Title: Quantum simulations/computing

Speakers: Matthew Johnson

Collection: SciComm Collider 2

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URL: https://pirsa.org/24050064

Learning about nothing From Something ~ M. Johnson

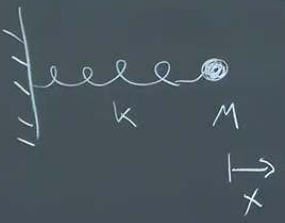
Nothing - Quantum Vacuum

Something - Quantum Computers / Quantum Simulators

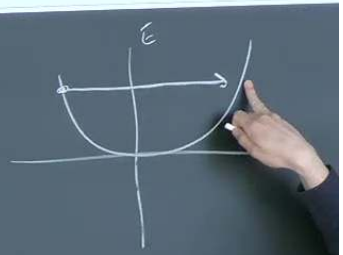
Nothing - Particles + forces -> fields

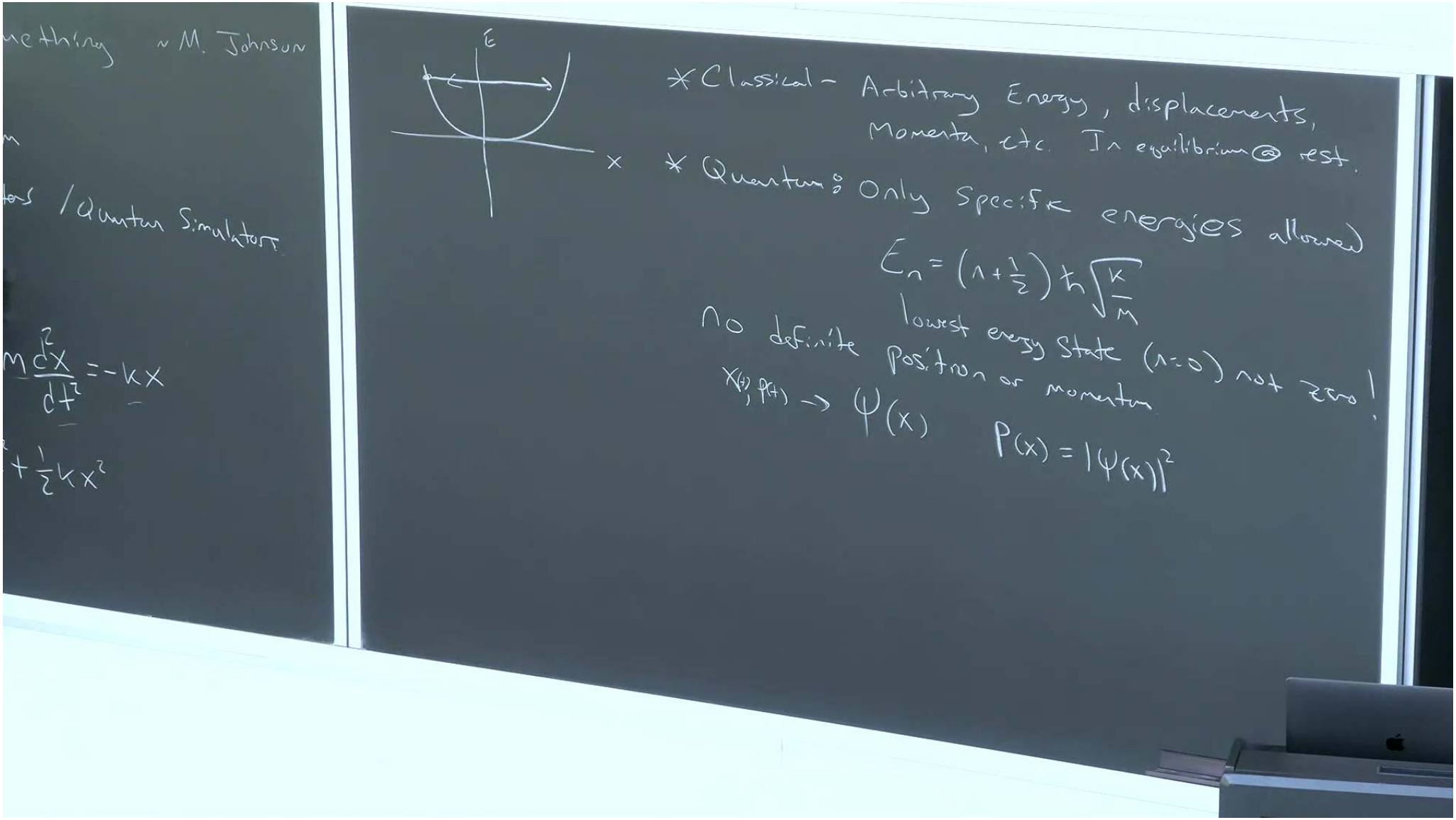
Harmonic oscillator

$$F = ma = m\frac{d^2x}{dt^2} = -kx$$



