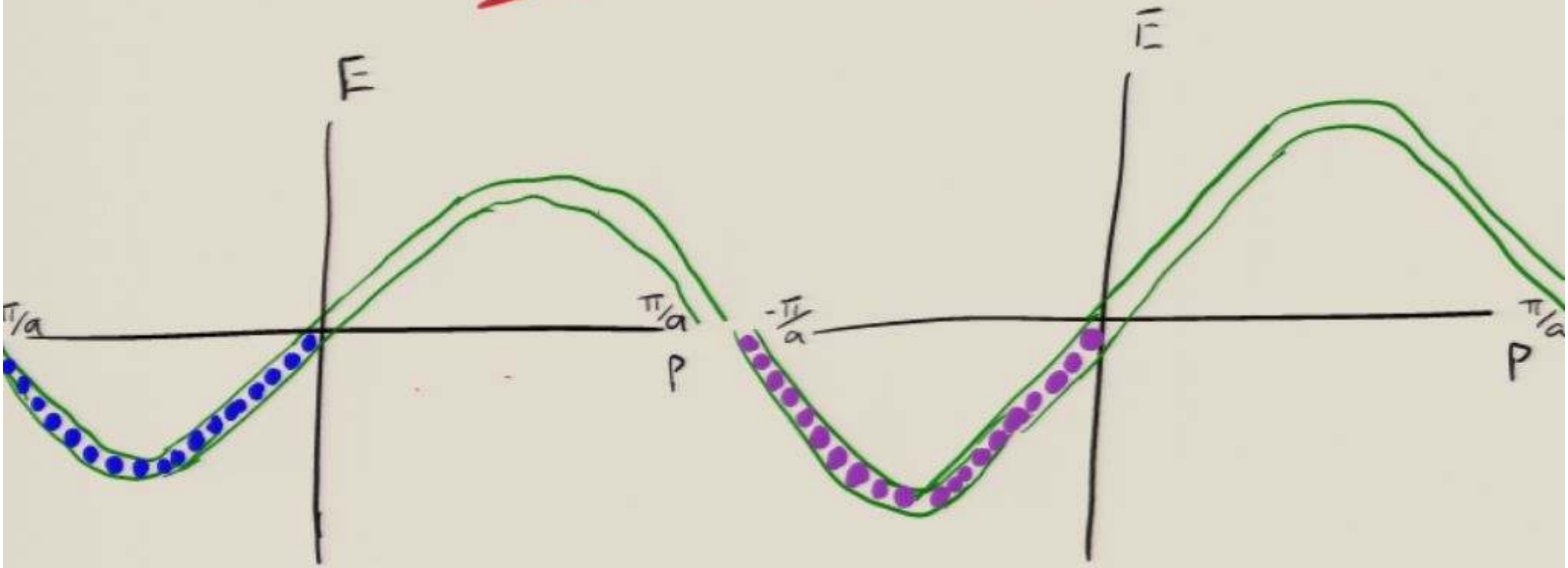

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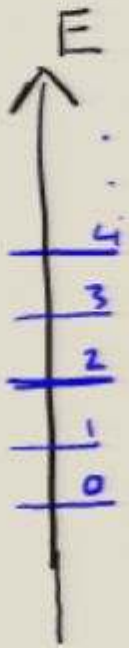

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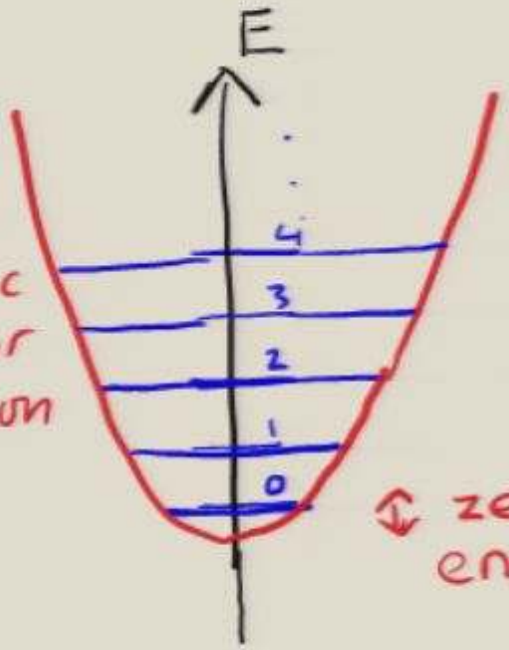

Simple harmonic oscillator description

Particles of momentum $\vec{p}$

↕ zero-point energy

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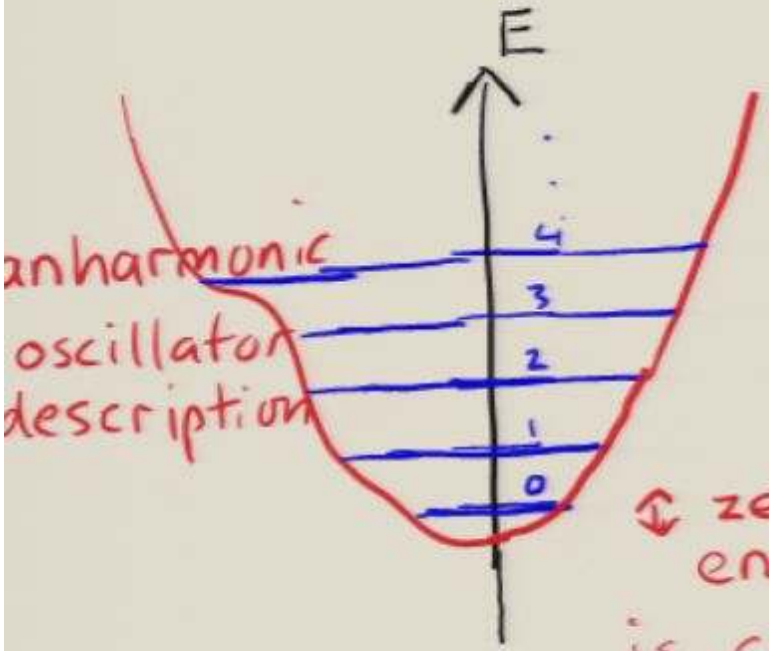

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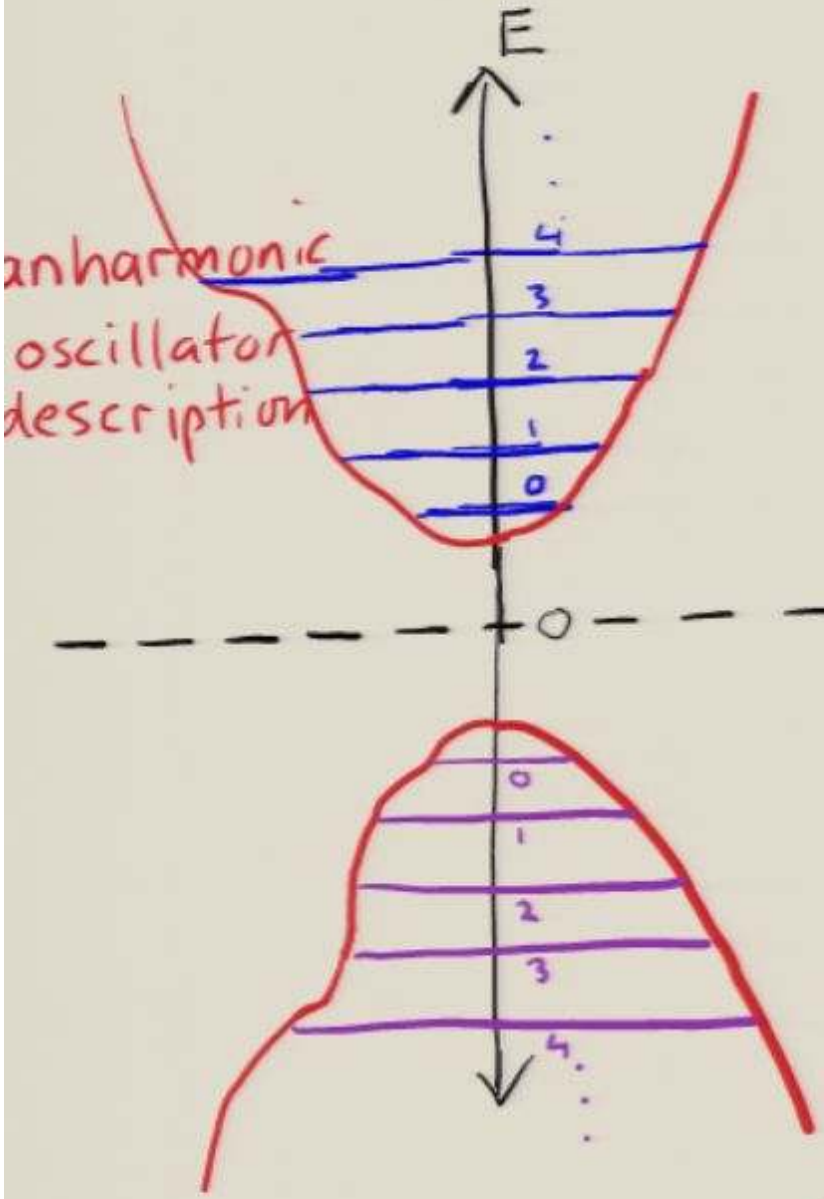

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$\{H, P\} = 0$

$E_{|0\rangle} = E_{|0\rangle} + E_{|0\rangle} = 0$

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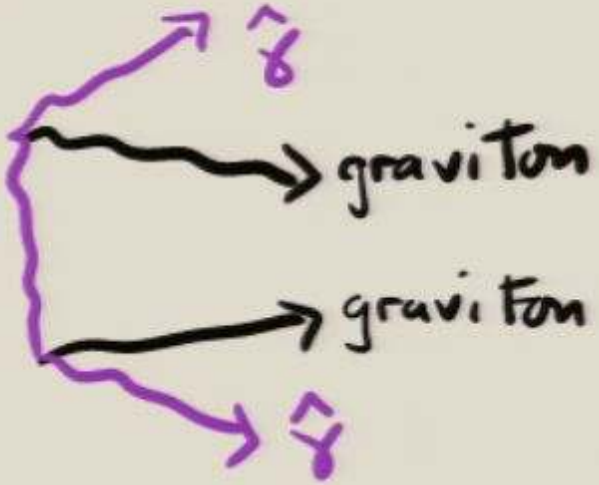
VACUUM DECAY CONSTRAINTS



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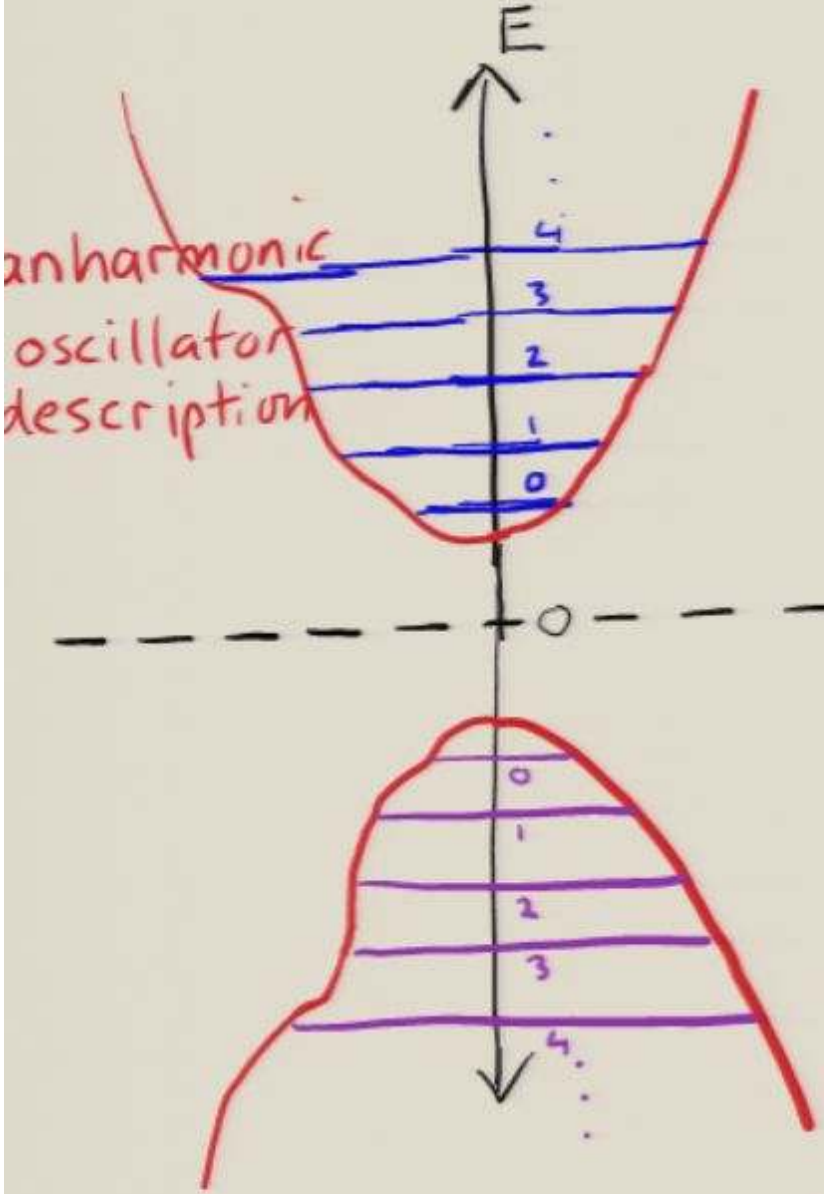

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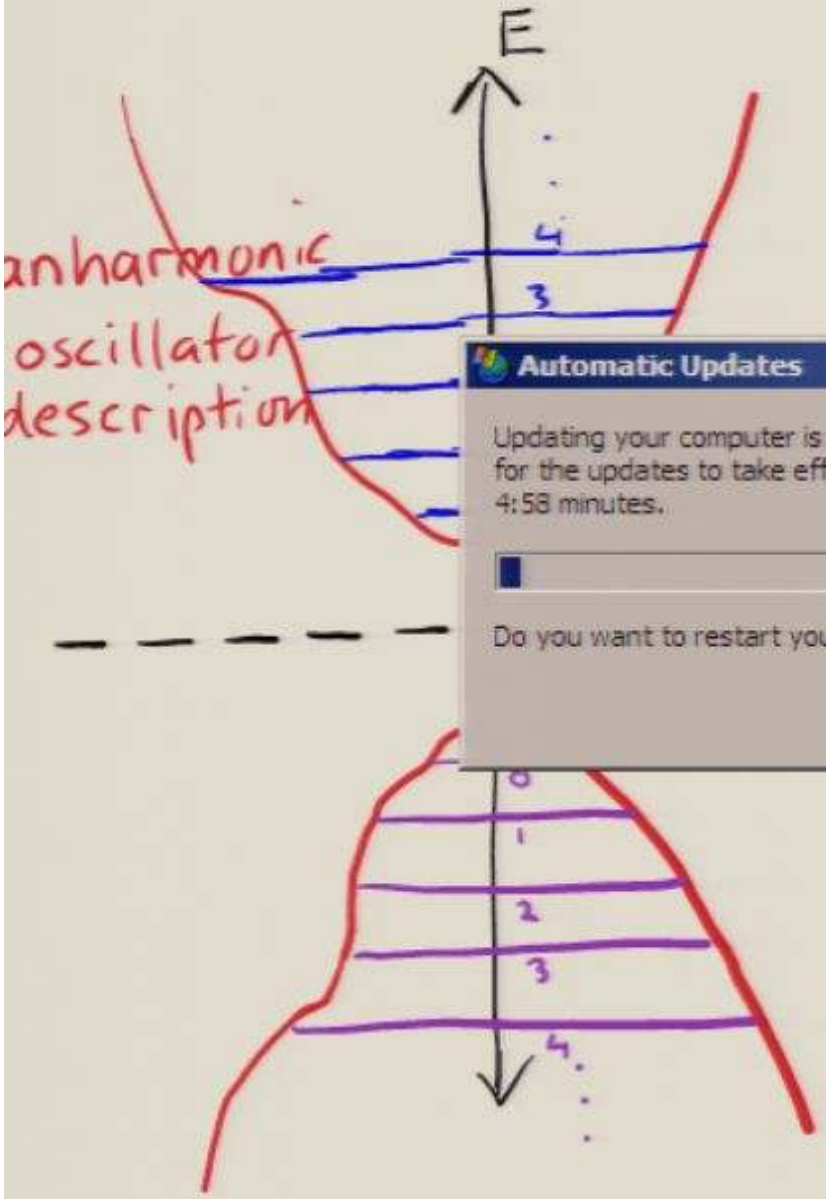

