Title: Beyond Standard Model-1

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Abstract:

Beyond the Standard Model (BSM)

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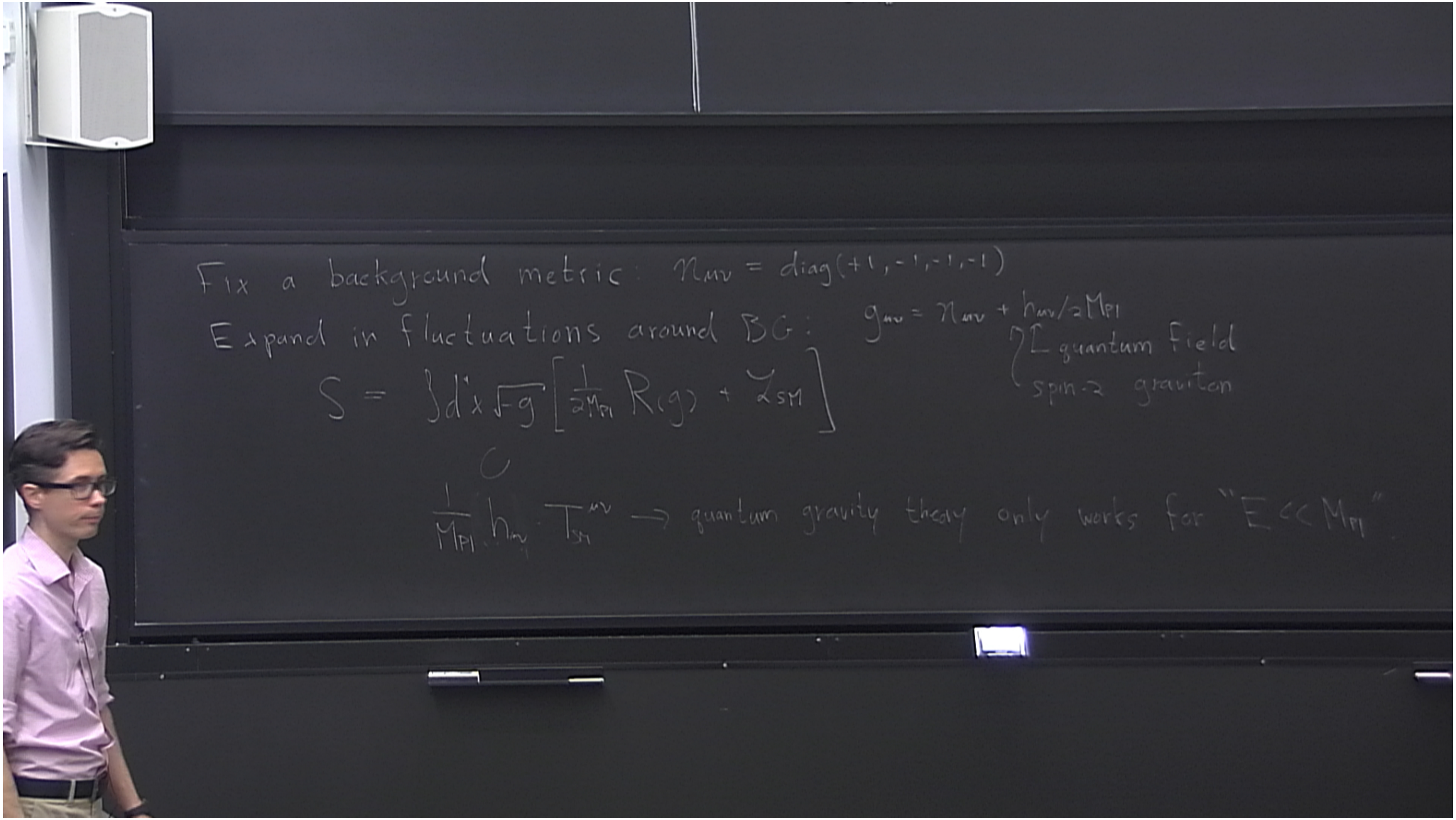
↑ course notes + info

