Title: Quantum simulations/computing

Speakers: Matthew Johnson

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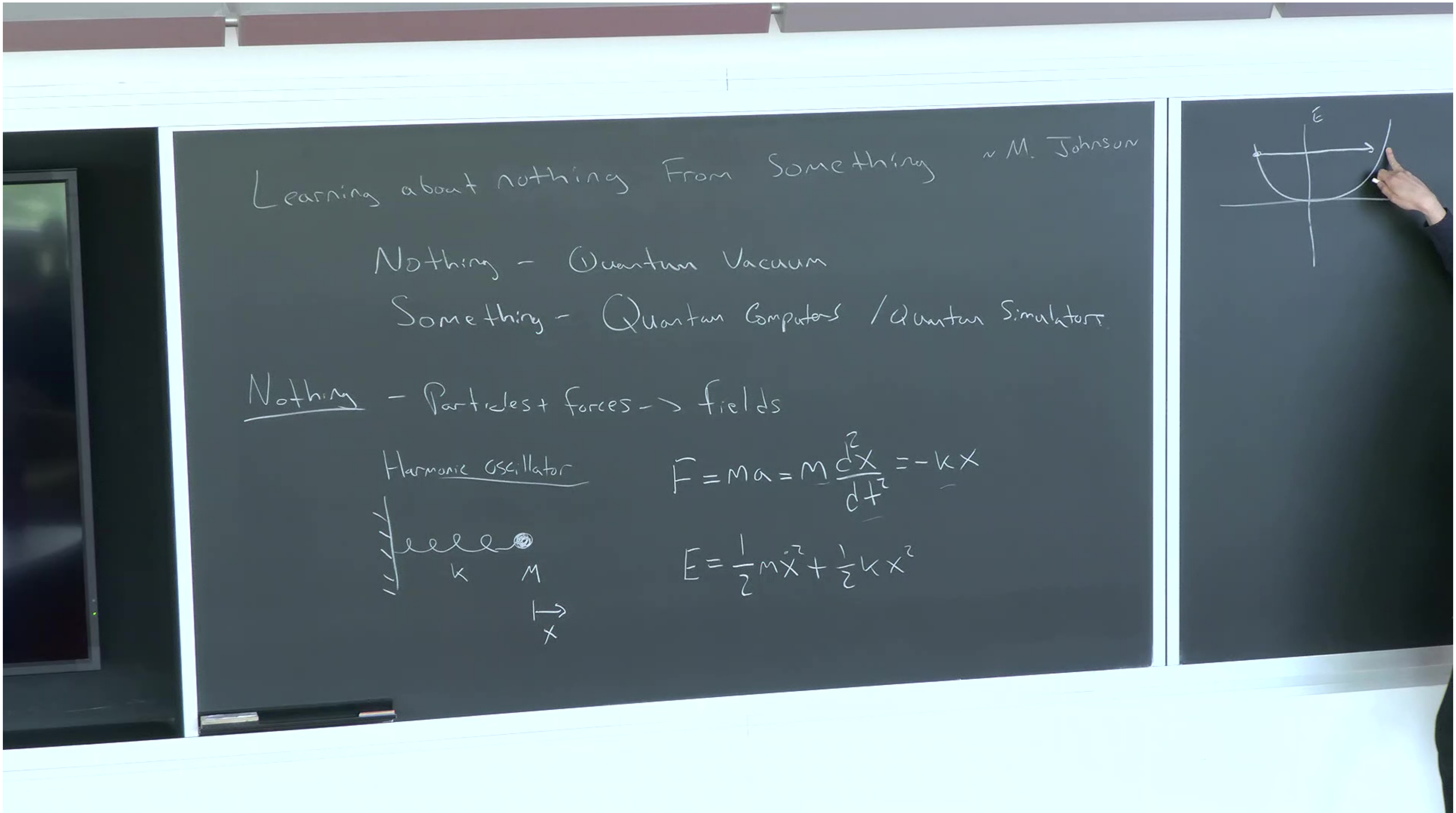