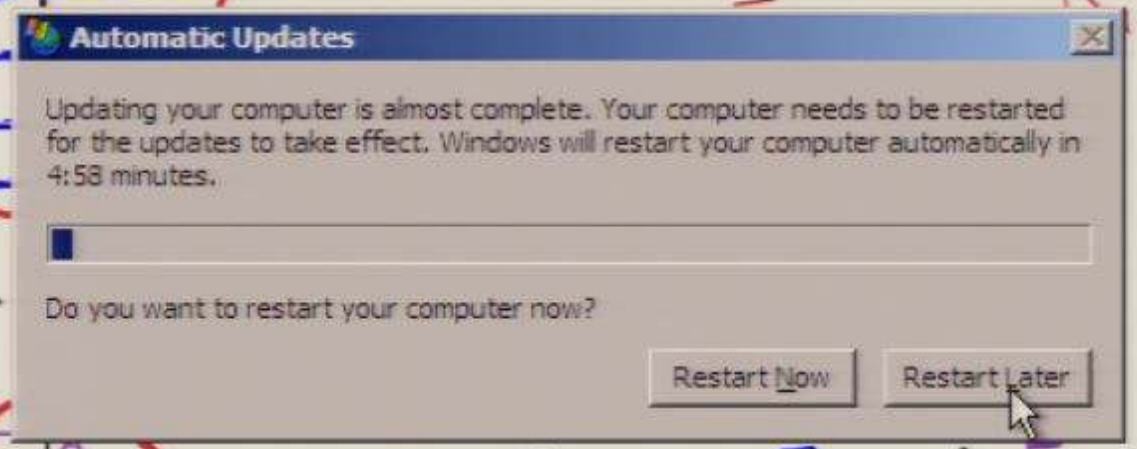

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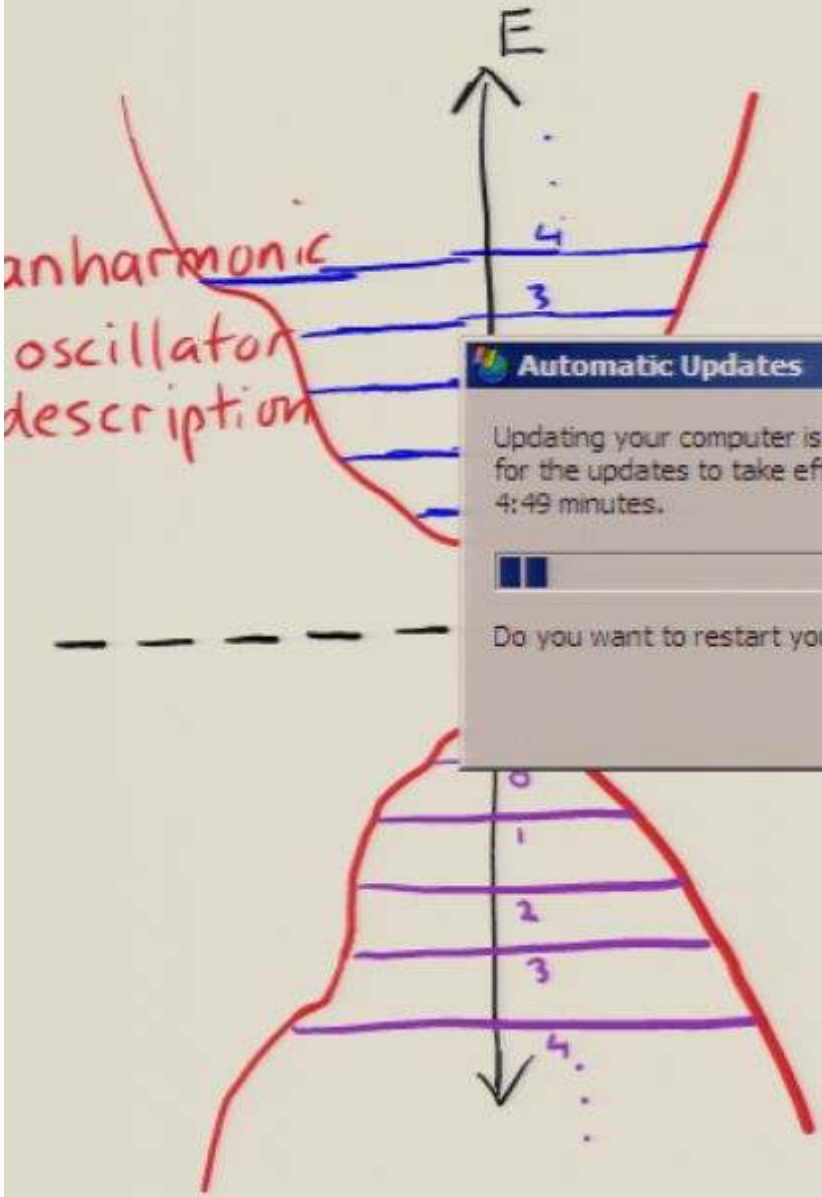

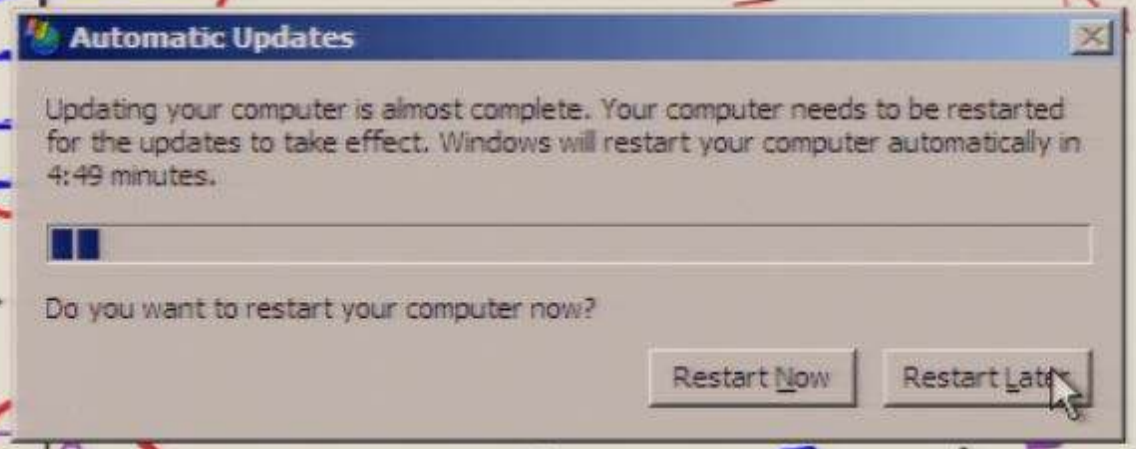

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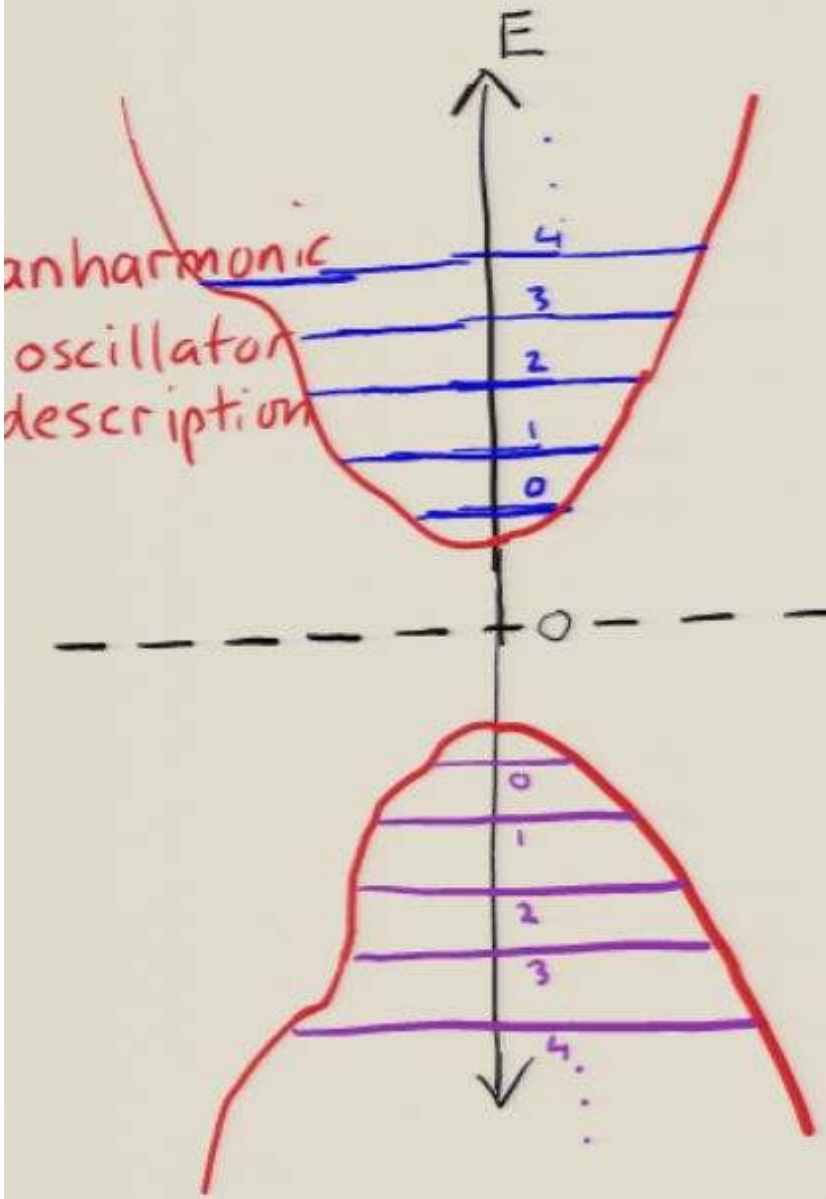

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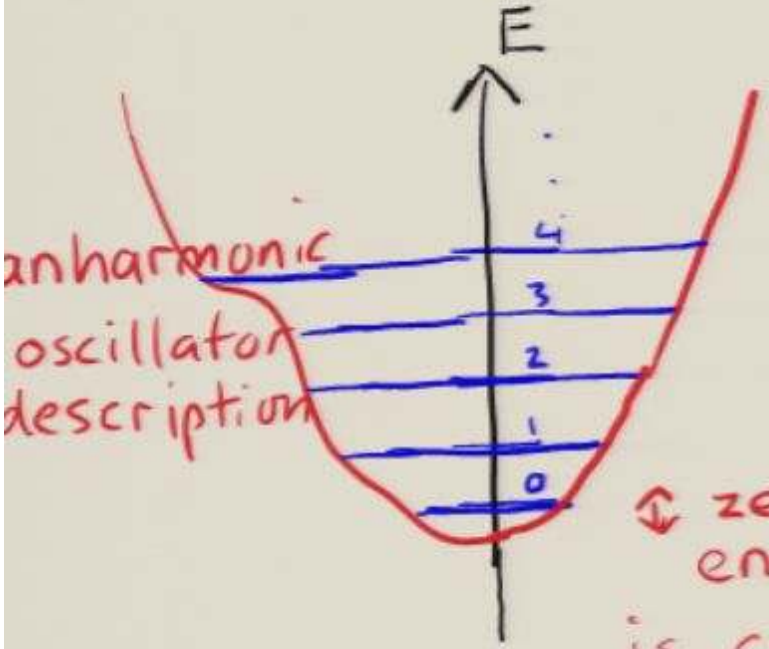

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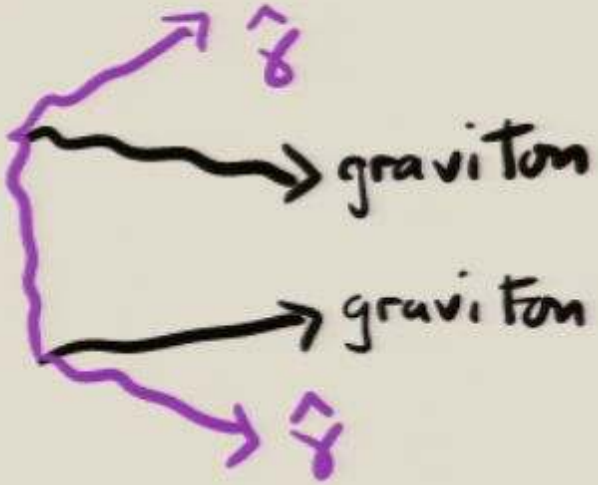