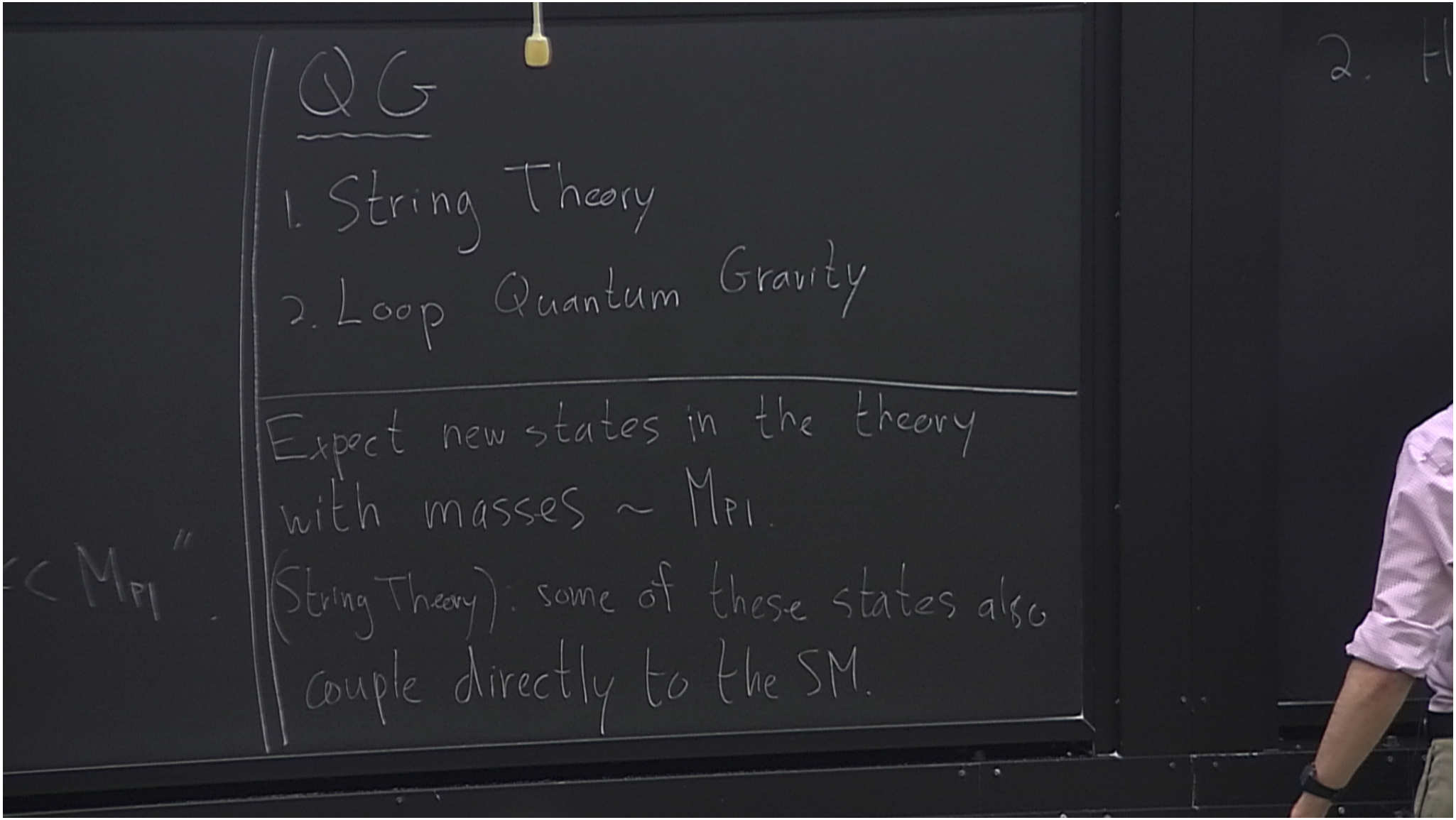
Motivation for BSM

1. Gravity

$$G_N = \frac{1}{8\pi M_{Pl}^2}, \quad M_{Pl} = 2.4 \times 10^{18}\ \text{GeV}$$

$$G_F = \frac{\sqrt{2}\, g^2}{8 M_W^2} \simeq 1.16 \times 10^{-5}\ \text{GeV}^{-2}$$


Fix a background metric: $\eta_{\mu\nu} = \mathrm{diag}(+1,-1,-1,-1)$
Expand in fluctuations around BG: $g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}/2M_{Pl}$
quantum field
spin-2 graviton
$S = \int d^4x \sqrt{-g}\left[\frac{1}{2M_{Pl}} R(g) + \mathcal{L}_{SM}\right]$
$\frac{1}{M_{Pl}} h_{\mu\nu} T_{SM}^{\mu\nu}$ → quantum gravity theory only works for "$E \ll M_{Pl}$"


QG
1. String Theory
2. Loop Quantum Gravity
Expect new states in the theory with masses ~ M_{Pl}.
(String Theory): some of these states also couple directly to the SM.
$< M_{Pl}$"

Theory

Quantum Gravity

ew states in the theory

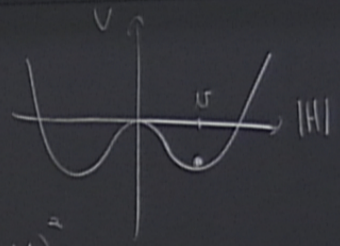
asses ~ M_{Pl}.

) some of these states also

irectly to the SM.

2. Hierarchy Problem

$$V = -\mu^2 |H|^2 + \frac{\lambda}{2} |H|^4$$



$$v^2 = \mu^2/\lambda \simeq (174\ \text{GeV})^2$$

$$m_h = \sqrt{2\lambda v^2} = 125\ \text{GeV}$$

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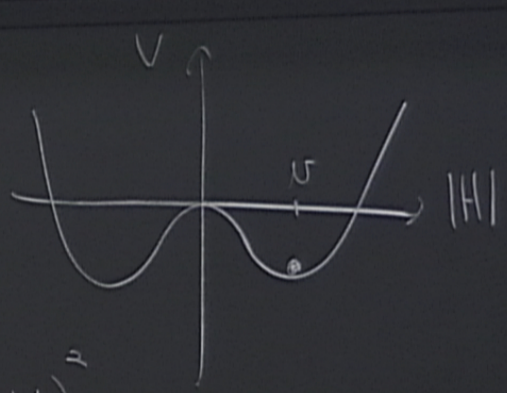