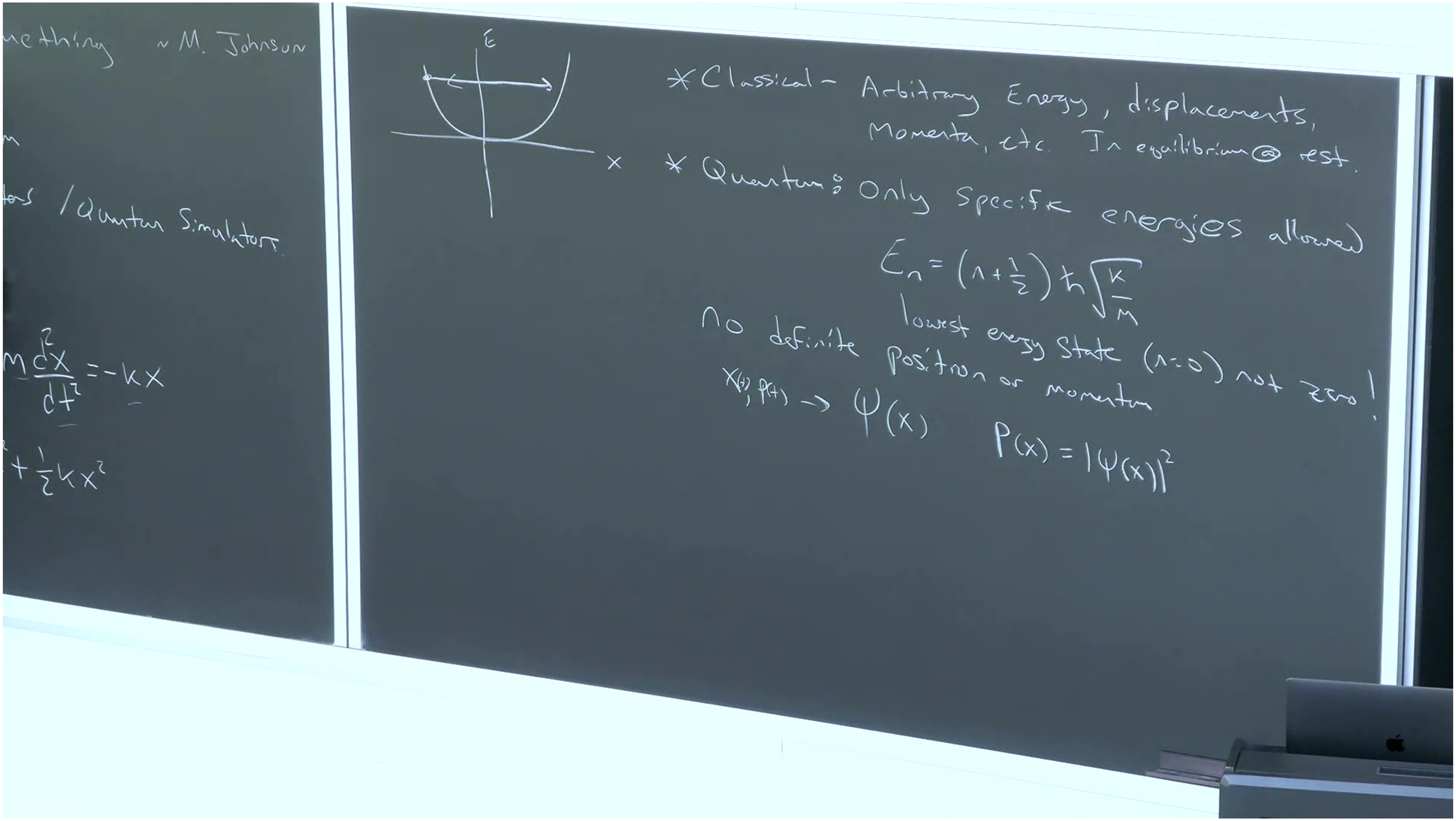
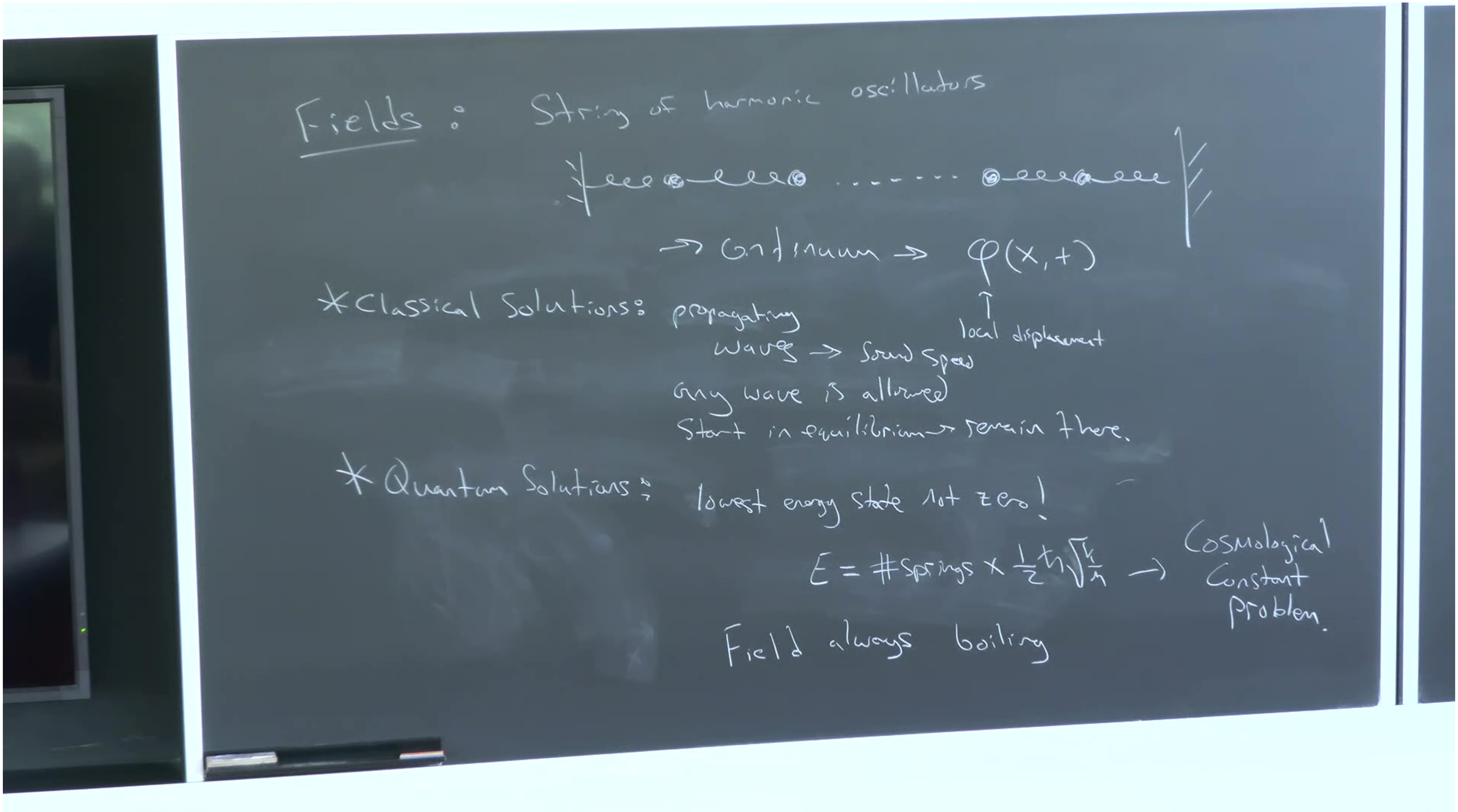