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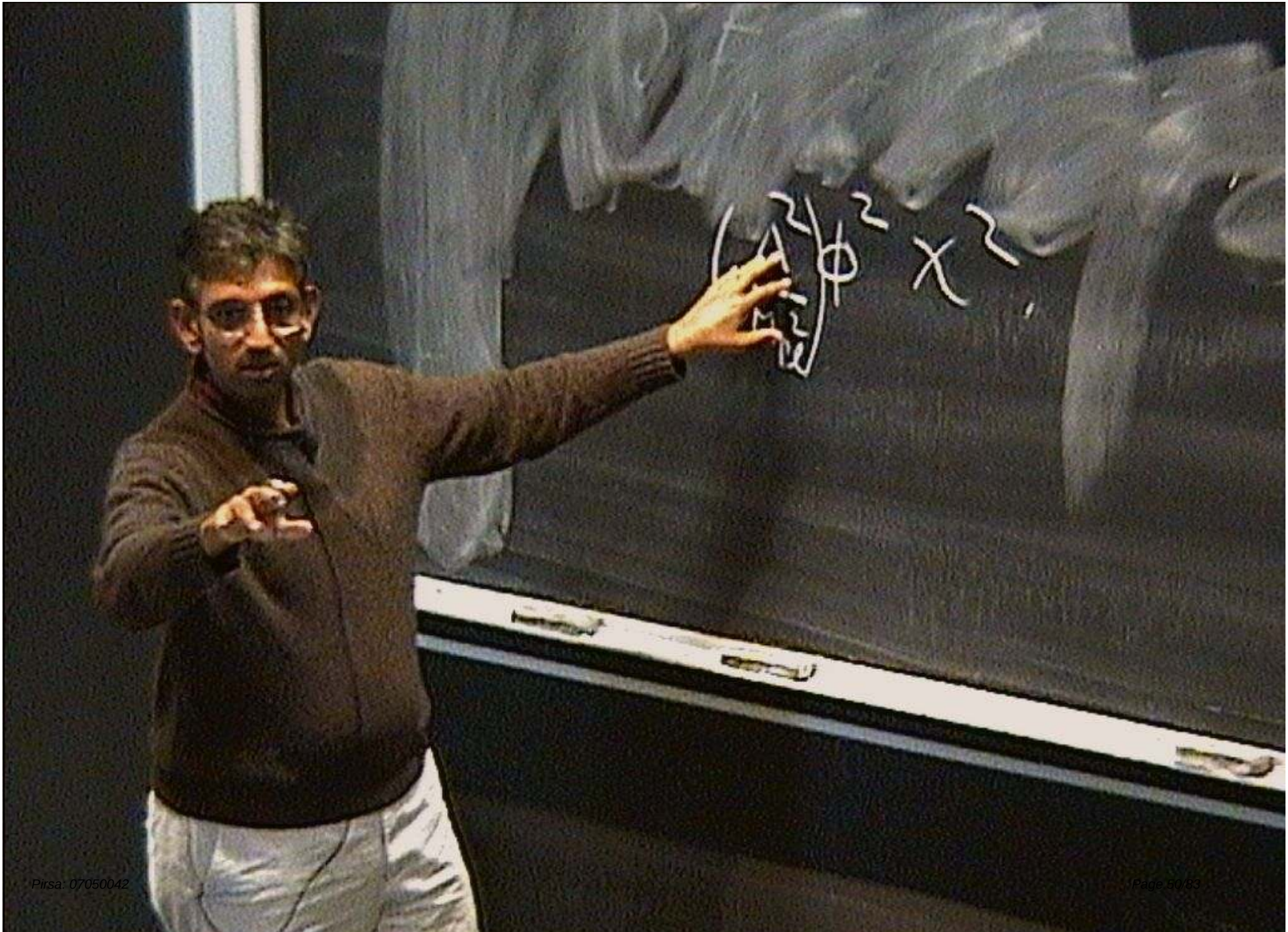
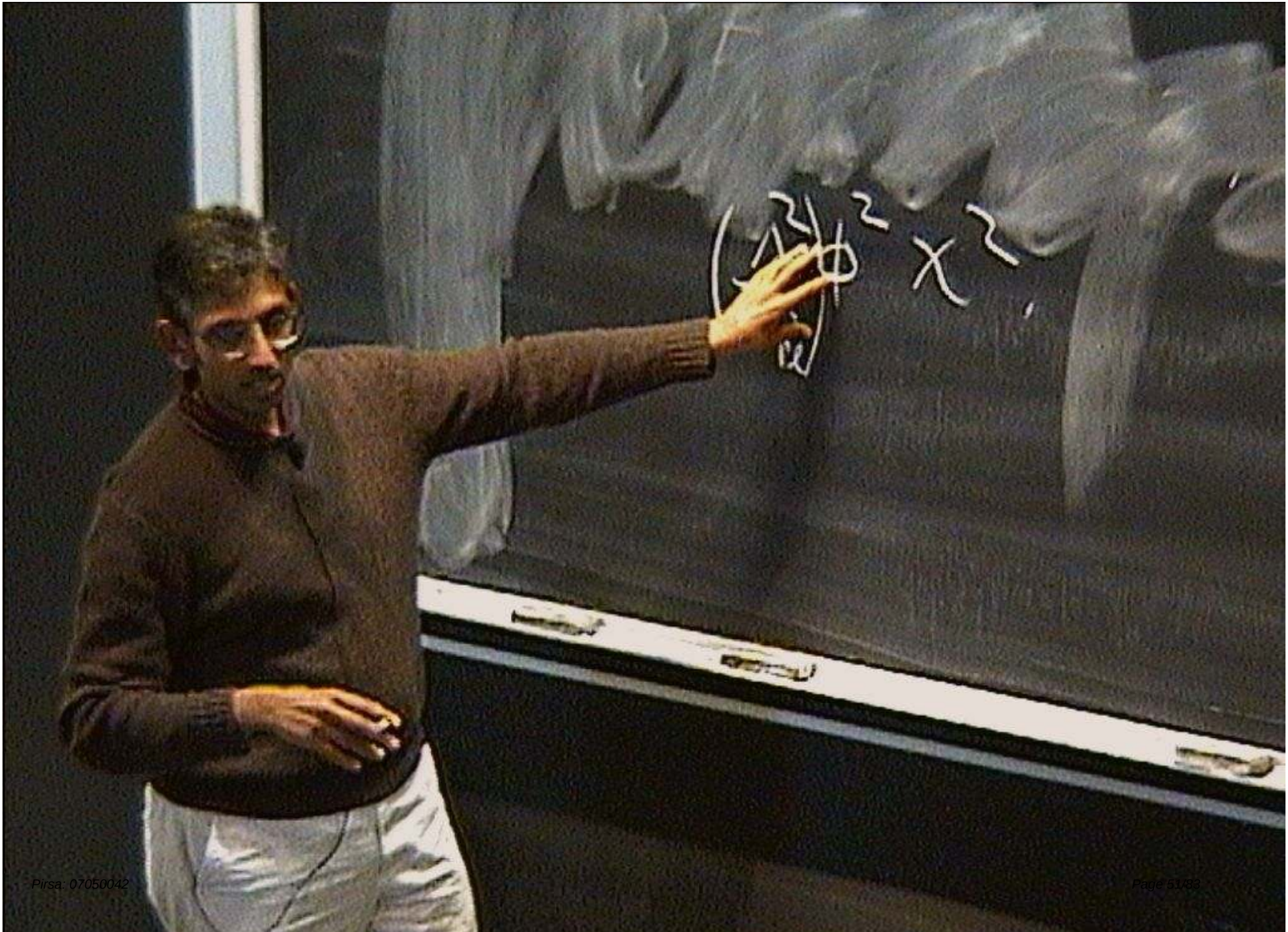
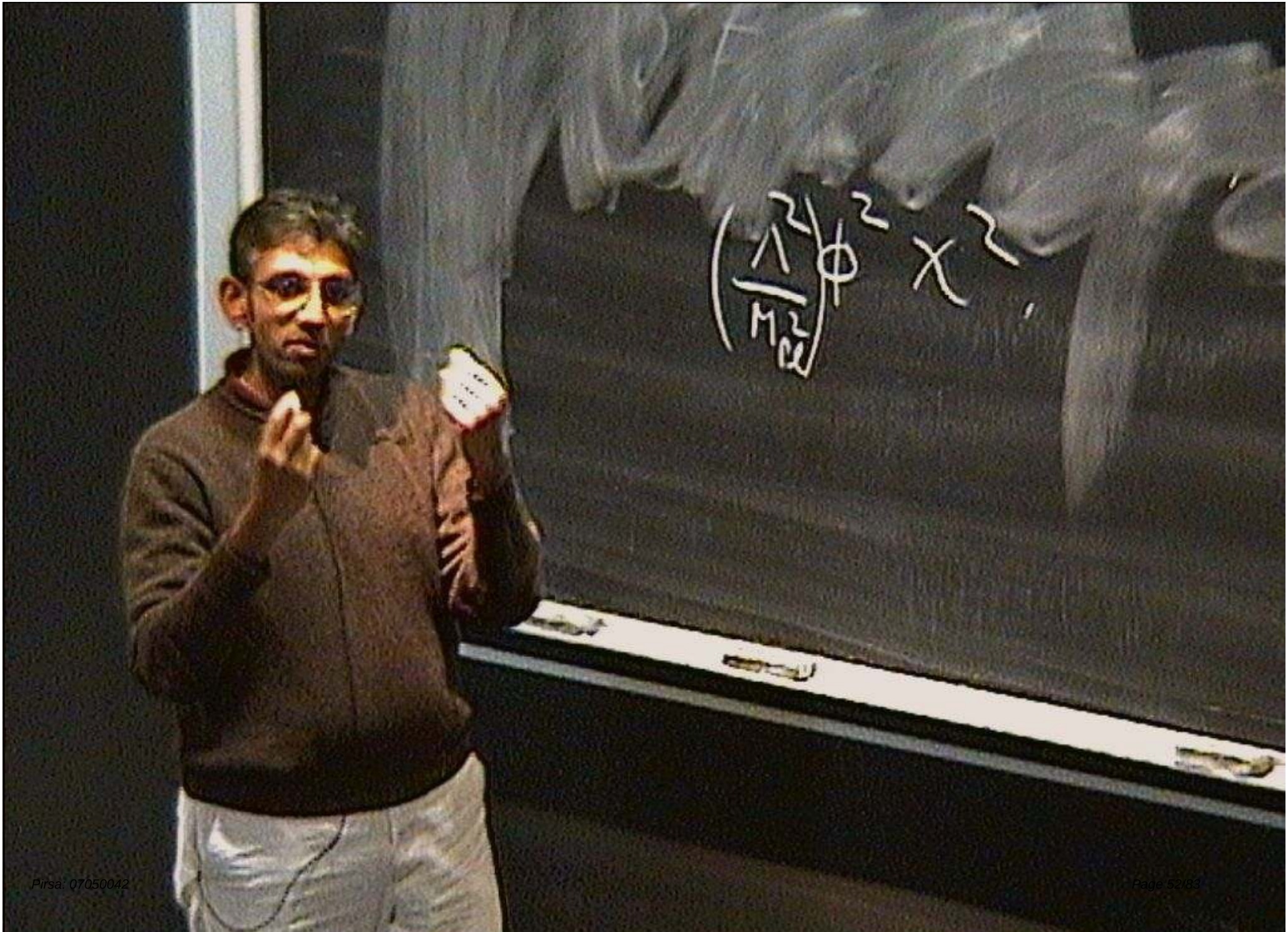

$(A)\phi^2 x^2$

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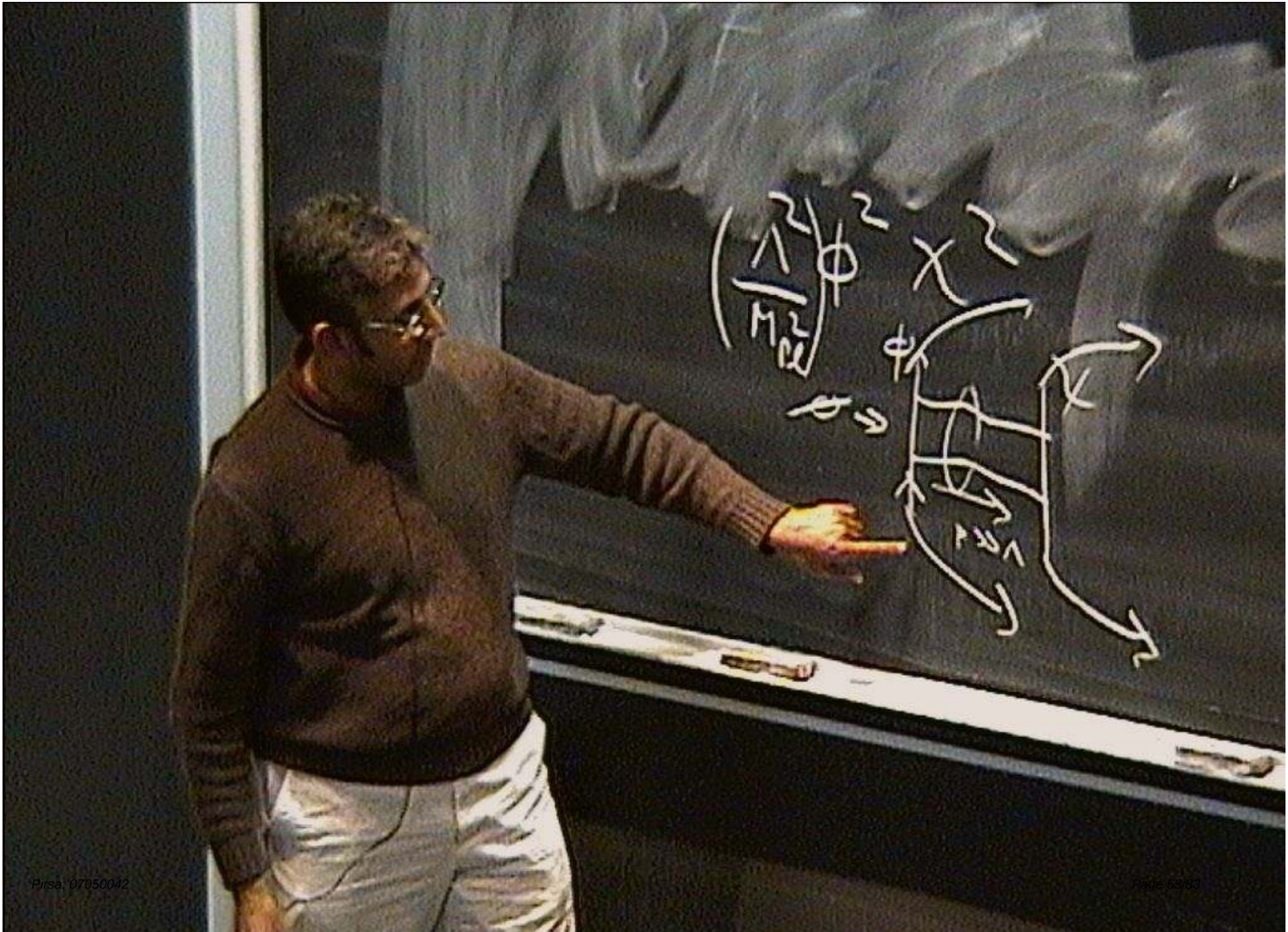