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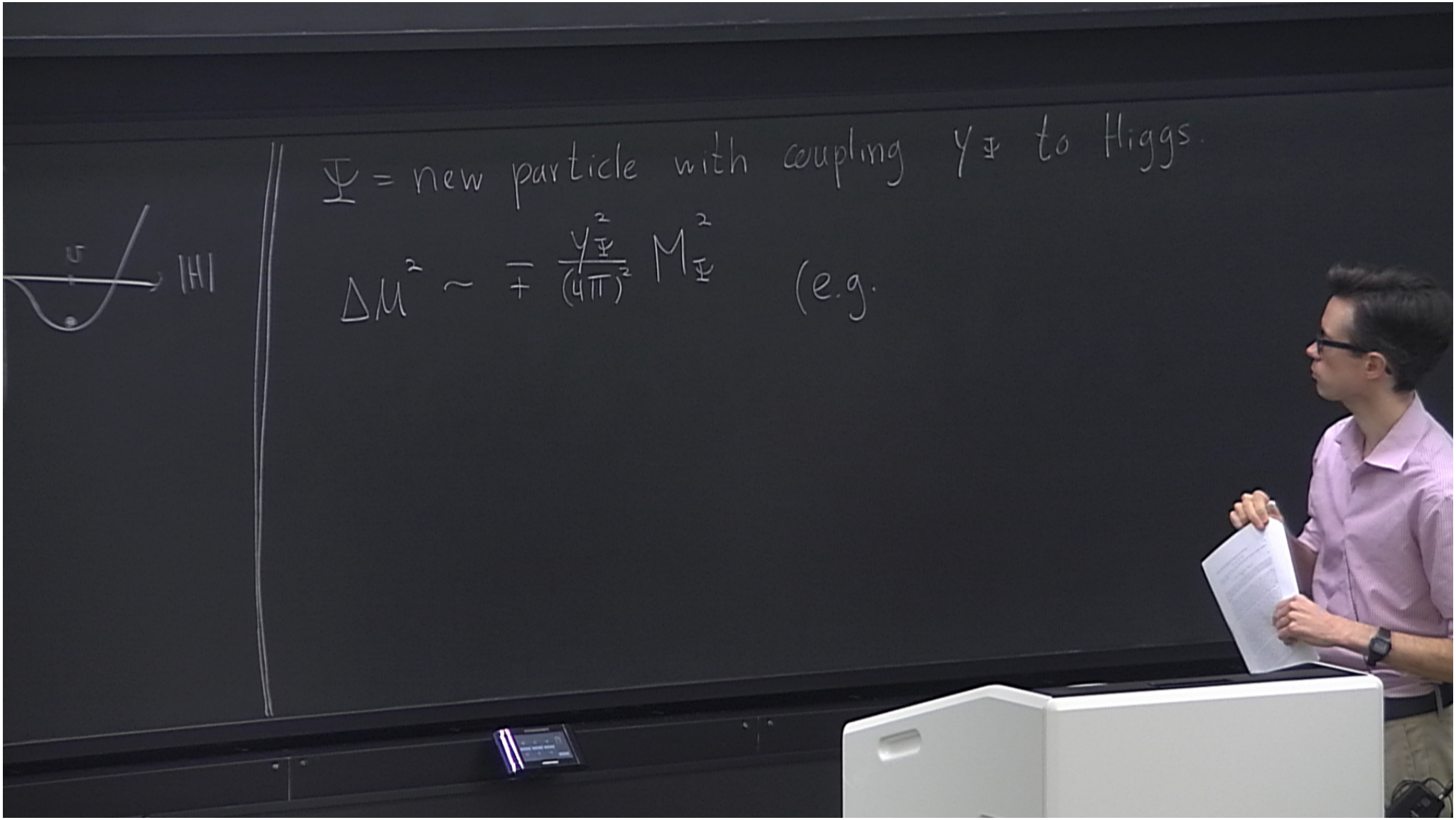
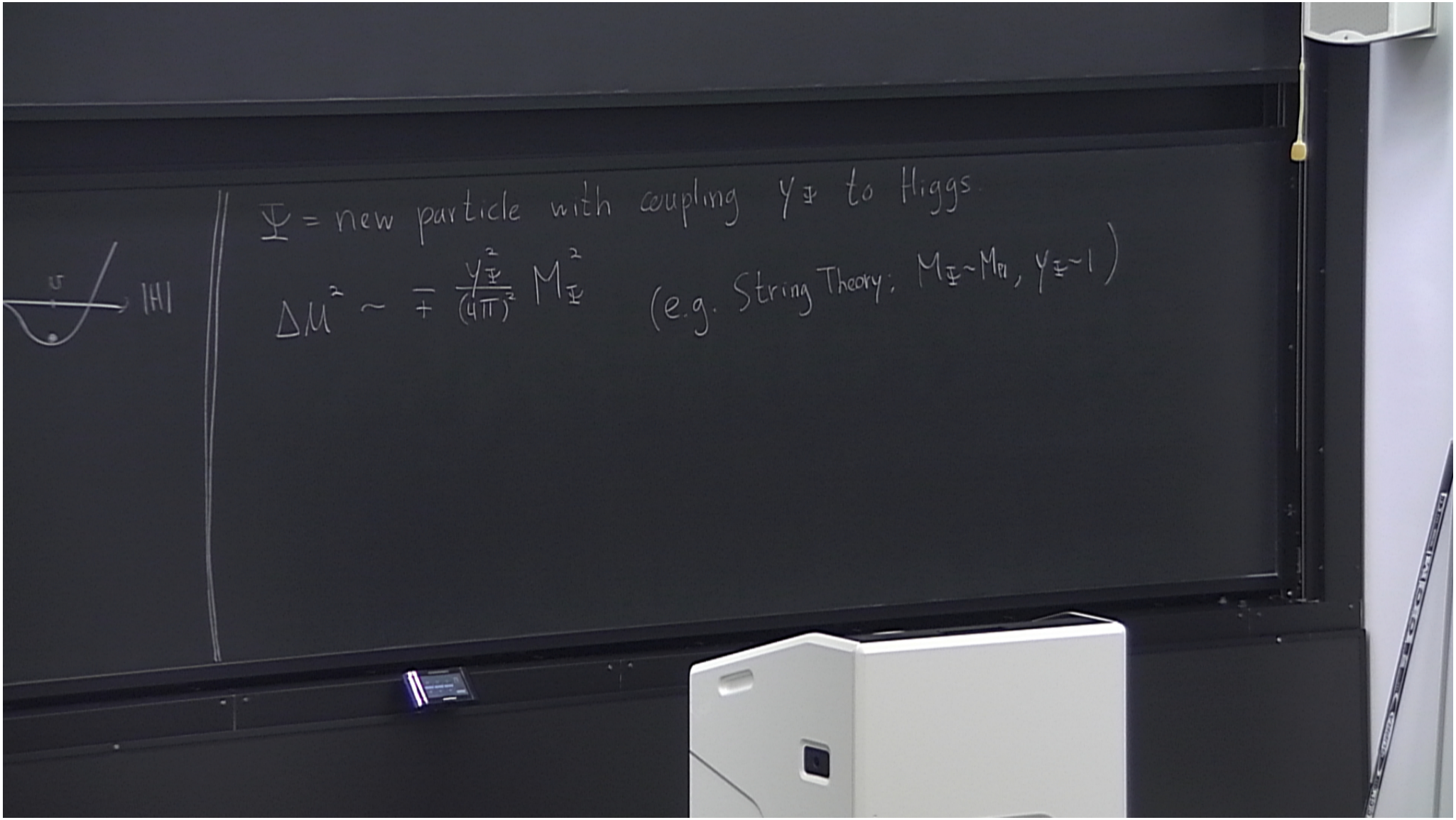
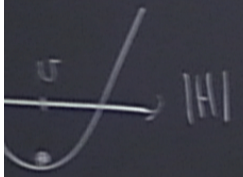