$$E = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}kx^2$$




E
x
* Classical - Arbitrary Energy, displacements, Momenta, etc. In equilibrium @ rest.
* Quantum: Only specific energies allowed
$E_n = (n+\frac{1}{2})\hbar\sqrt{\frac{k}{m}}$
lowest energy state (n=0) not zero!
No definite position or momentum
$x(t), p(t) \rightarrow \psi(x)$
$P(x) = |\psi(x)|^2$
$m\frac{d^2x}{dt^2} = -kx$
$+\frac{1}{2}kx^2$

Fields: String of harmonic oscillators

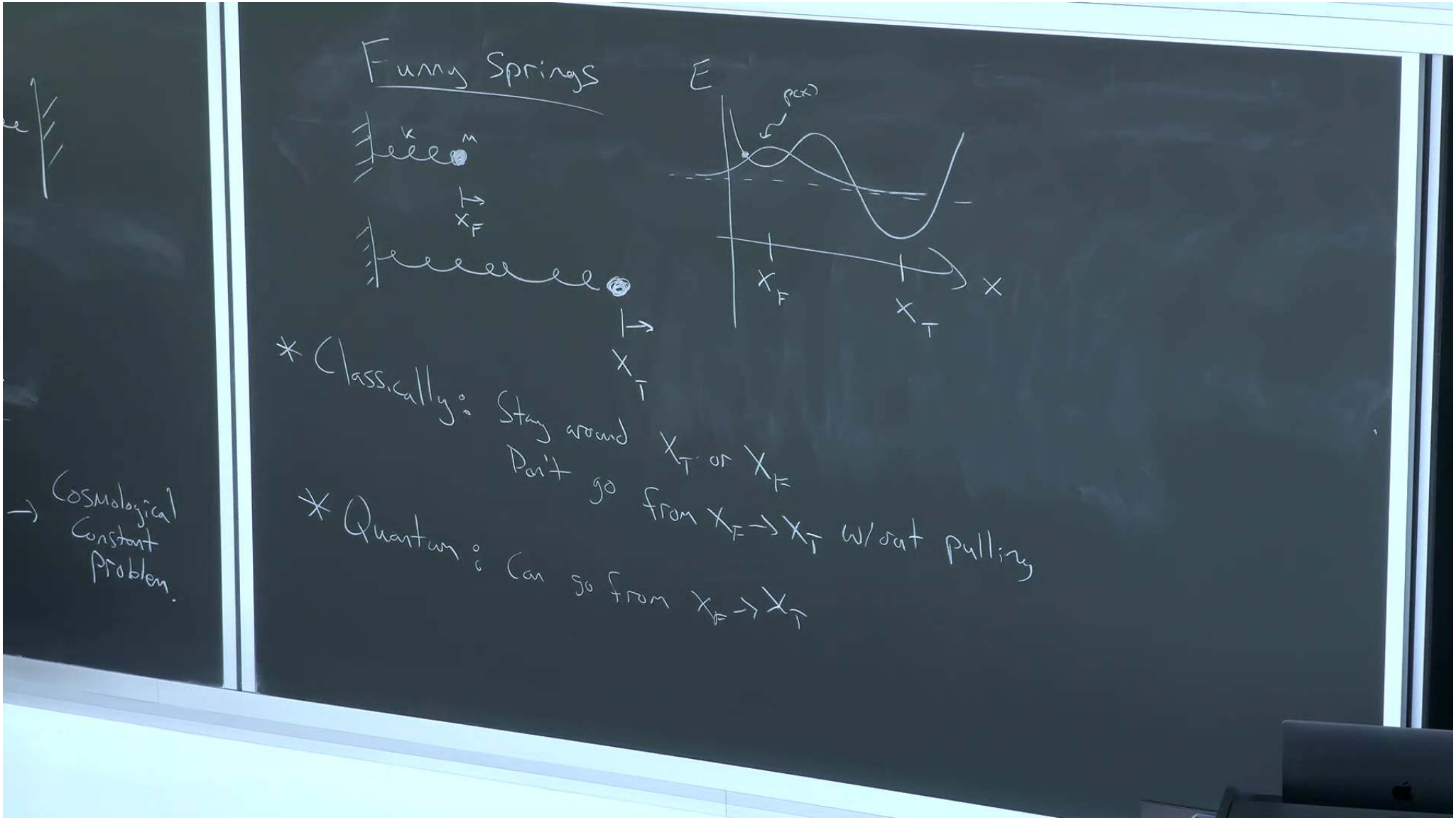
→ Continuum → $\varphi(x,t)$ ← local displacement