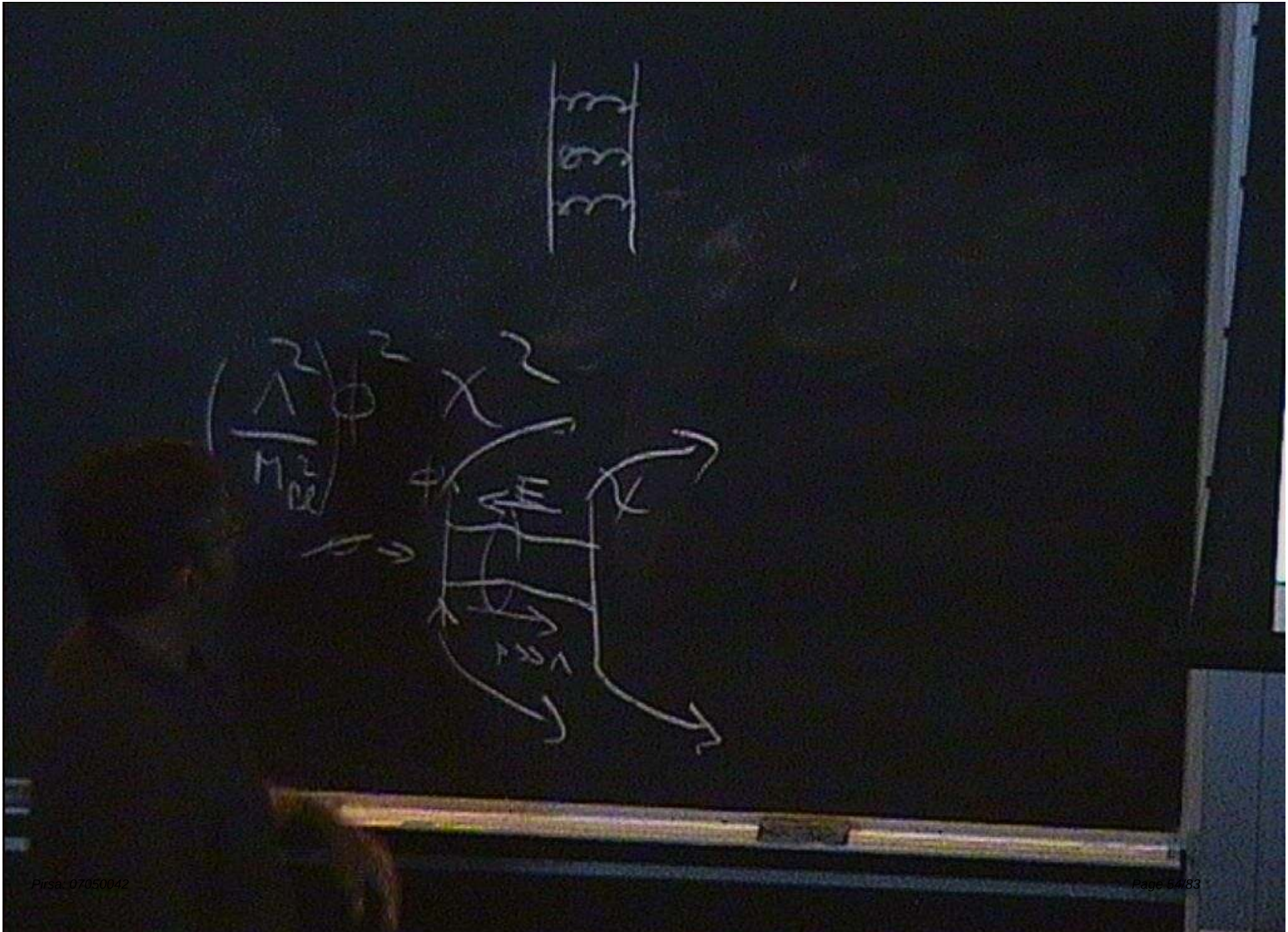
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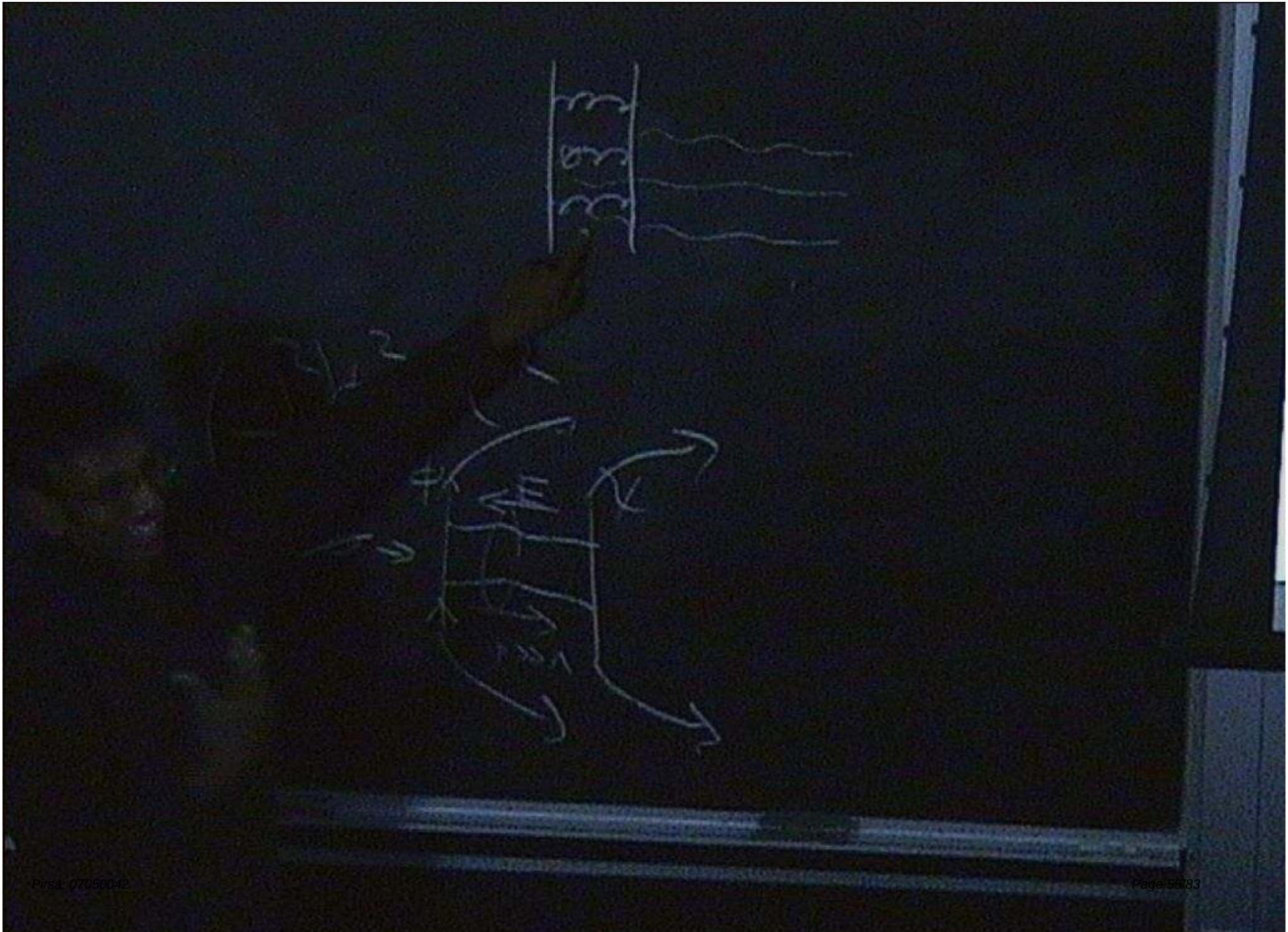
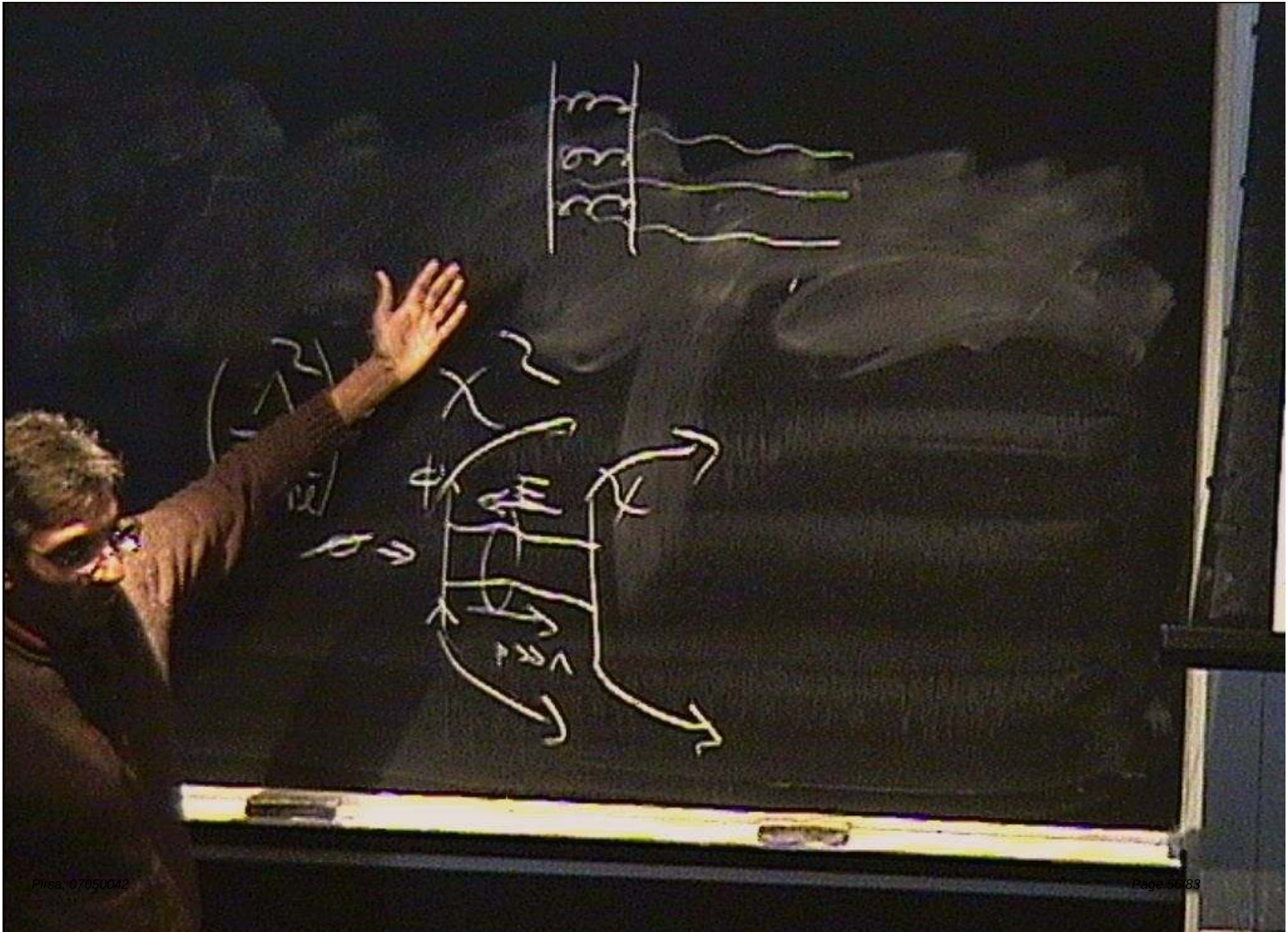
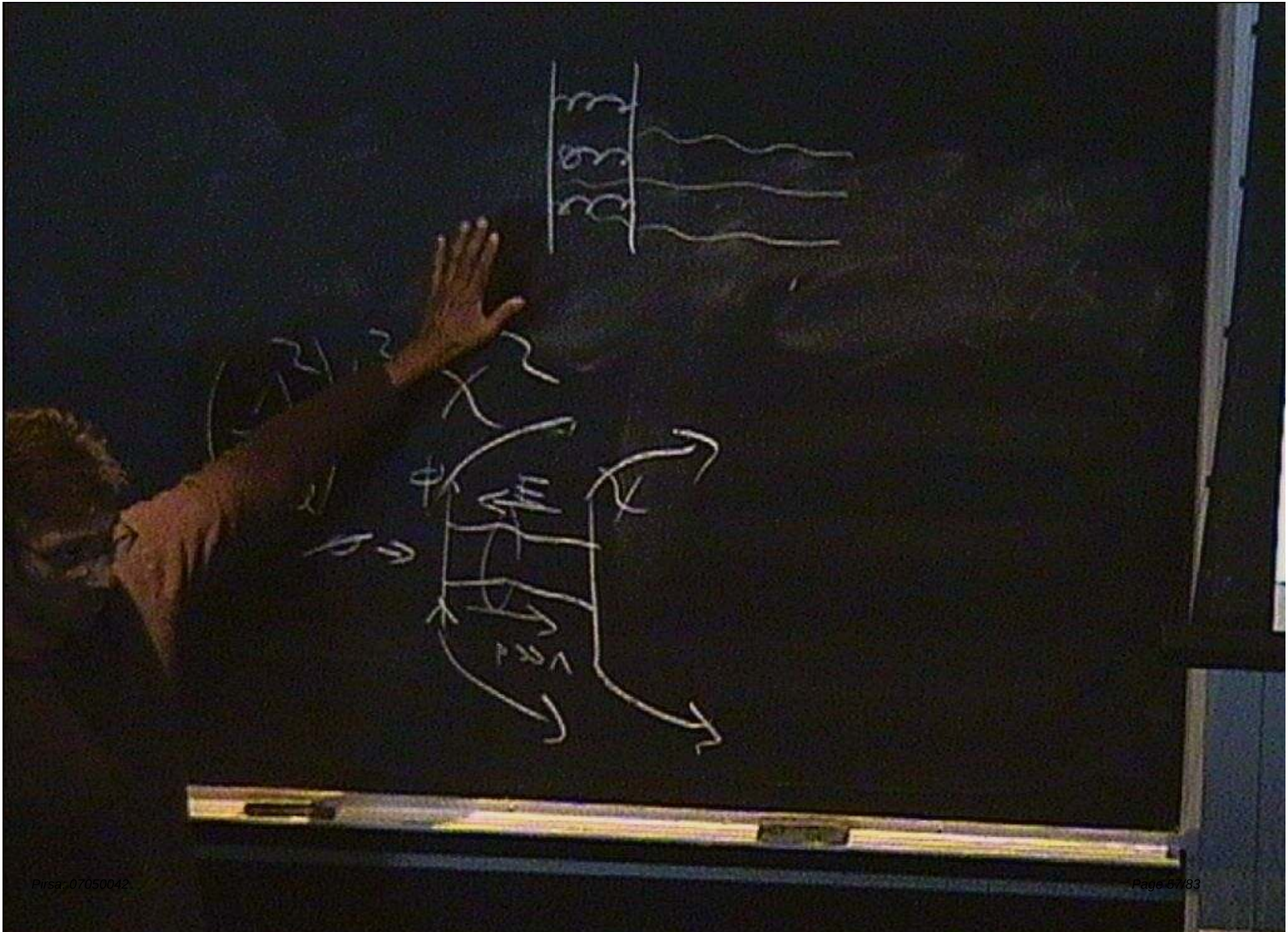
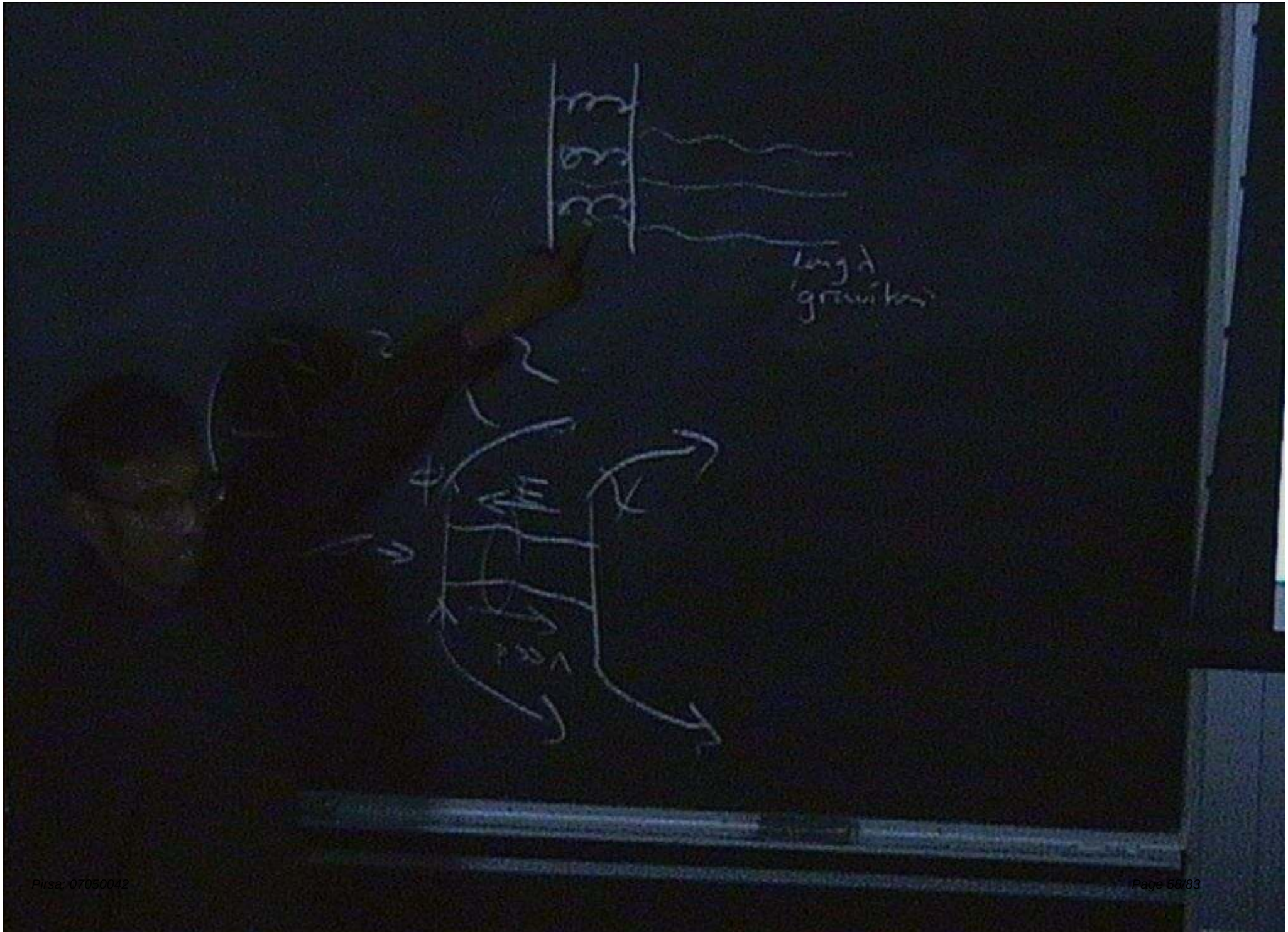
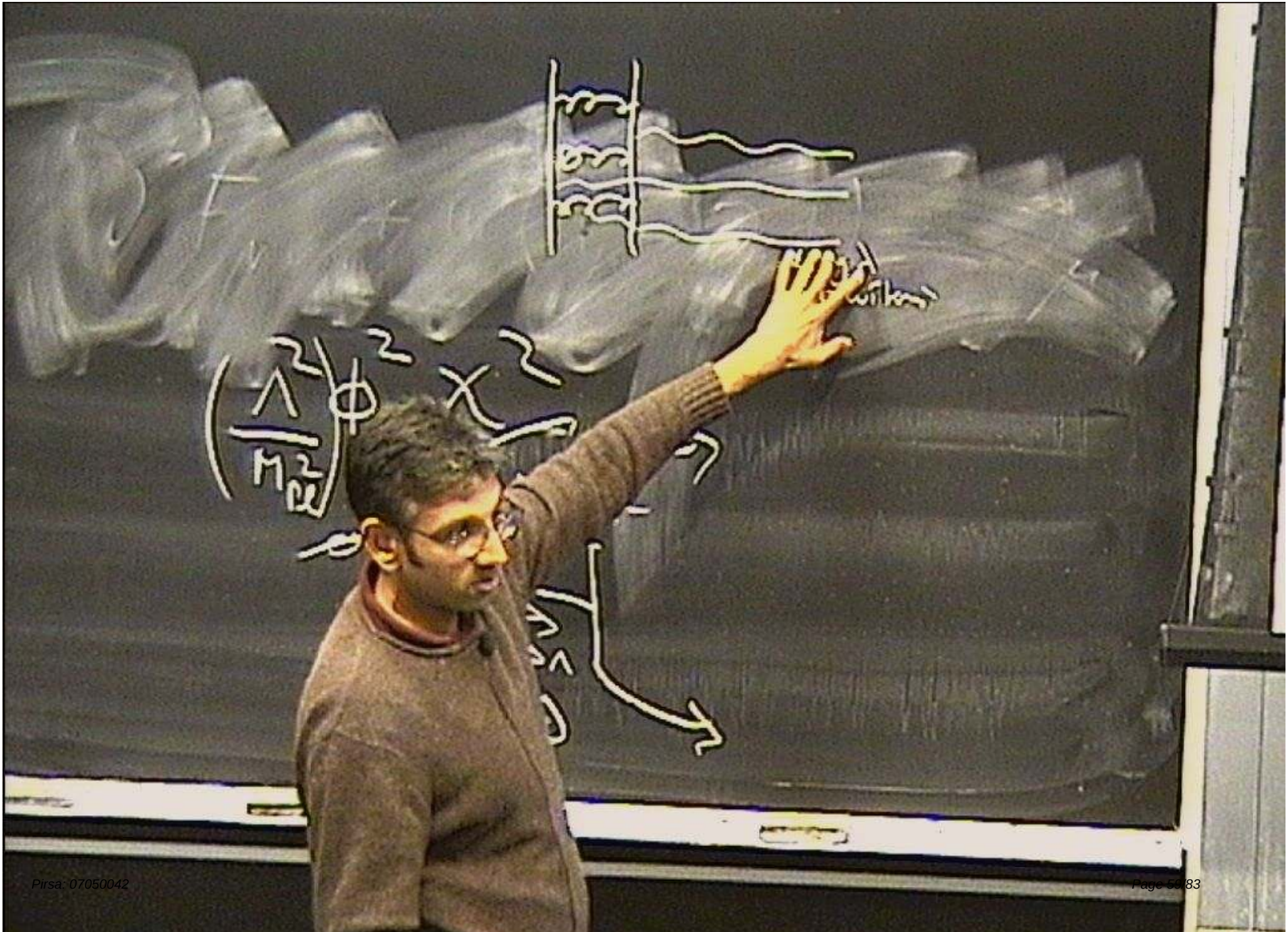
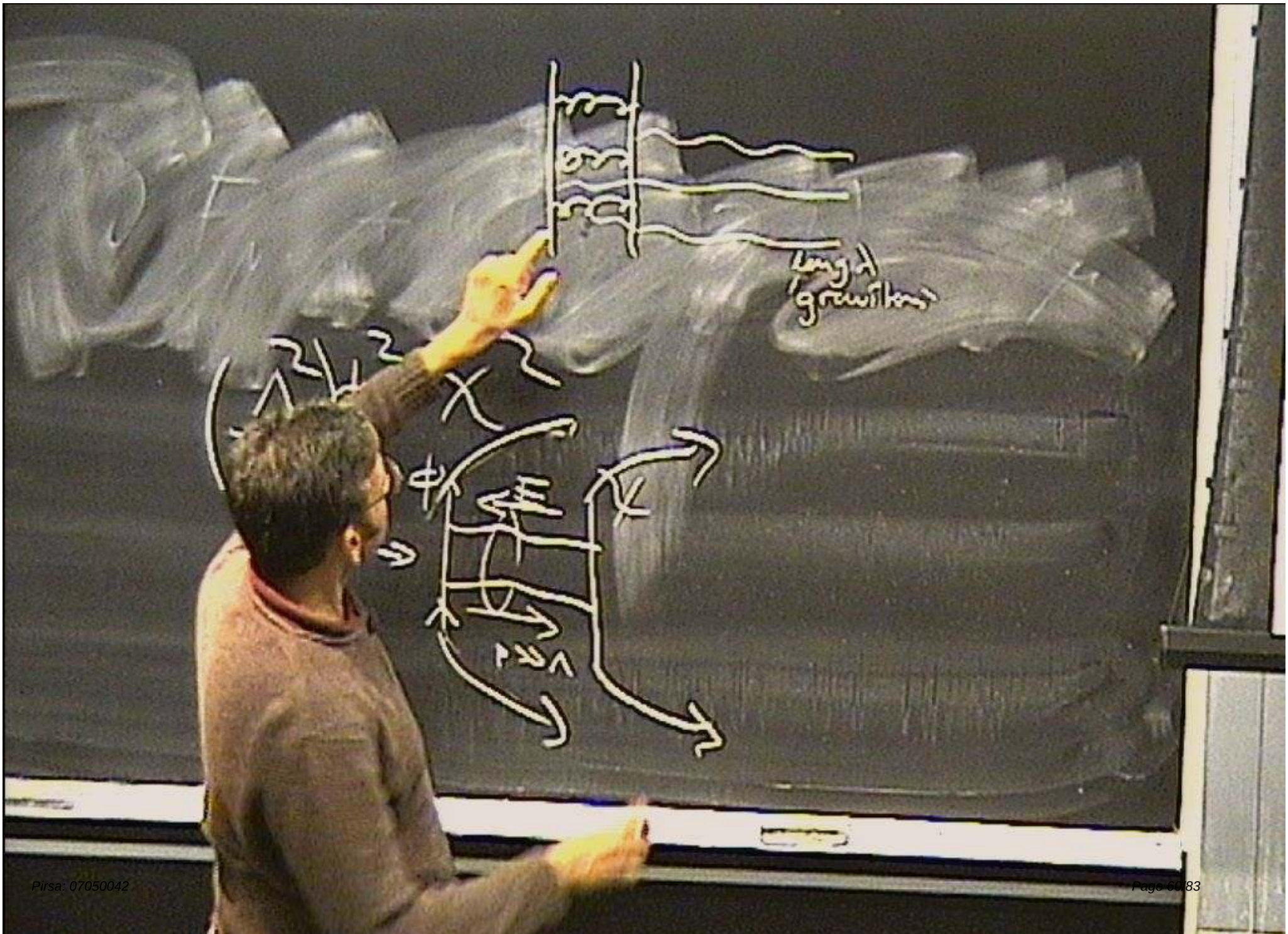