Ψ = new particle with coupling y_Ψ to Higgs.
$\Delta\mu^2 \sim \mp \frac{y_\Psi^2}{(4\pi)^2} M_\Psi^2$ (e.g.
V
|H|


Ψ = new particle with coupling y_Ψ to Higgs
$\Delta M^2 \sim \mp \frac{y_\Psi^2}{(4\pi)^2} M_\Psi^2$
(e.g. String Theory: $M_\Psi \sim M_{Pl}$, $y_\Psi \sim 1$)
U
|H|



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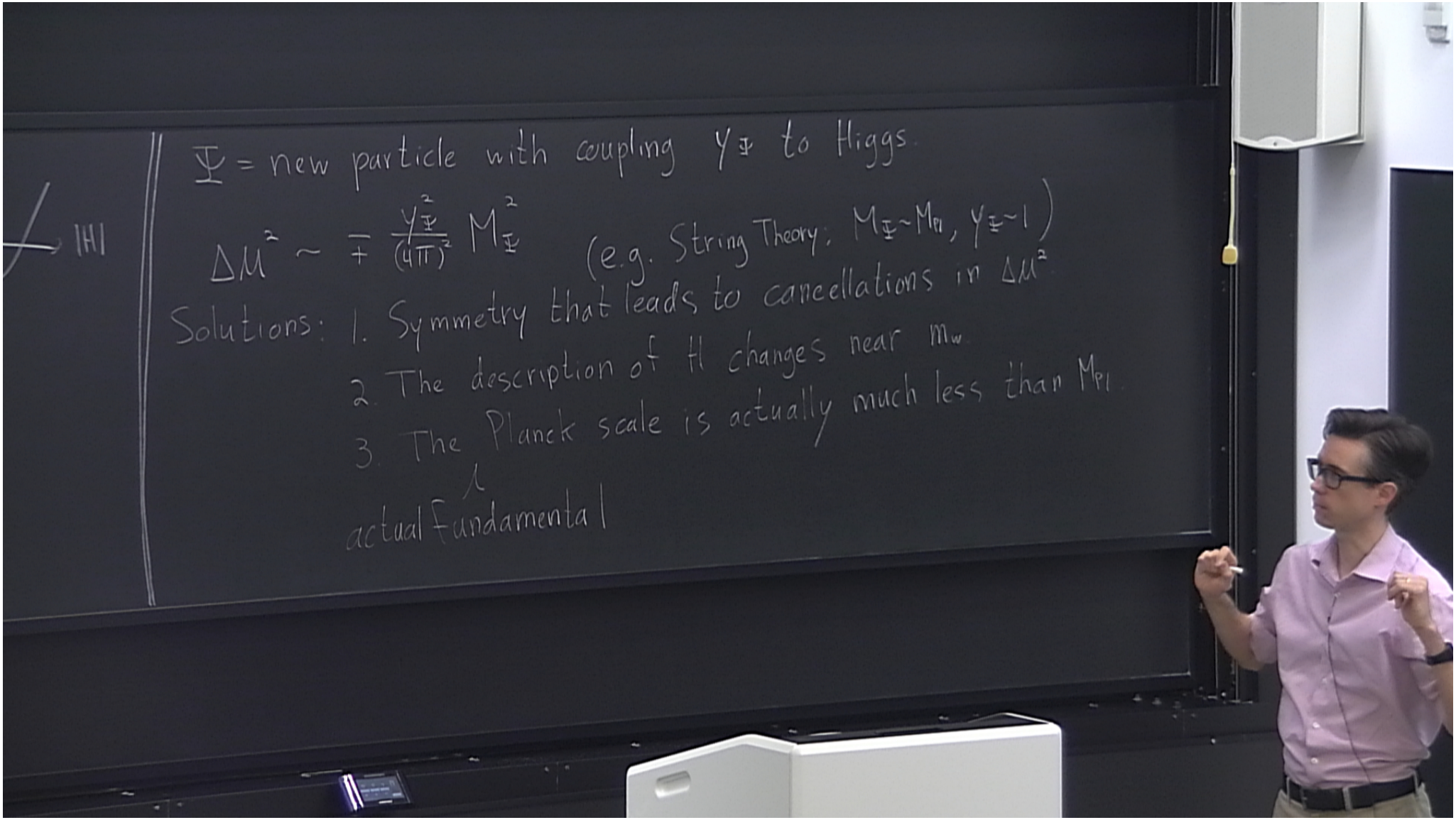
Solutions: 1. Symmetry that leads to cancellations in ΔM^2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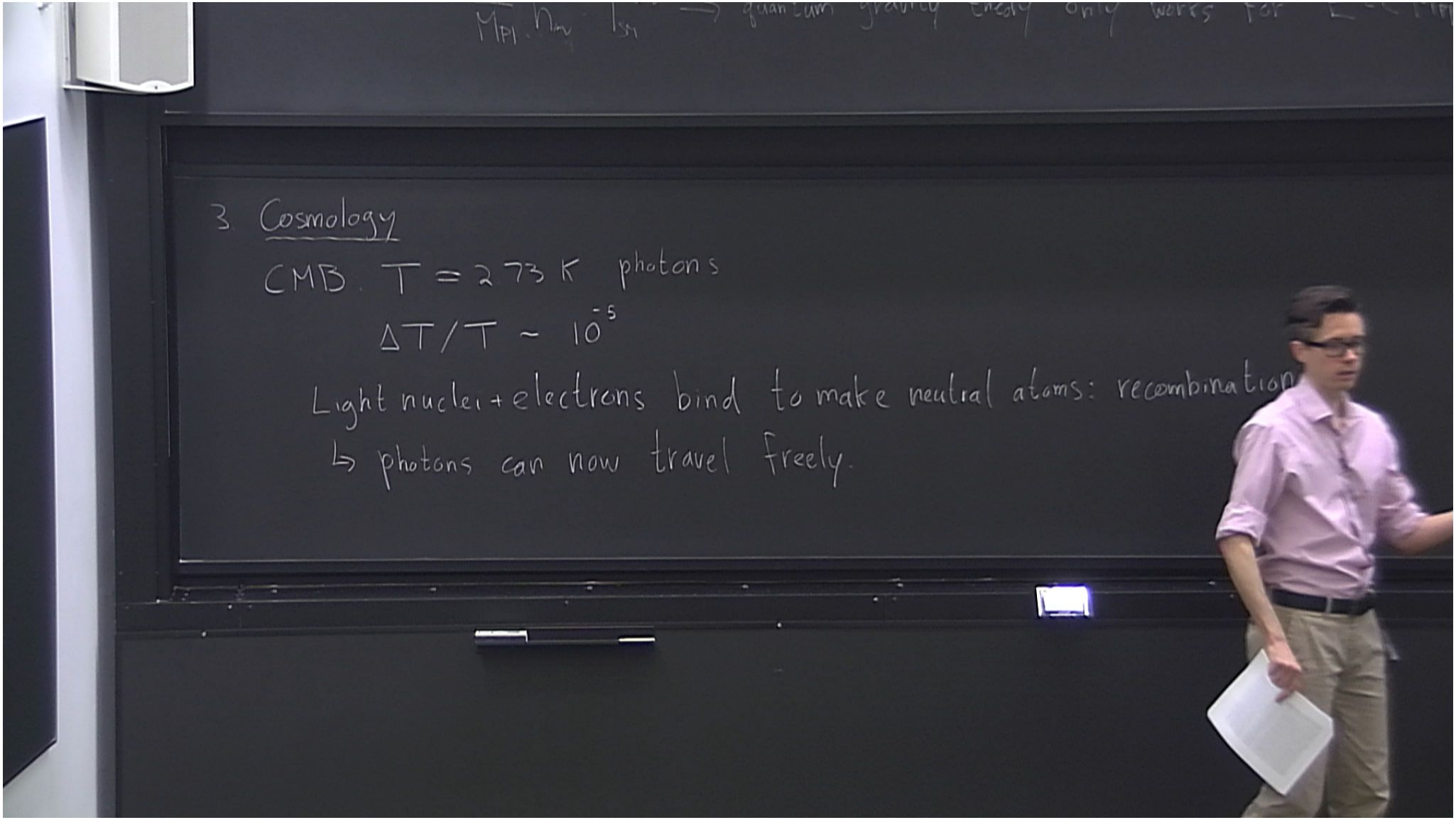
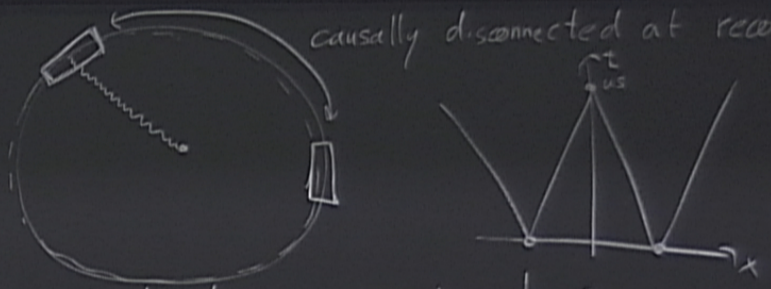
Solutions: 1. Symmetry that leads to cancellations in ΔM^2
2. The description of H changes near m_W
3. The Planck scale is actually much less than M_{Pl}
actual fundamental