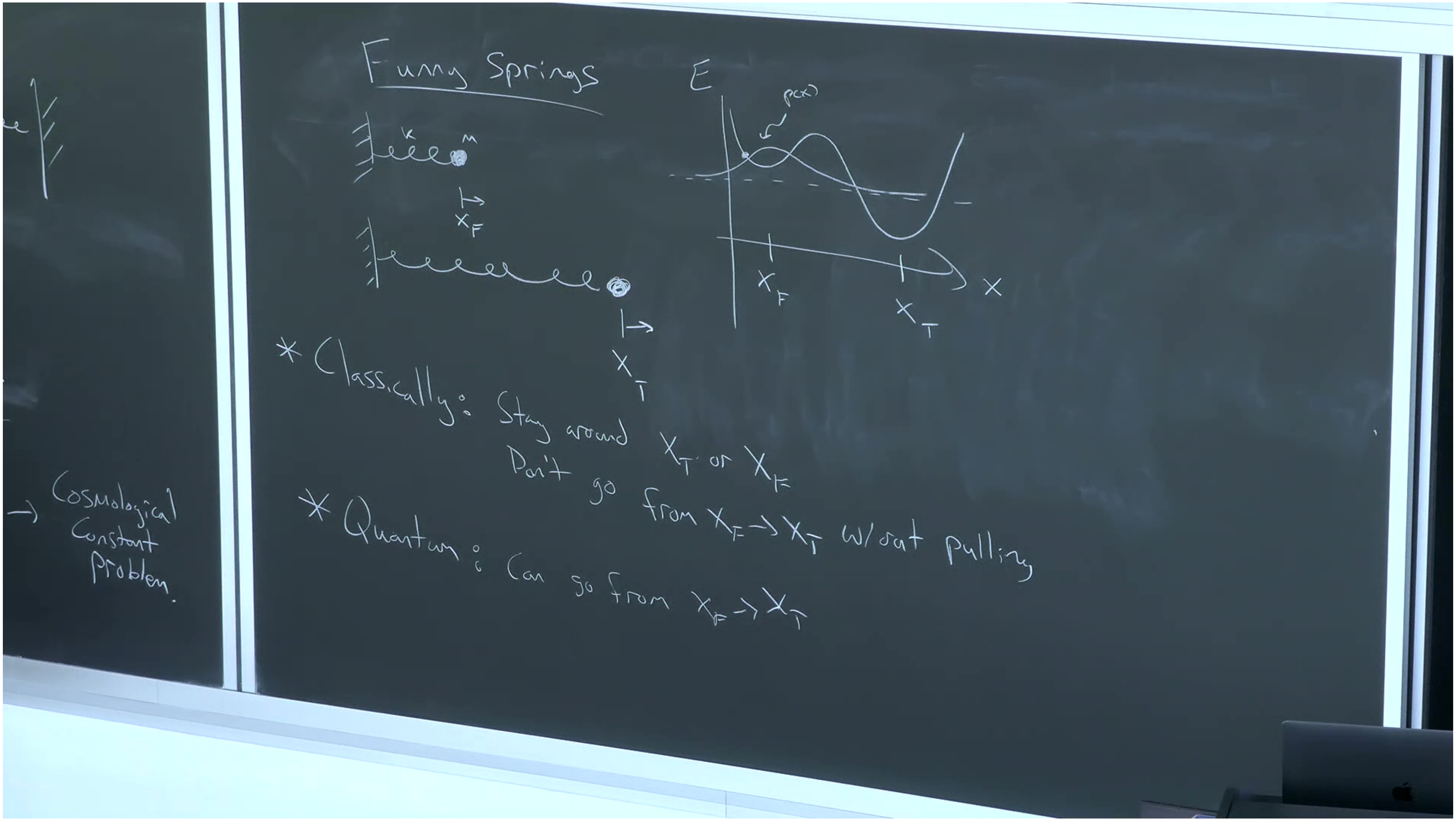
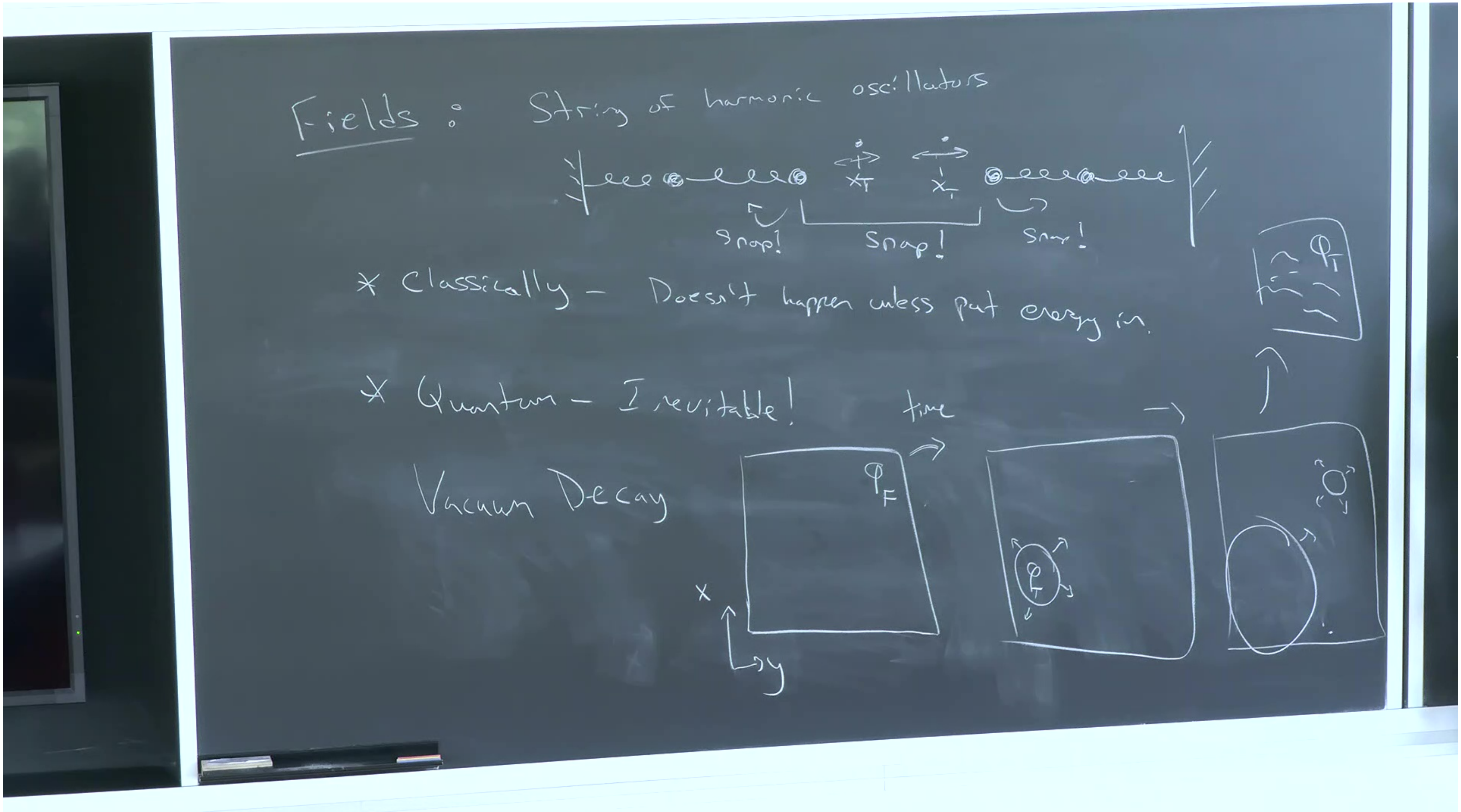