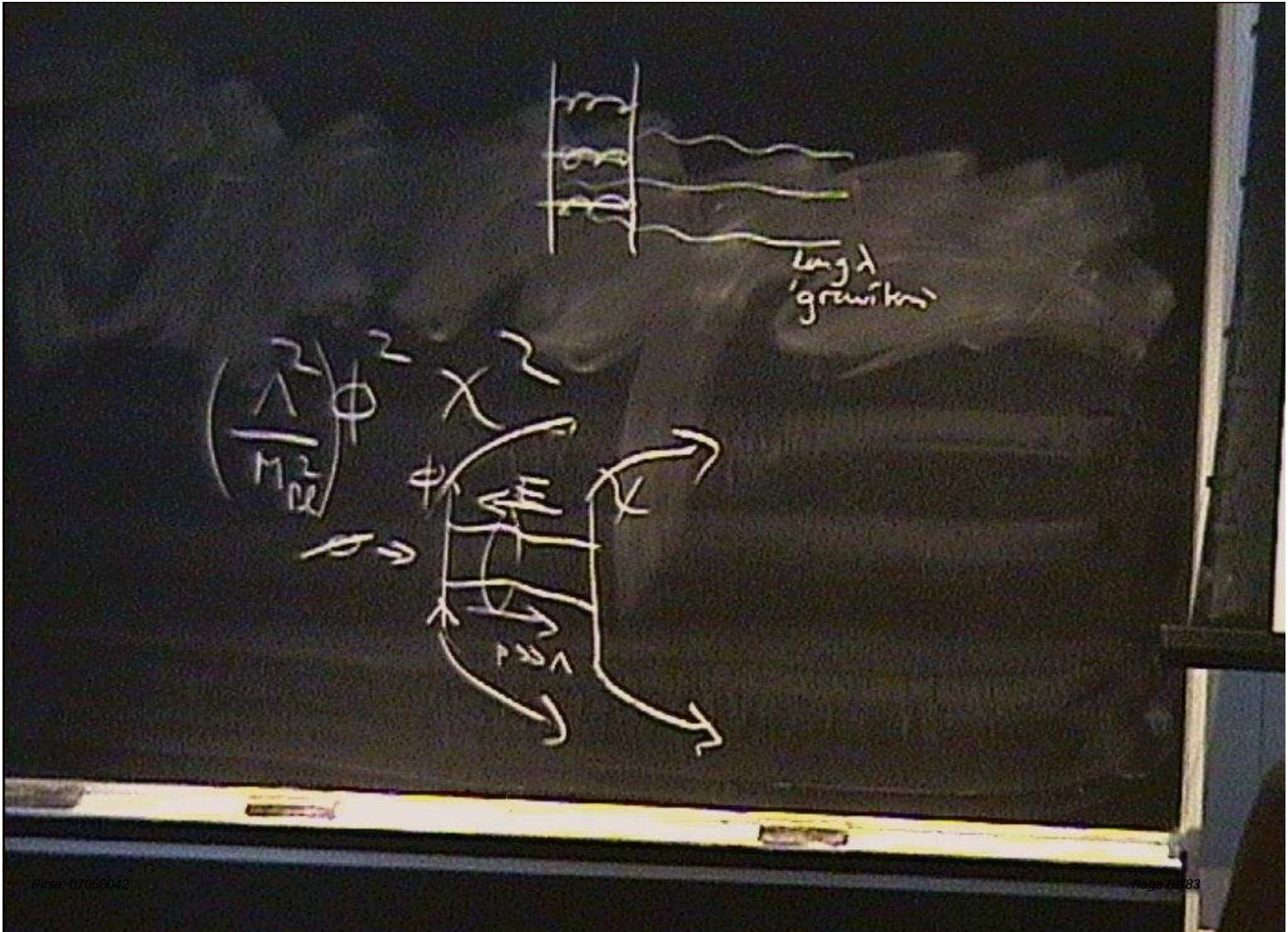





long λ
gravitons



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'graviton'
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ϕ
χ
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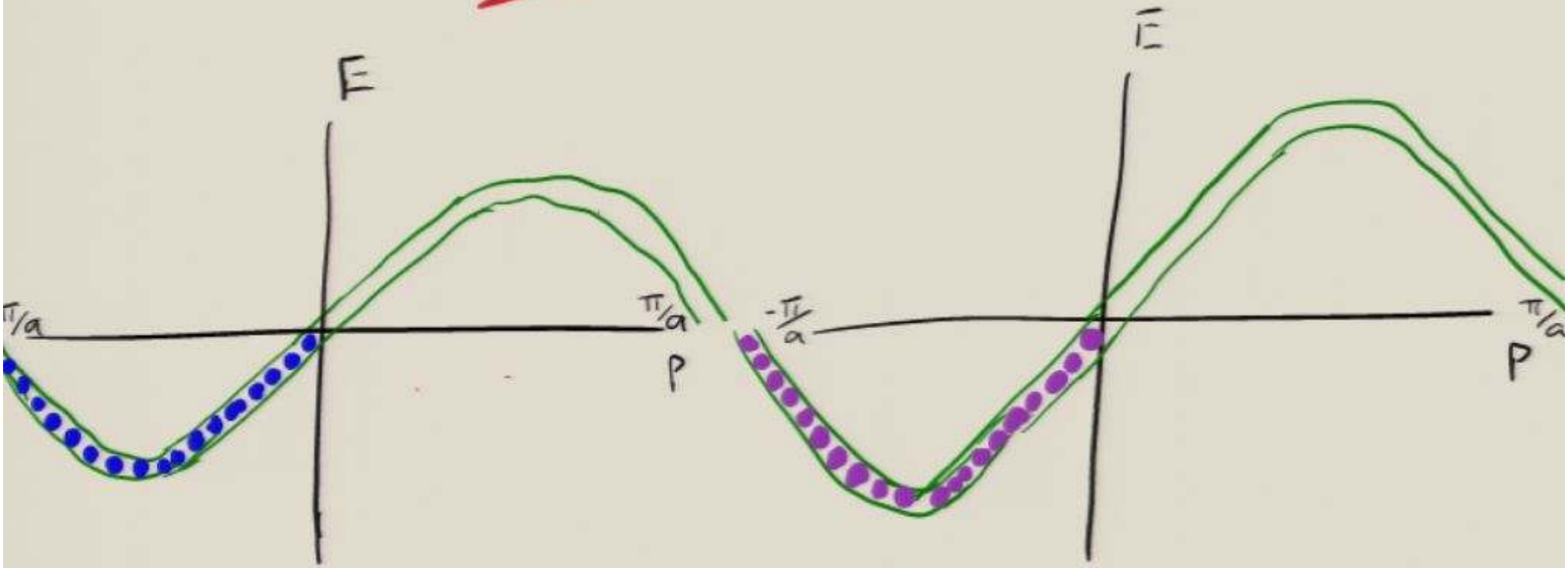

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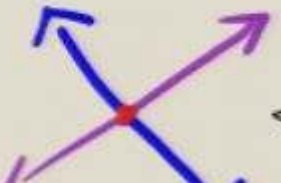

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GHOSTS IN FIELD THEORY

Classically,

$$\mathcal{L} = \sqrt{-g}\left\{ M_{Pl}^2 R - \rho + \mathcal{L}_{matter}(\Psi, D_\mu) - \mathcal{L}_{matter}(\hat{\Psi}, D_\mu) \right\}$$