3 Cosmology
CMB T = 2.73 K photons
ΔT/T ~ 10^-5
Light nuclei + electrons bind to make neutral atoms: recombination
↳ photons can now travel freely.

3 Cosmology

CMB $T = 2.73\,K$ photons

$\Delta T/T \sim 10^{-5}$

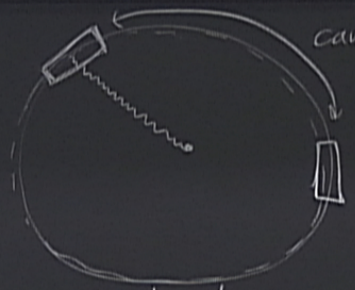


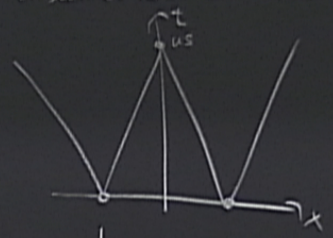
Light nuclei + electrons bind to make neutral atoms: recombination.

↳ photons can now travel freely.

couple directly to the SM.

causally disconnected at recombination





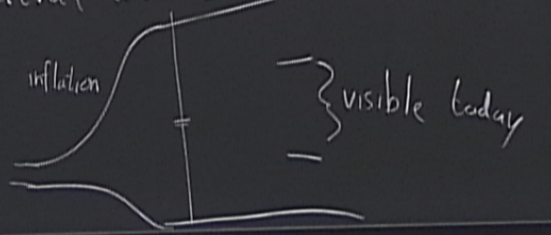
Motivates inflation

Driven by potential energy of a new scalar field

photons

ns bind to make neutral atoms: recombination.

travel freely.