Learning about nothing From Something
~ M. Johnson
Nothing - Quantum Vacuum
Something - Quantum Computers / Quantum Simulators
Nothing - Particles + forces -> fields
Harmonic oscillator
$F = ma = m\frac{d^2x}{dt^2} = -kx$
k
M
x
$E = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}kx^2$
E

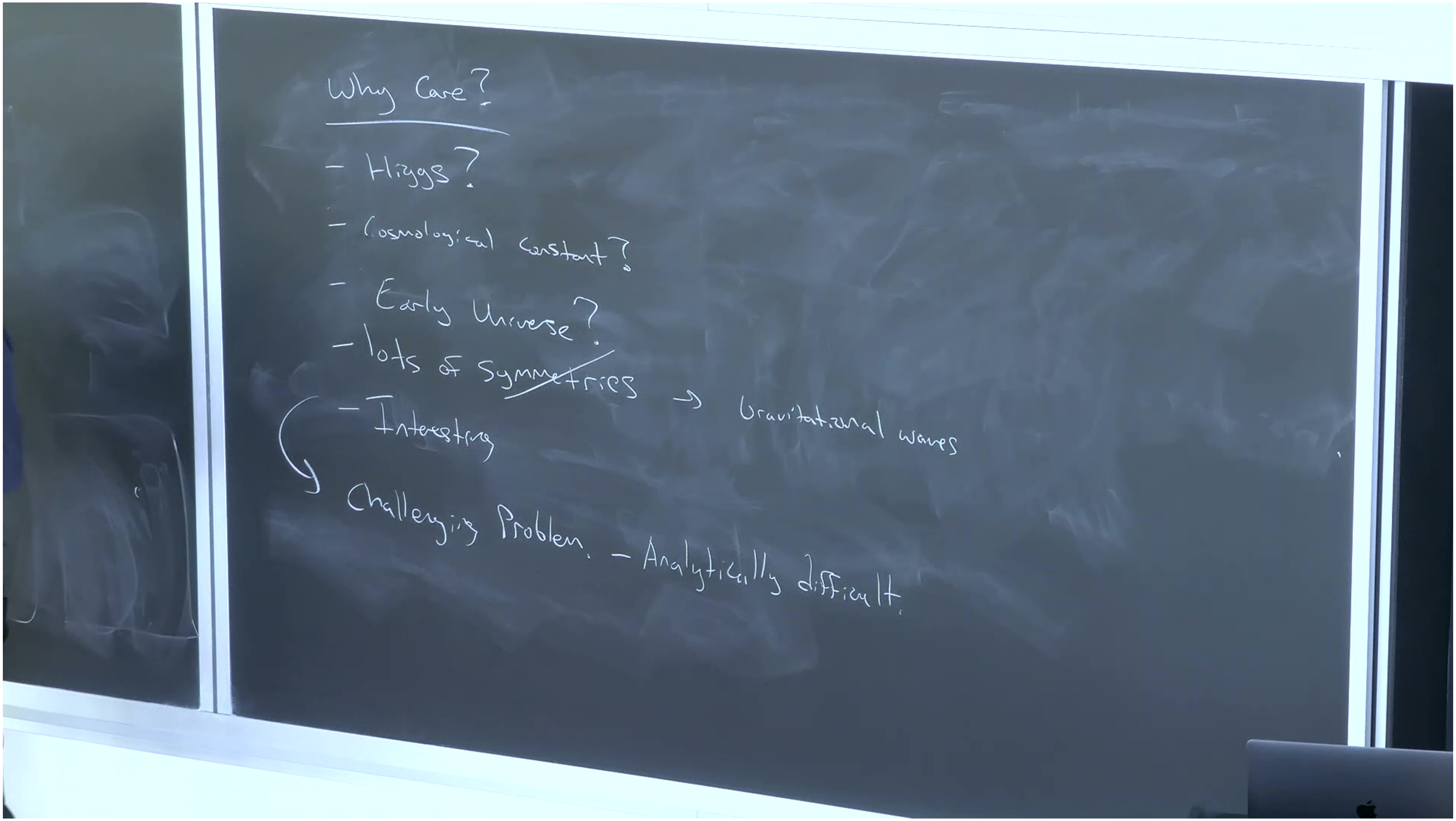

~ M. Johnson
/Quantum Simulators
* Classical - Arbitrary Energy, displacements, Momenta, etc. In equilibrium @ rest.
* Quantum: Only Specific energies allowed
E_n = (n + 1/2) ħ √(k/m)
lowest energy State (n=0) not zero!
no definite position or momentum
x(t), p(t) → ψ(x)
P(x) = |ψ(x)|²
m d²x/dt² = -kx
+ 1/2 kx²