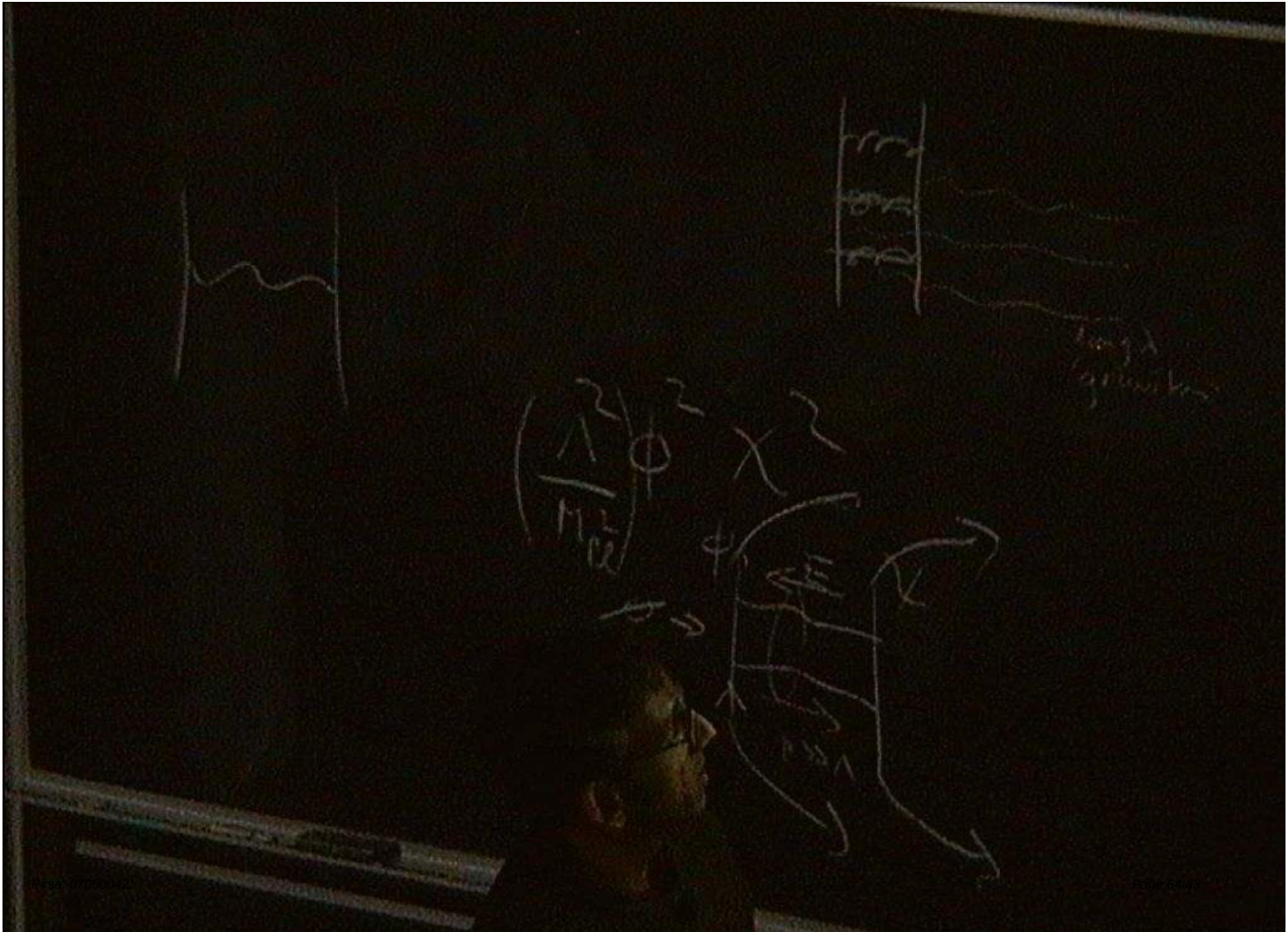
Ghosts

as proposed by Linde '84

Perturbative Quantization:

Non-Ghosts $\quad \dfrac{i}{p^2 - m^2 + i\varepsilon}$

Ghosts $\quad \dfrac{-i}{p^2 - m^2 - i\varepsilon}$ $\quad (i \to -i)$



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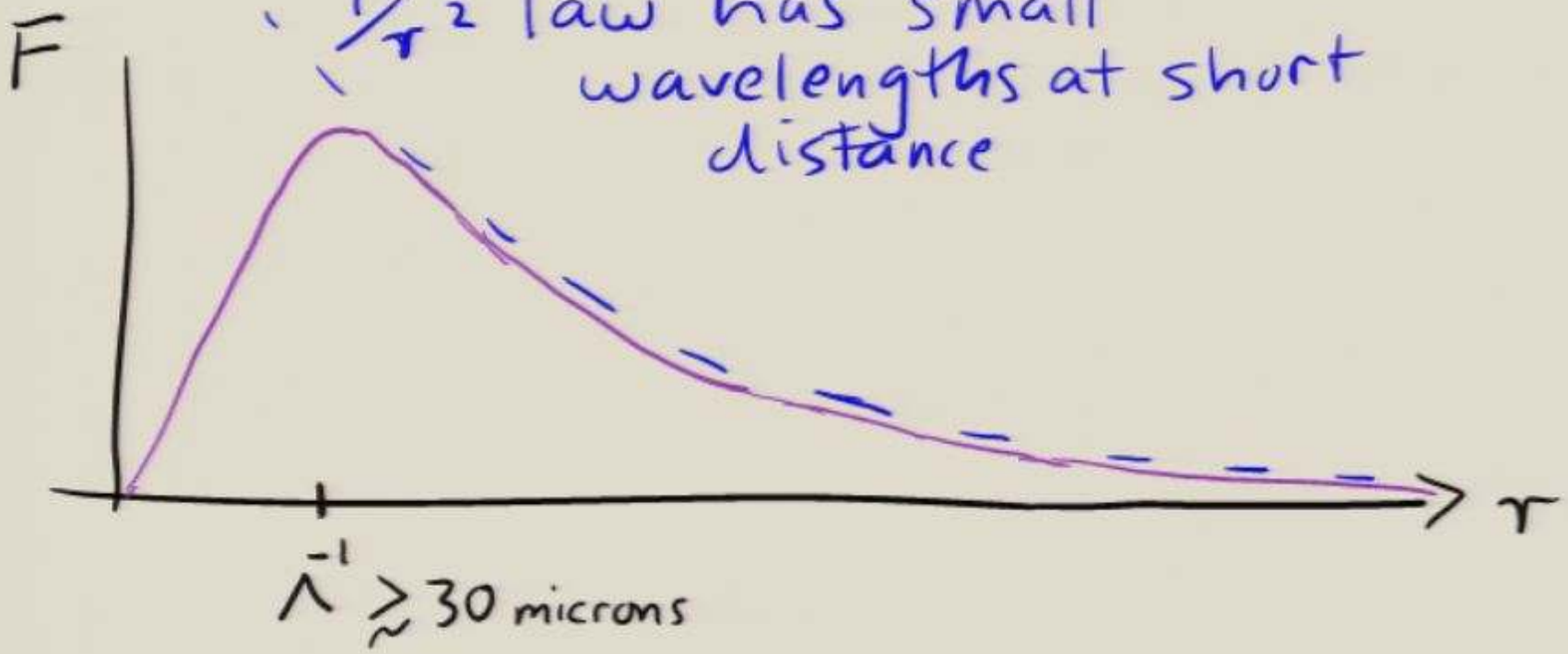
should reveal breakdown of Newton's Law due to grav. $\vec{p}$ cutoff, Λ:



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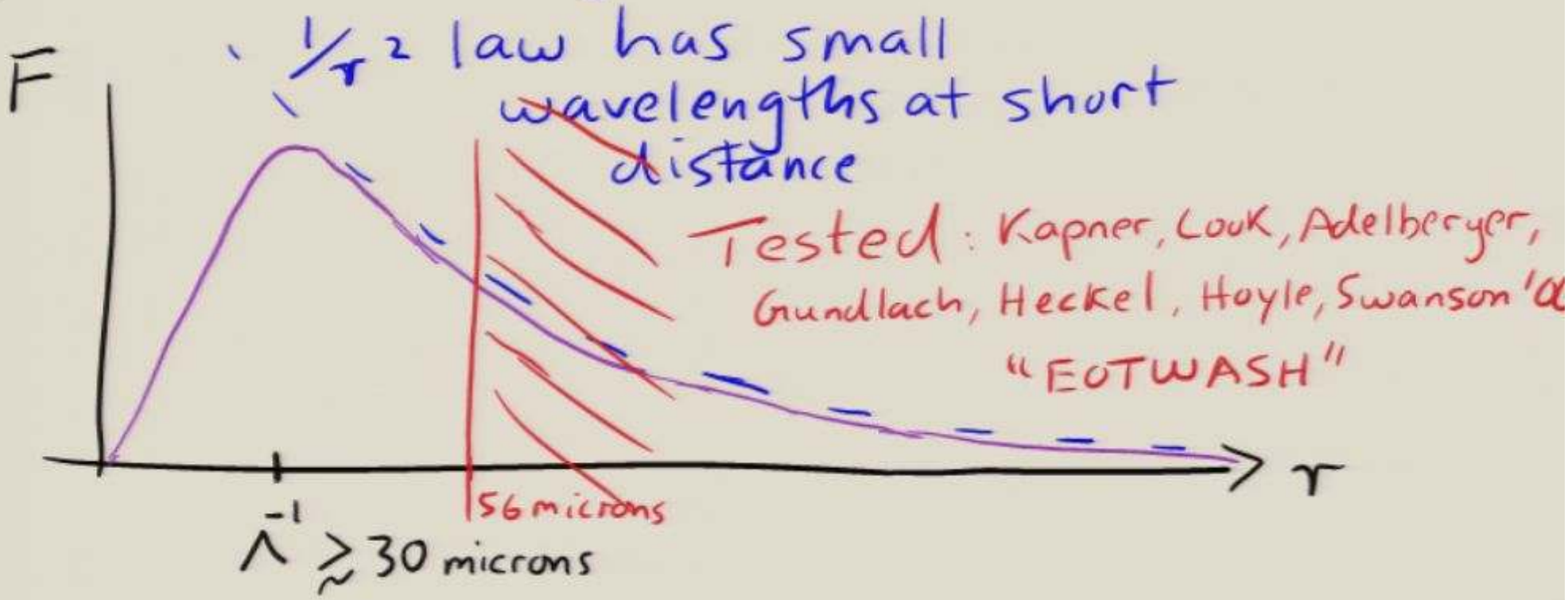
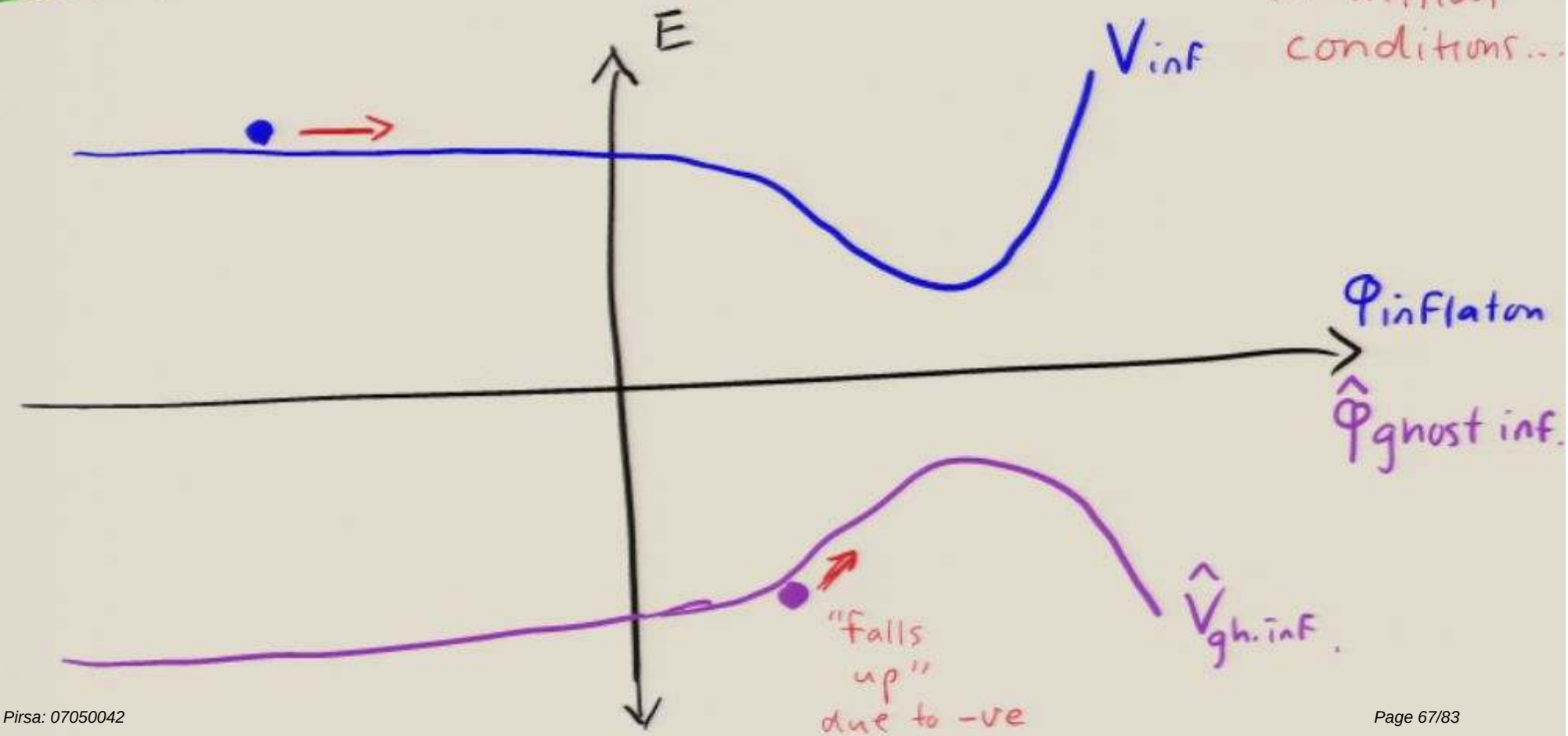


GHOST BUSTERS

Why are ghosts so rare apparently?

Inflation

Linde '84 : Initially, modest asymmetry in initial conditions...



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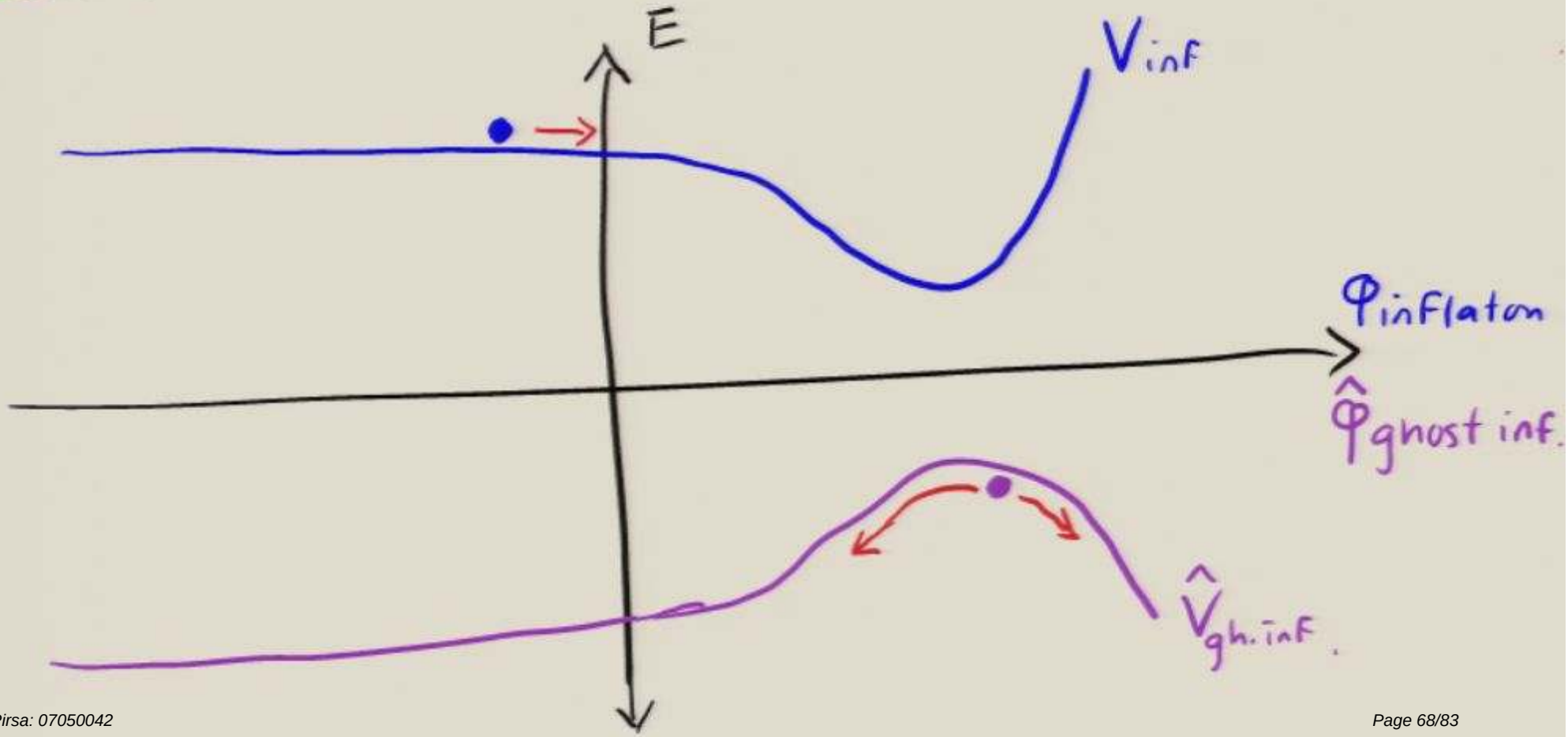