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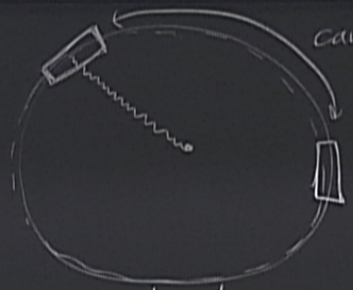

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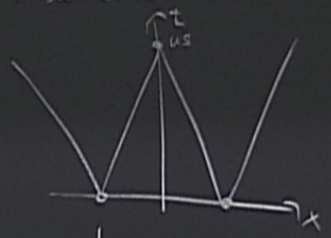

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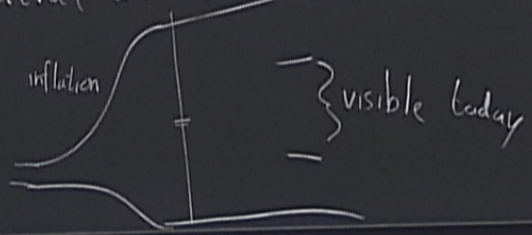
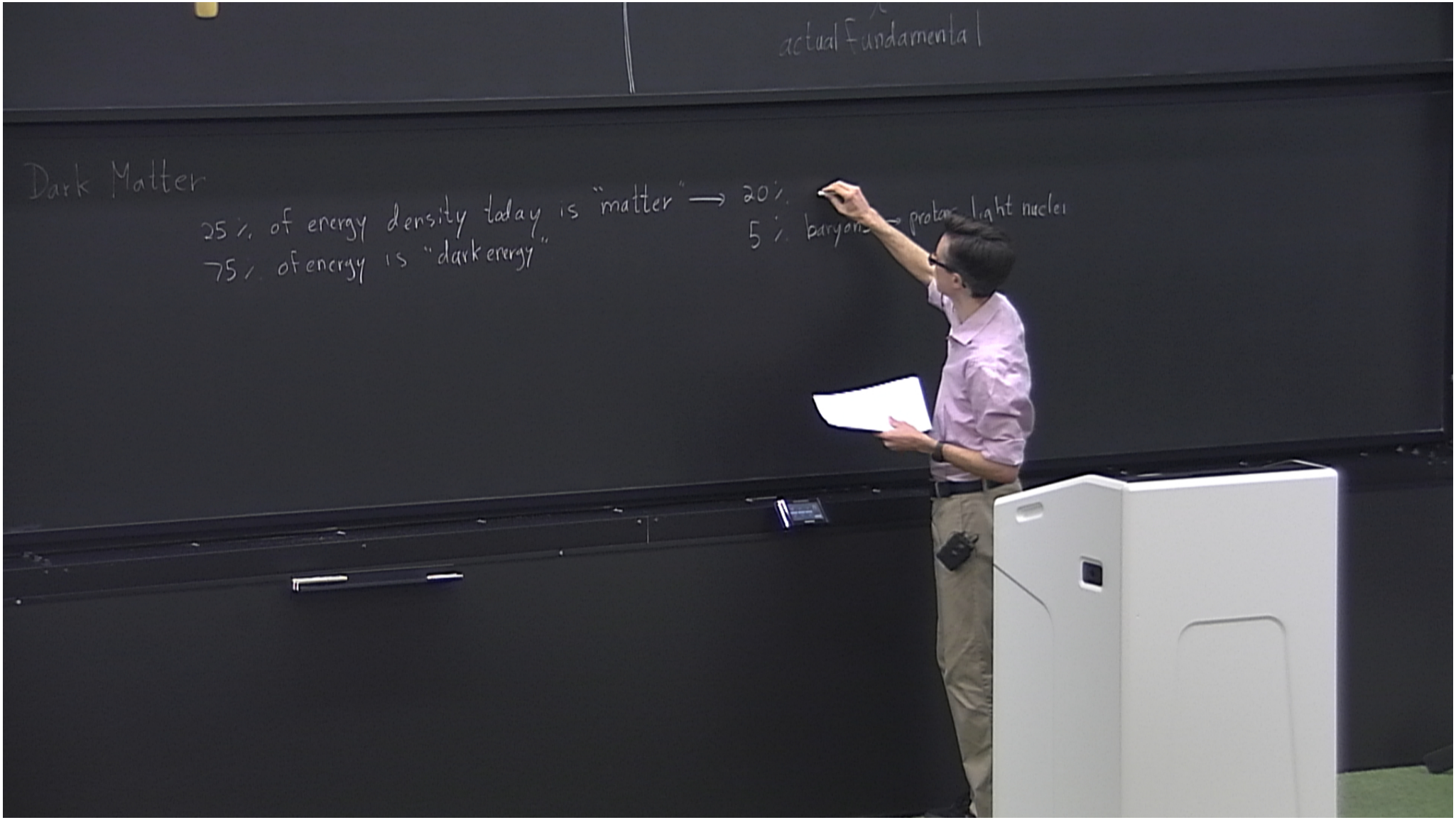
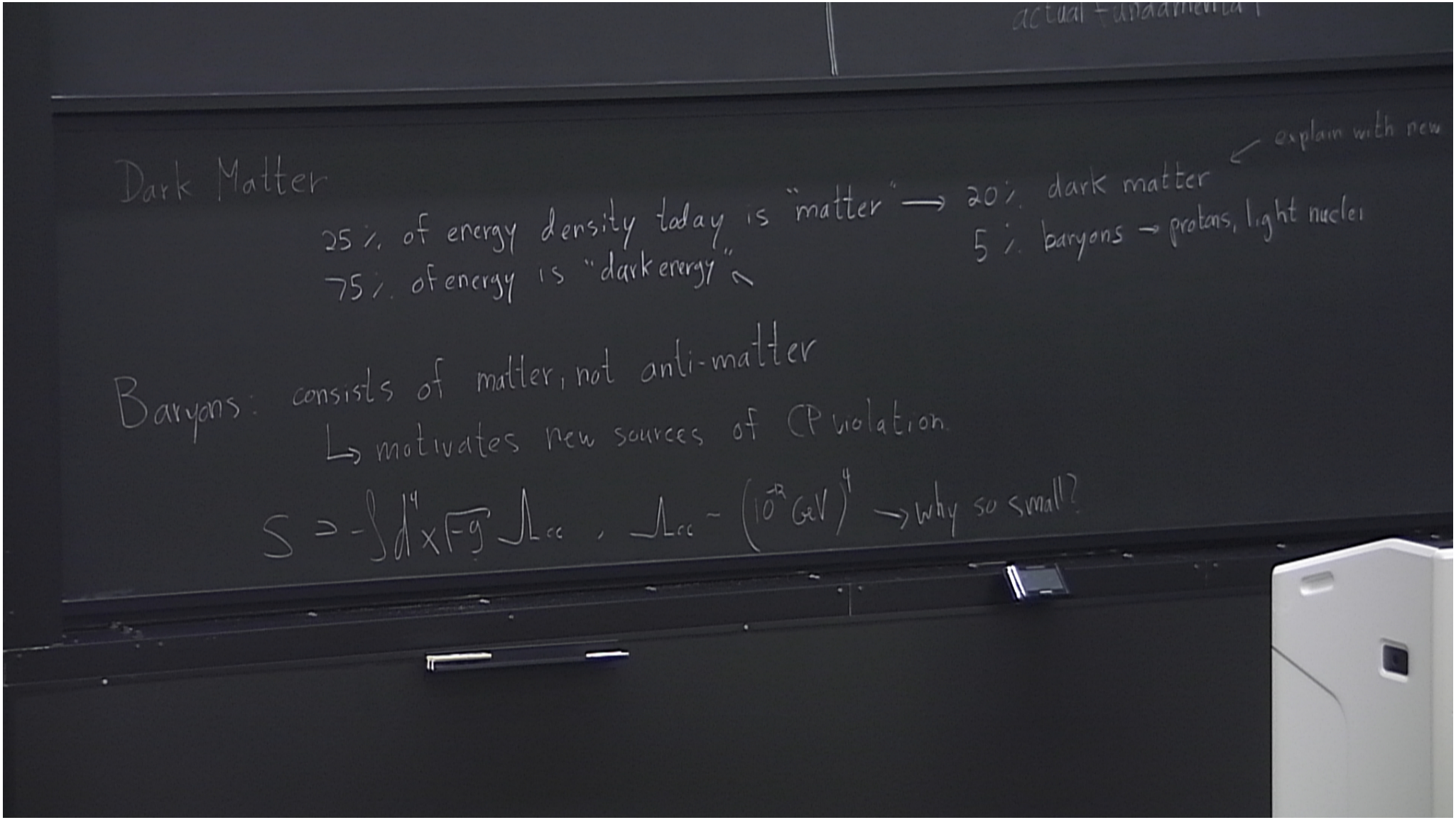
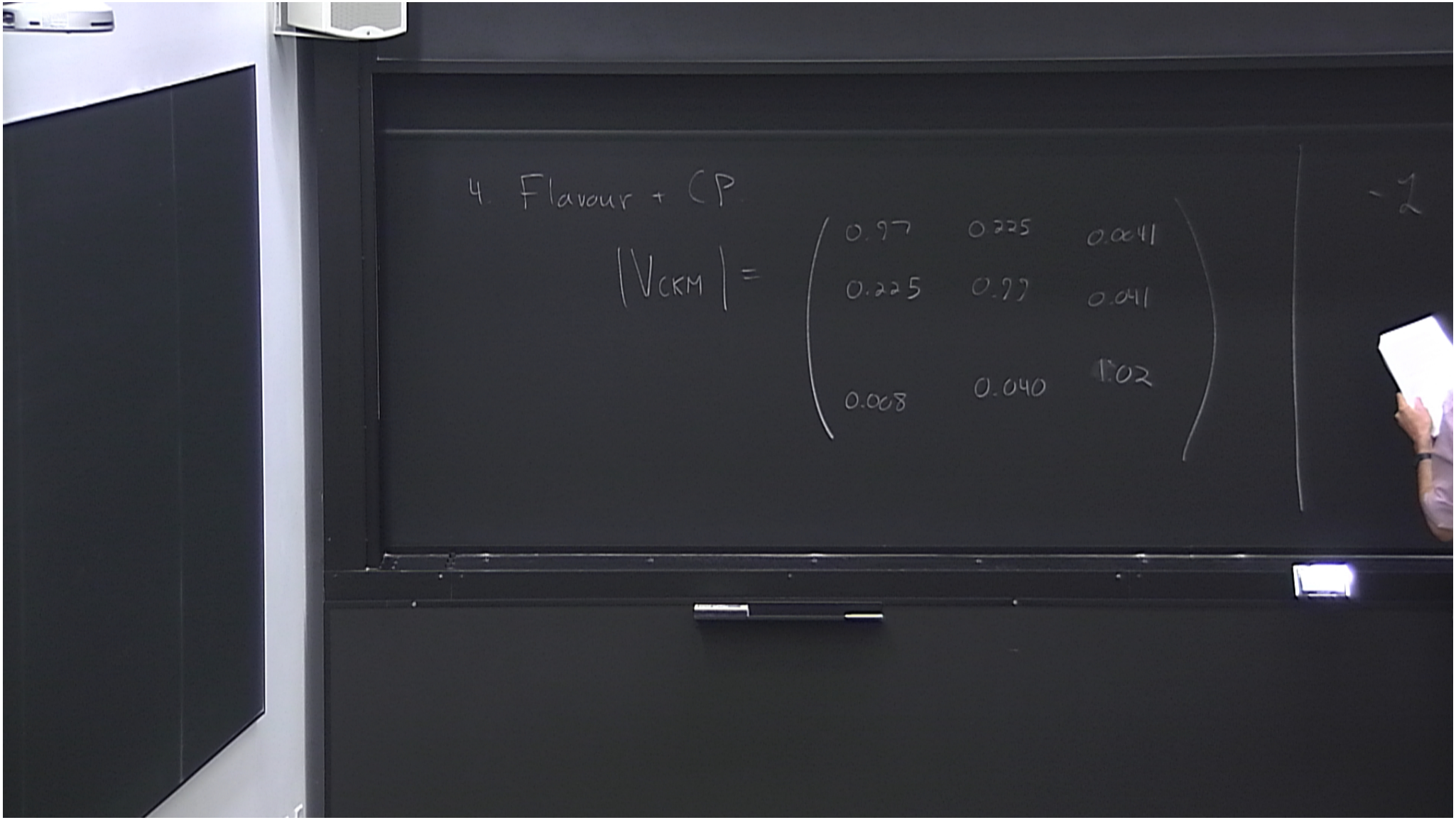
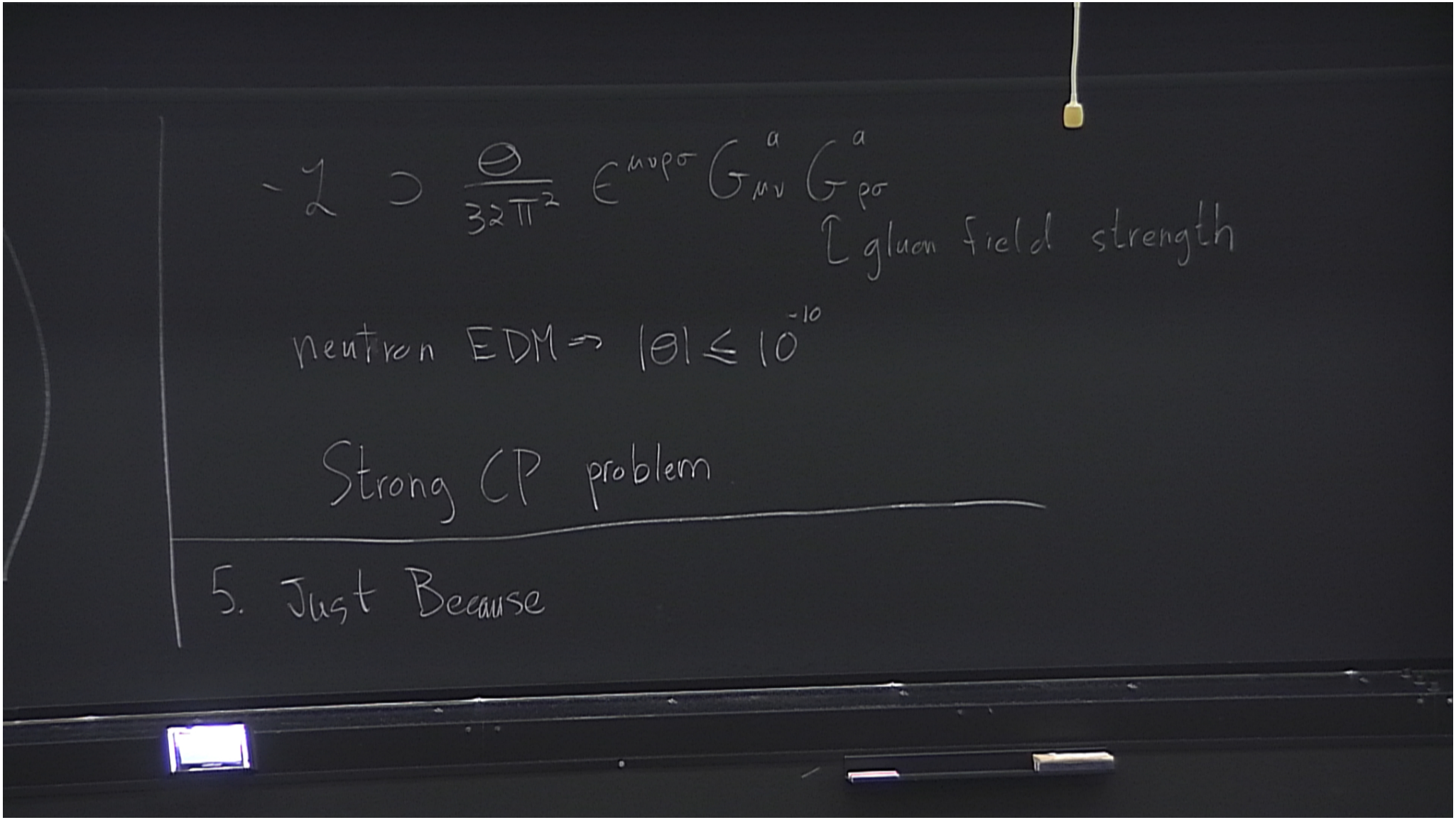



actual fundamental
Dark Matter
25 %. of energy density today is "matter" ⟶ 20 %.
5 %. baryons → protons, light nuclei
75 %. of energy is "dark energy"


actual fundamental
Dark Matter
25 %: of energy density today is "matter" → 20 %: dark matter ← explain with new
5 %: baryons → protons, light nuclei
75 %: of energy is "dark energy"
Baryons: consists of matter, not anti-matter
↳ motivates new sources of CP violation
$S = -\int d^4x \sqrt{-g}\, \mathcal{L}_{CC}$, $\mathcal{L}_{CC} \sim (10^{-12}\,\mathrm{GeV})^4$ → why so small?


4. Flavour + CP
$|V_{CKM}| = \begin{pmatrix} 0.97 & 0.225 & 0.041 \\ 0.225 & 0.97 & 0.041 \\ 0.008 & 0.040 & 1.02 \end{pmatrix}$


$-\mathcal{L} \supset \frac{\theta}{32\pi^2} \epsilon^{\mu\nu\rho\sigma} G^a_{\mu\nu} G^a_{\rho\sigma}$
[gluon field strength
neutron EDM → $|\theta| \leq 10^{-10}$
Strong CP problem
5. Just Because