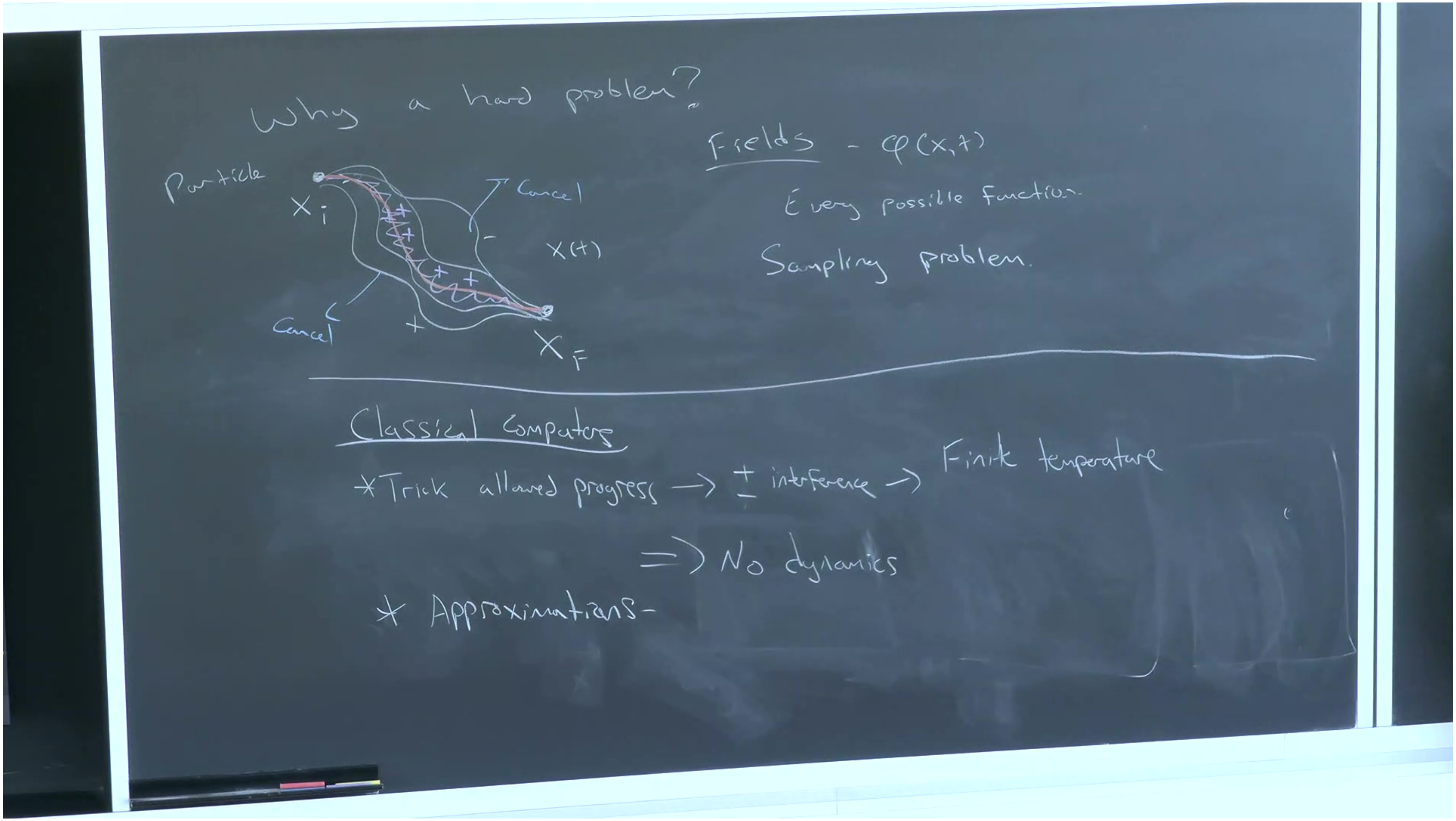

Fields :
String of harmonic oscillators
→ Continuum → φ(x,t)
local displacement
* Classical Solutions: propagating
waves → sound speed
any wave is allowed
Start in equilibrium → remain there.
* Quantum Solutions: lowest energy state not zero!
E = #springs × ½ħ√(k/m) →
Cosmological Constant Problem.
Field always boiling