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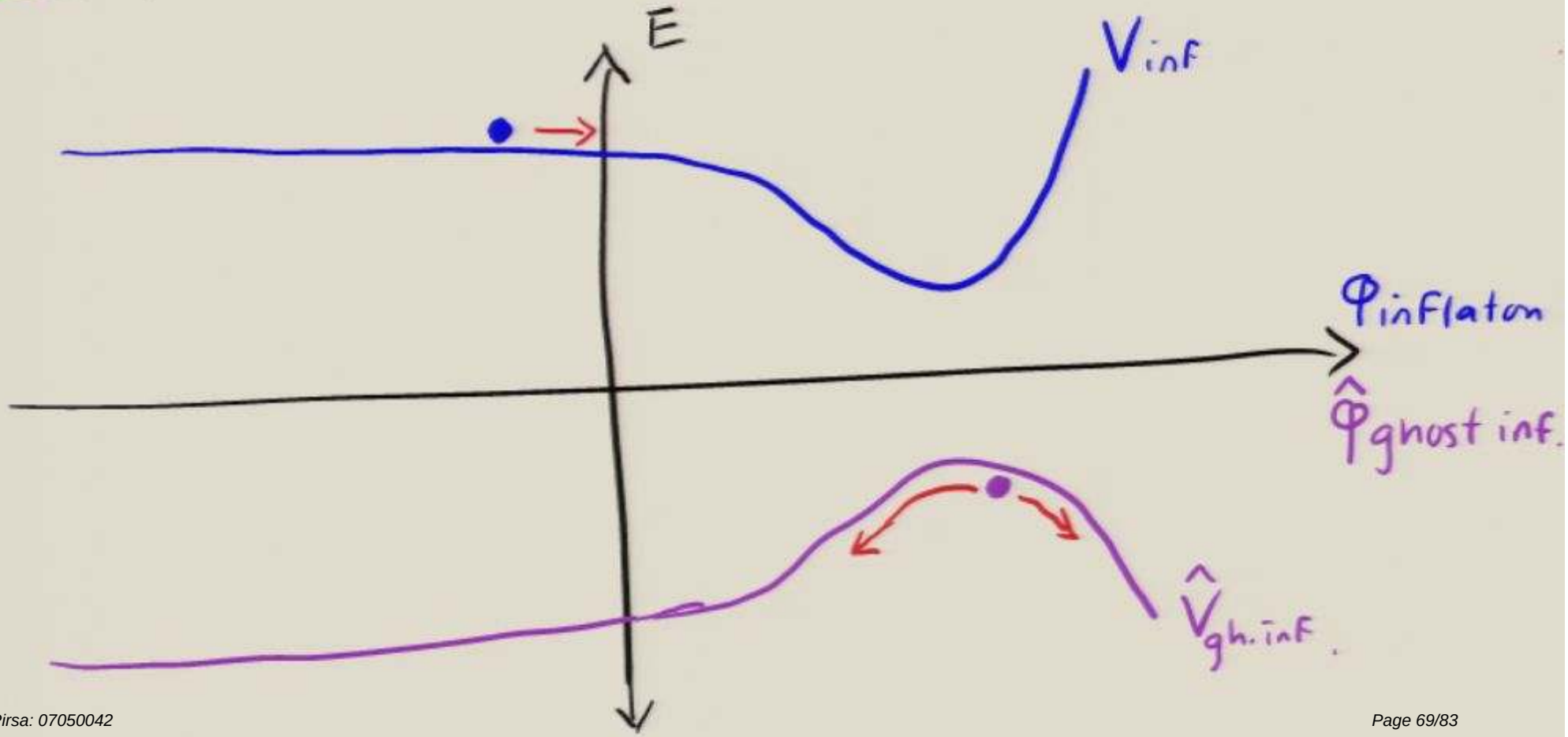

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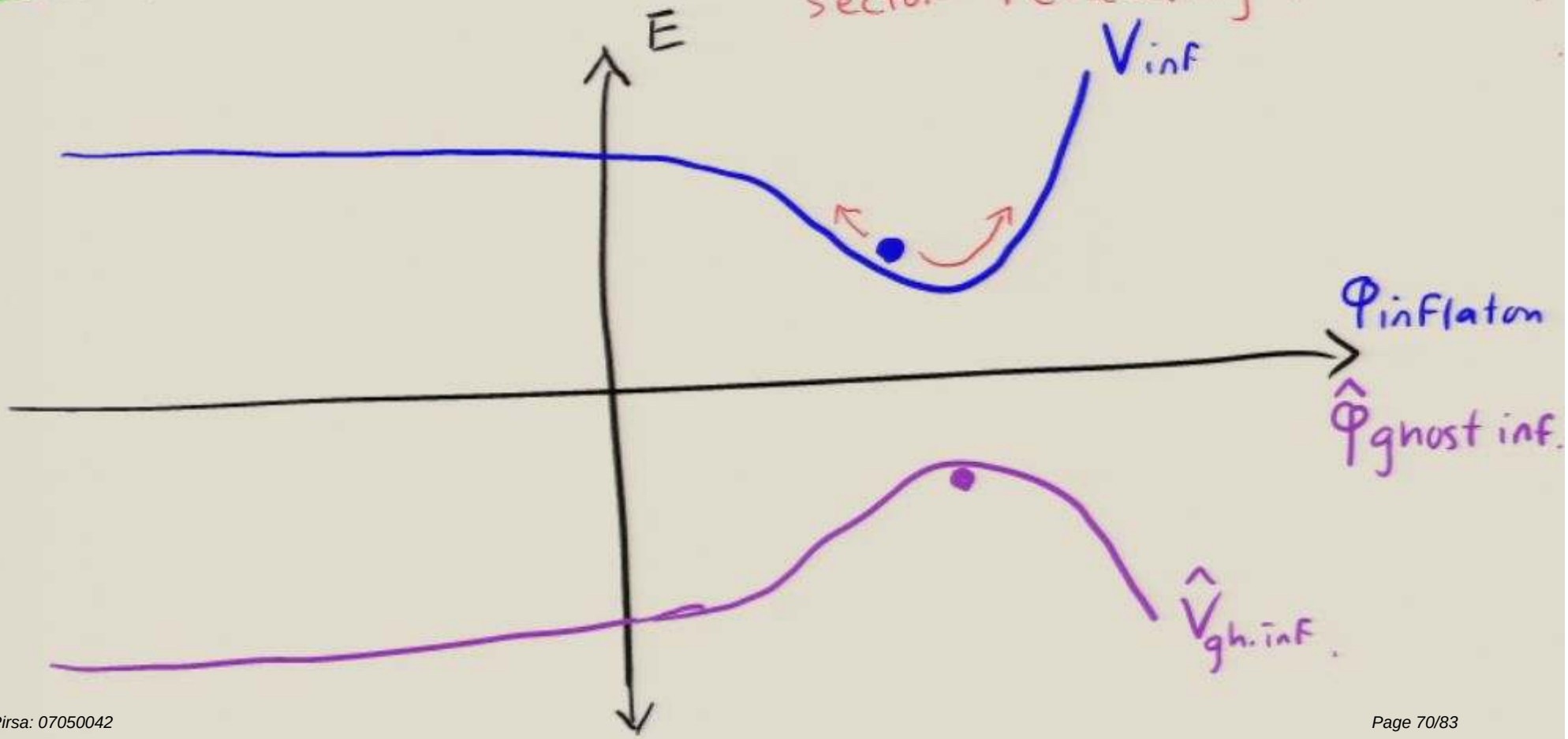

NEWTON'S GHOST

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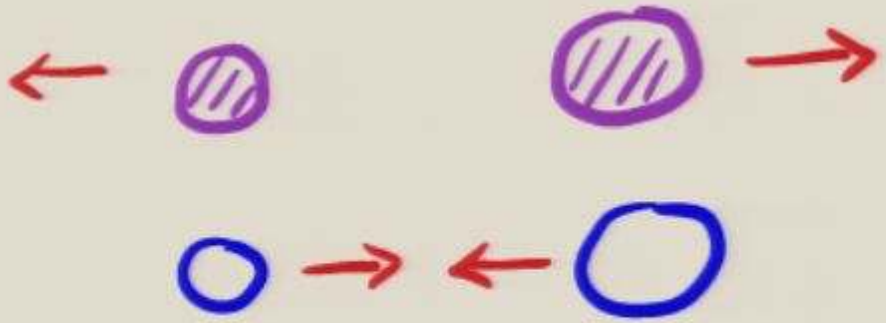
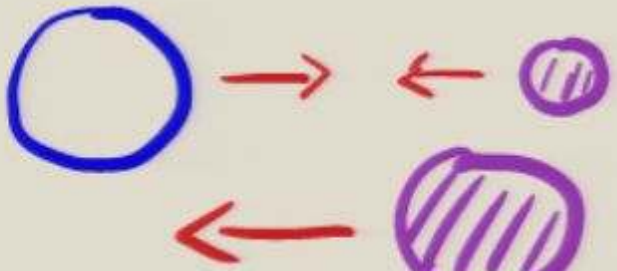
Newtonian Forces:

Relative forces:





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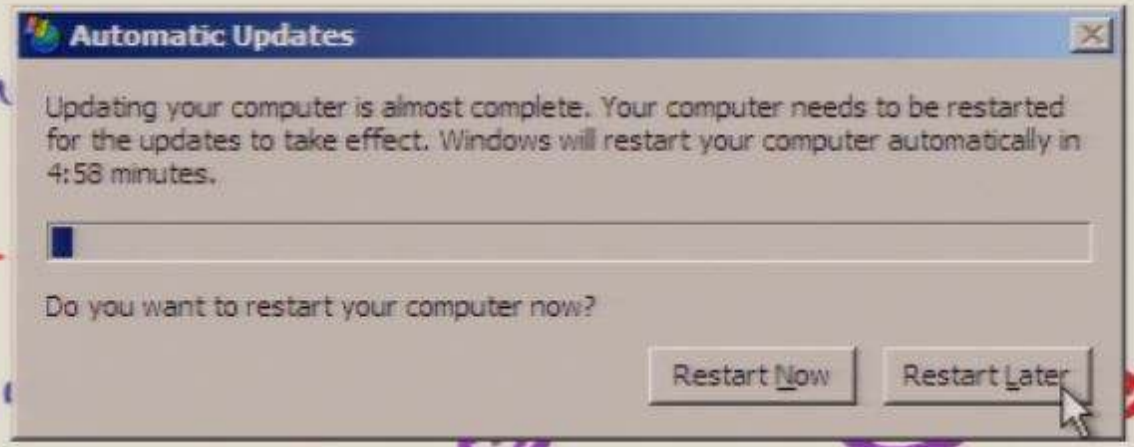

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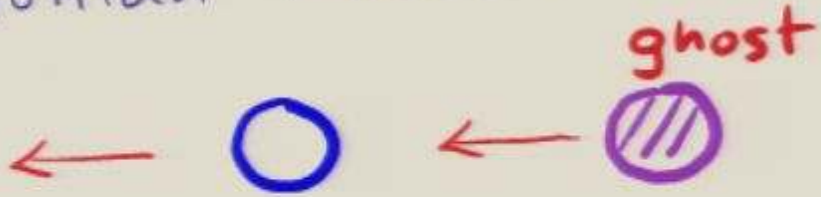
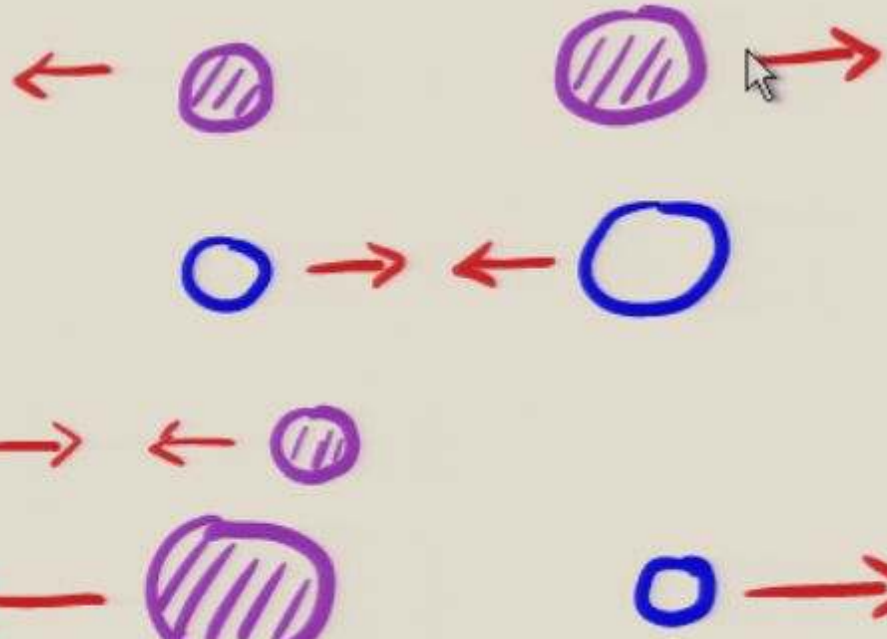


Relative forces:



IMPLEMENTING Λ

Effective field theories of ~~Lorentz~~ gravity exist

Jacobson, Mattingly '00

Arkani-Hamed, Cheng, Luty, Mukohyama '04

Dubovsky '05

Construction of ~~Lorentz~~ pure gravity theory with $\vec{p}$-cutoff Λ

Schwartz, Sundrum

Impose Λ as (soft) $\vec{p}$-cutoff such as $e^{\nabla^2/\Lambda^2} \equiv e^{-\vec{p}^2/\Lambda^2}$ in $\mathcal{L} \Rightarrow$ t-local, $\vec{x}$-nonlocal

Work in co-moving coordinates of aether.

Implement Λ to maintain perturbative unitarity.

NEWTON'S GHOST

Any remaining ghost matter is v. exotic dark matter. Can it be detected?