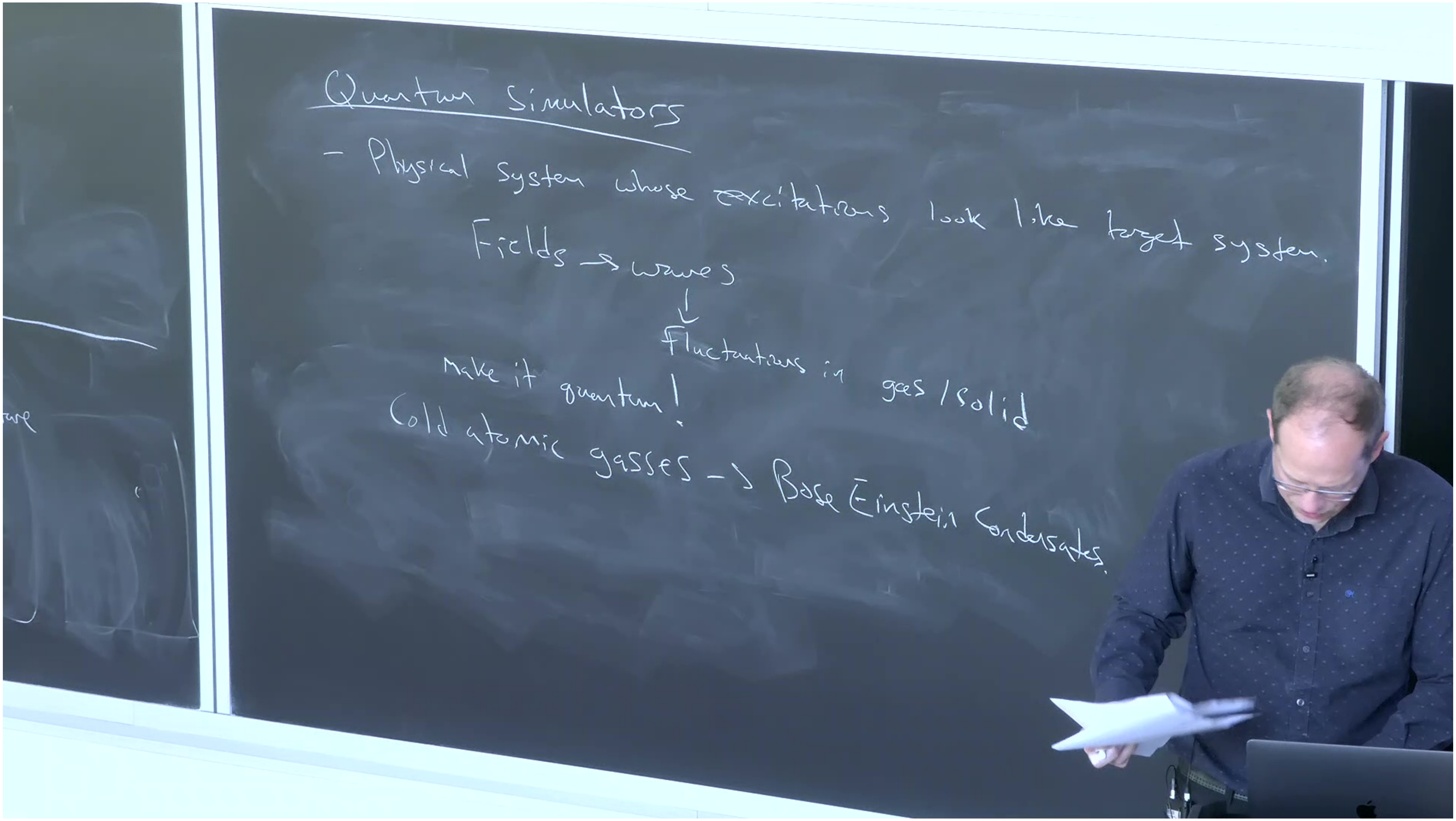


Funny Springs
k
m
x_F
x_T
E
ρ(x)
x_F
x_T
x
* Classically: Stay around x_T or x_F
Don't go from x_F → x_T w/out pulling
* Quantum: Can go from x_F → x_T
→ Cosmological Constant Problem.


Fields : String of harmonic oscillators
Snap!
Snap!
Snap!
* Classically - Doesn't happen unless put energy in.
* Quantum - Inevitable!
time
Vacuum Decay
φ_F
φ_T
x
y


Why Care?
- Higgs?
- Cosmological constant?
- Early Universe?
- lots of Symmetries
→ Gravitational waves
- Interesting
Challenging Problem. - Analytically difficult.


Why a hard problem?
Particle
X_i
Cancel
$X(t)$
Cancel
X_F
Fields - $\varphi(x,t)$
Every possible function
Sampling problem
Classical Computers
*Trick allowed progress → ± interference → Finite temperature
⇒ No dynamics
* Approximations -


Quantum Simulators
- Physical system whose excitations look like target system.
Fields → waves
Fluctuations in gas/solid
Make it quantum!
Cold atomic gasses → Bose Einstein Condensates.

QSimFP

QSimFP
Quantum Simulators for Fundamental Physics

https://qsimfp.org

Consortium of theorists/ experimentalists in UK/Canada funded by UKRI to develop quantum simulators of fundamental physics in cosmology and black holes.

Quantum simulators of false vacuum decay

- Two-species Bose-Einstein Condensate systems can serve as quantum simulators of false vacuum decay:

GPEs:

$$i\hbar\dot{\psi}_1 = -\frac{\hbar^2\nabla^2}{2m}\psi_1 + \boxed{g_s\left|\psi_1\right|^2\psi_1 + g_c\left|\psi_2\right|^2\psi_1} - \boxed{\nu\psi_2}$$

$$i\hbar\dot{\psi}_2 = -\frac{\hbar^2\nabla^2}{2m}\psi_2 + \boxed{g_s\left|\psi_2\right|^2\psi_2 + g_c\left|\psi_1\right|^2\psi_2} - \boxed{\nu\psi_1}$$

scattering mixing/coupling

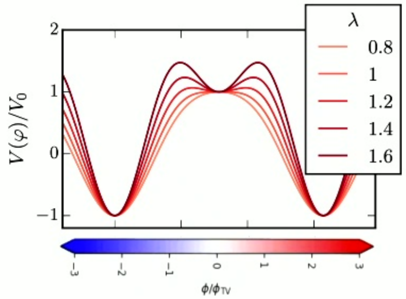
Son & Stephanov; Fialkov et. al.

- Change basis $\psi_i = \sqrt{\rho_i}e^{i\phi_i}$ and integrate out density and total phase:

$$\mathcal{L}_{\rm eff} = \frac{\dot{\varphi}^2}{2} - \frac{(\nabla\varphi)^2}{2} + \frac{4\nu\bar{n}(g_s - g_c)}{\hbar^2}\cos\varphi \qquad \varphi \equiv \phi_1 - \phi_2$$

See 1712.02356 for details.

Quantum simulators of false vacuum decay



See 1904.07873 for details.