Newtonian Forces:

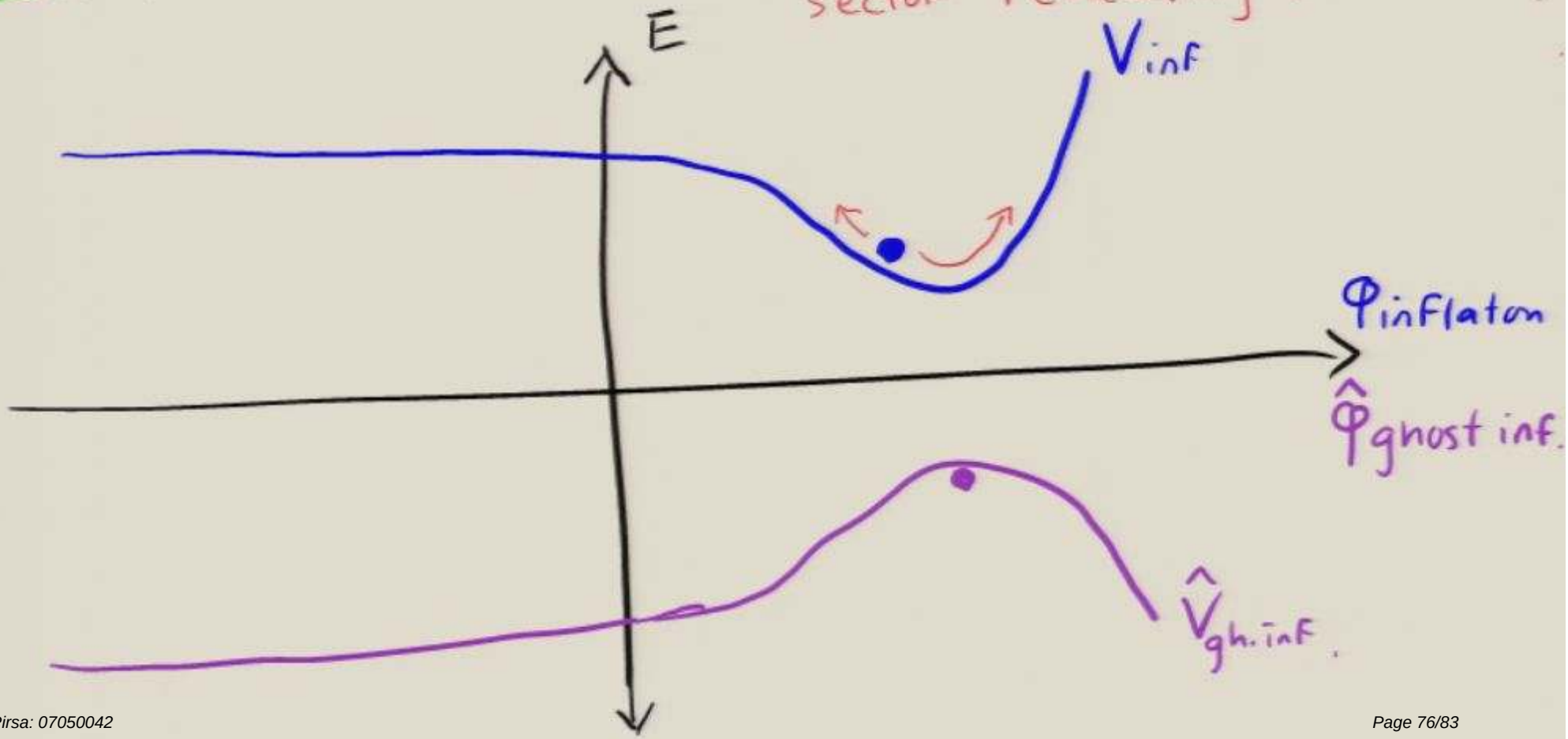
Relative forces:

GHOST BUSTERS

Why are ghosts so rare apparently?

Inflation

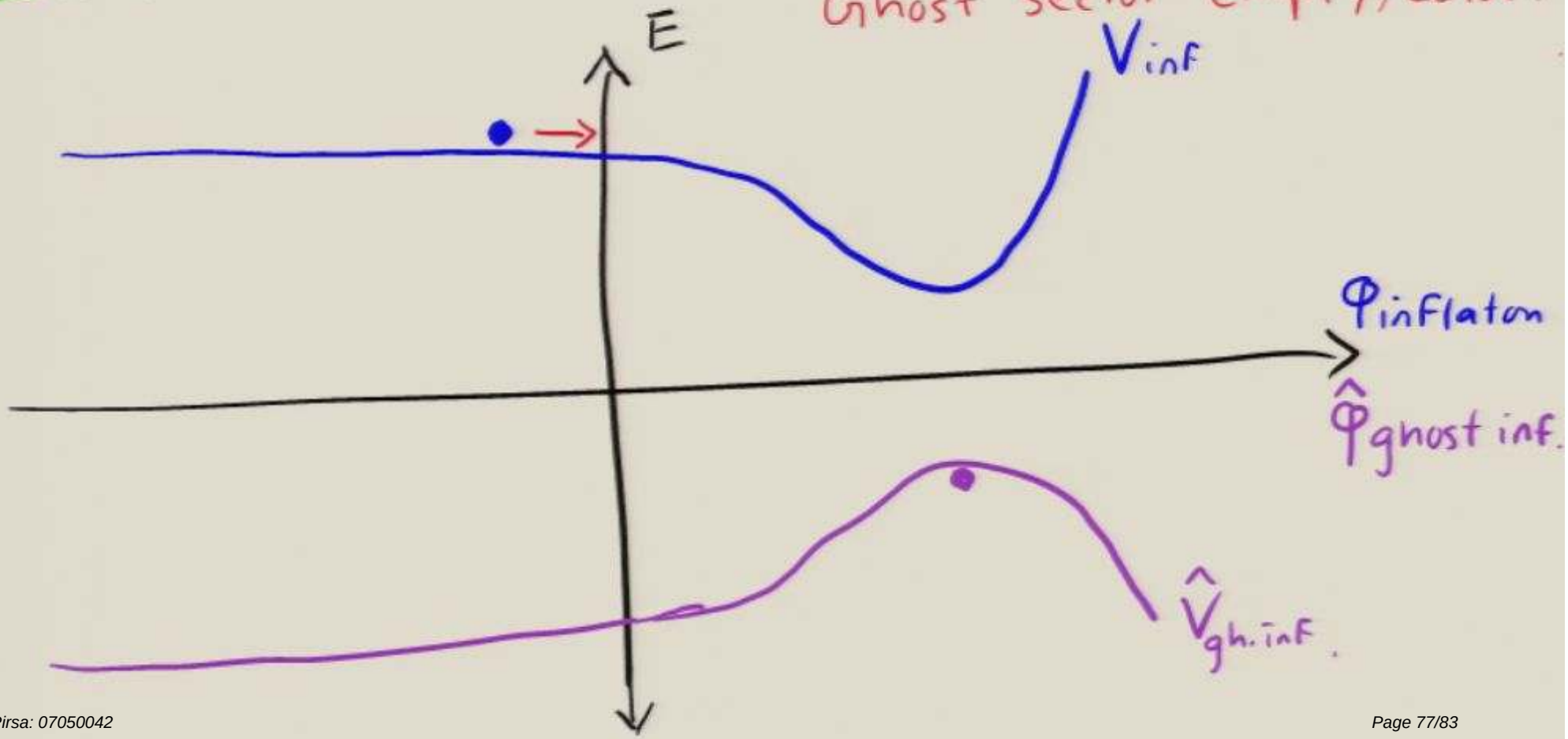
Linde '84 : Inflation ends with "our" sector reheating.



GHOST BUSTERS

Why are ghosts so rare apparently?

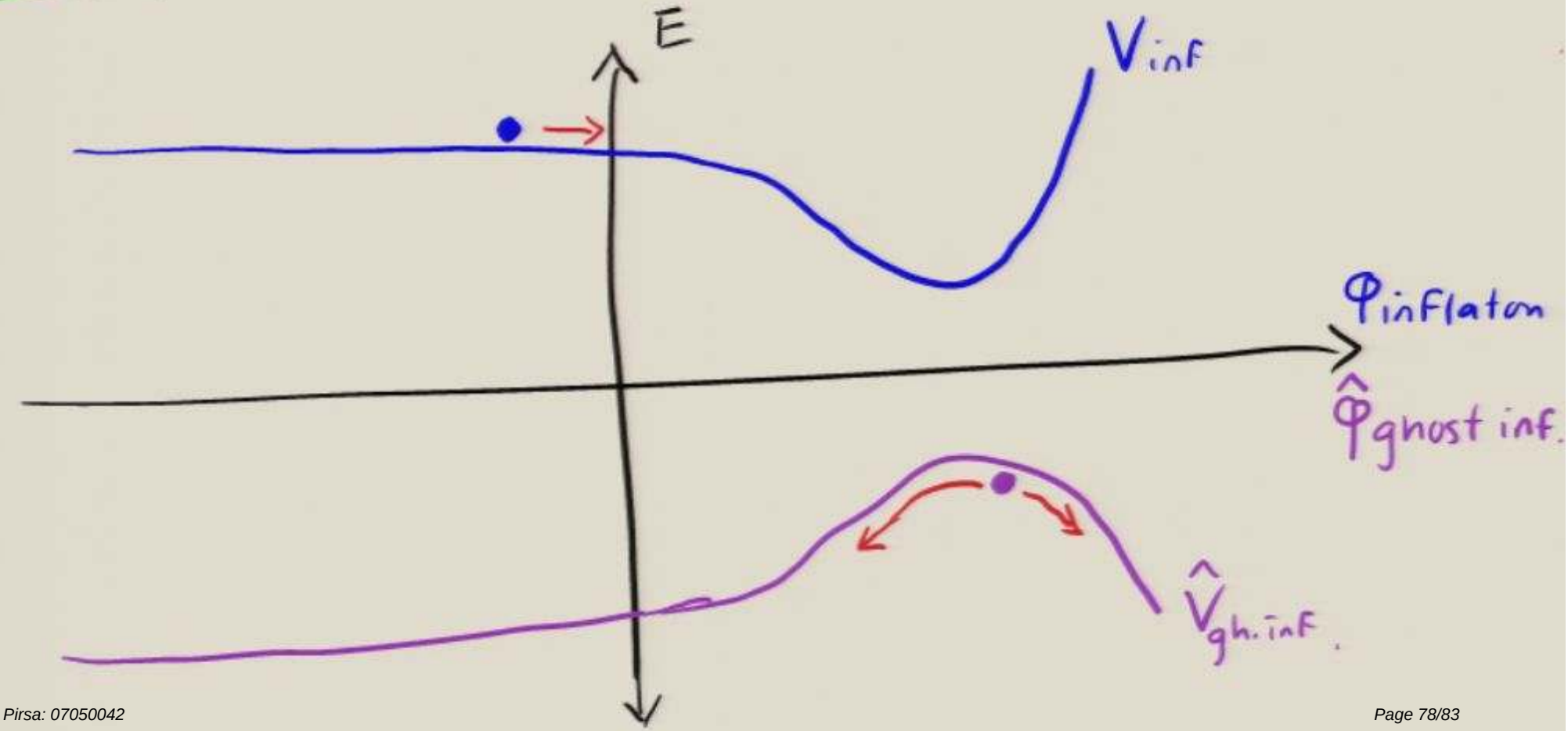
Inflation Linde '84 : ... is inflated away.
Ghost sector empty, cold.



GHOST BUSTERS

Why are ghosts so rare apparently?

Inflation Linde '84 : Ghost reheating . . .

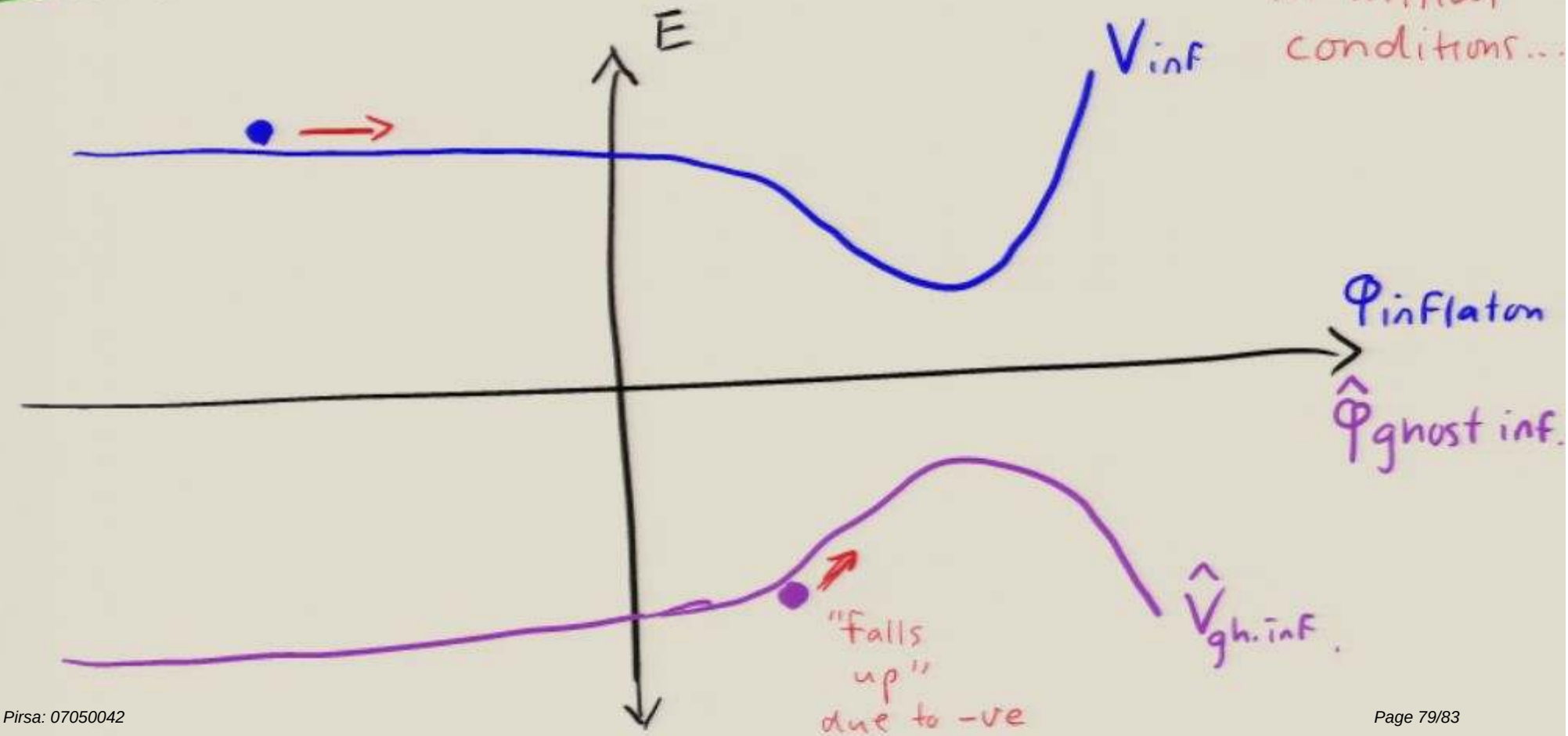


GHOST BUSTERS

Why are ghosts so rare apparently?

Inflation

Linde '84 : Initially, modest asymmetry in initial conditions...



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THE ISSUES

Unitarity requires Λ-deformation of a manifestly unitary gauge-fixing

physical in presence of aether

Eg. Yang-Mills in $\partial_i A^a_i = 0$ Coulomb gauge.

$$\mathcal{L}(A_\mu, \partial_\nu) = \mathcal{L}_2(A_\mu, \partial_\nu) + \mathcal{L}_{int}(A_\mu, \partial_\nu)$$

$$\longrightarrow \mathcal{L}_2(A_\mu, \partial_\nu) + \mathcal{L}_{int}(e^{\nabla^2/\Lambda^2} A_\mu, \partial_\nu)$$

$\Rightarrow$ UV finite canonical quantization perturbation th

Gauge-Fixing needed, else $\mathcal{L}_2$ not invertible, but $\mathcal{L}$ not gauge invariant

Relativistic gauges would yield propagating -ve probabilit

$|\vec{k}| \ll \Lambda$ reverts to standard gauge-Fixed relativist

STRONG COUPLINGS ?

Similar issue to massive gravity,
bad propagator behavior $\Rightarrow$ strong couplings $\lll M_{Pl}$

ArKani-Hamed, Georgi, Schwartz '02

Eg. Coulomb gauge propagator

$$G_{ij} = \frac{\delta_{ij} - \frac{p_i p_j}{\vec{p}^2}}{E^2 - \vec{p}^2 + i\varepsilon}$$

$$G_{00} = \frac{1}{\vec{p}^2} \gg \frac{1}{E^2 - \vec{p}^2} \quad \text{for} \quad E \gg \vec{p}$$

cancelation of bad behavior, $\equiv$ Feynman gauge,
usual guaranteed by gauge invariance.

Presently investigating sufficient cancelation by subgroup

FUTURE . . .

Build unitary, perturbative graviton amplitudes (+ matter) with
∧ $\vec{p}$-cutoff to realize E-parity idea.

Investigate non-perturbative instabilities, Large Redshifts

Consistency with holographic principles

Identify most promising experimental/observational tests.