*Classical Solutions: propagating waves → sound speed
any wave is allowed
Start in equilibrium → remain there.

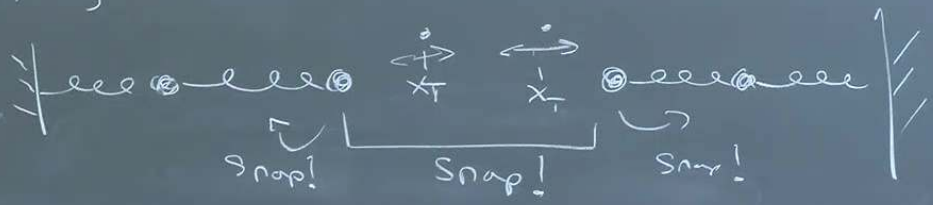
*Quantum Solutions: lowest energy state not zero!

$E = \#\text{Springs} \times \frac{1}{2}\hbar\sqrt{\frac{k}{m}}$ → Cosmological Constant problem.

Field always boiling


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

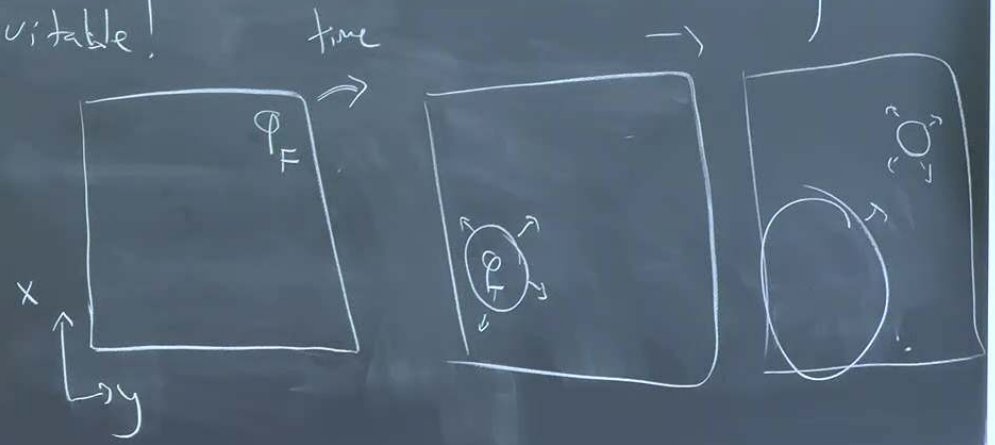
Fields : String of harmonic oscillators

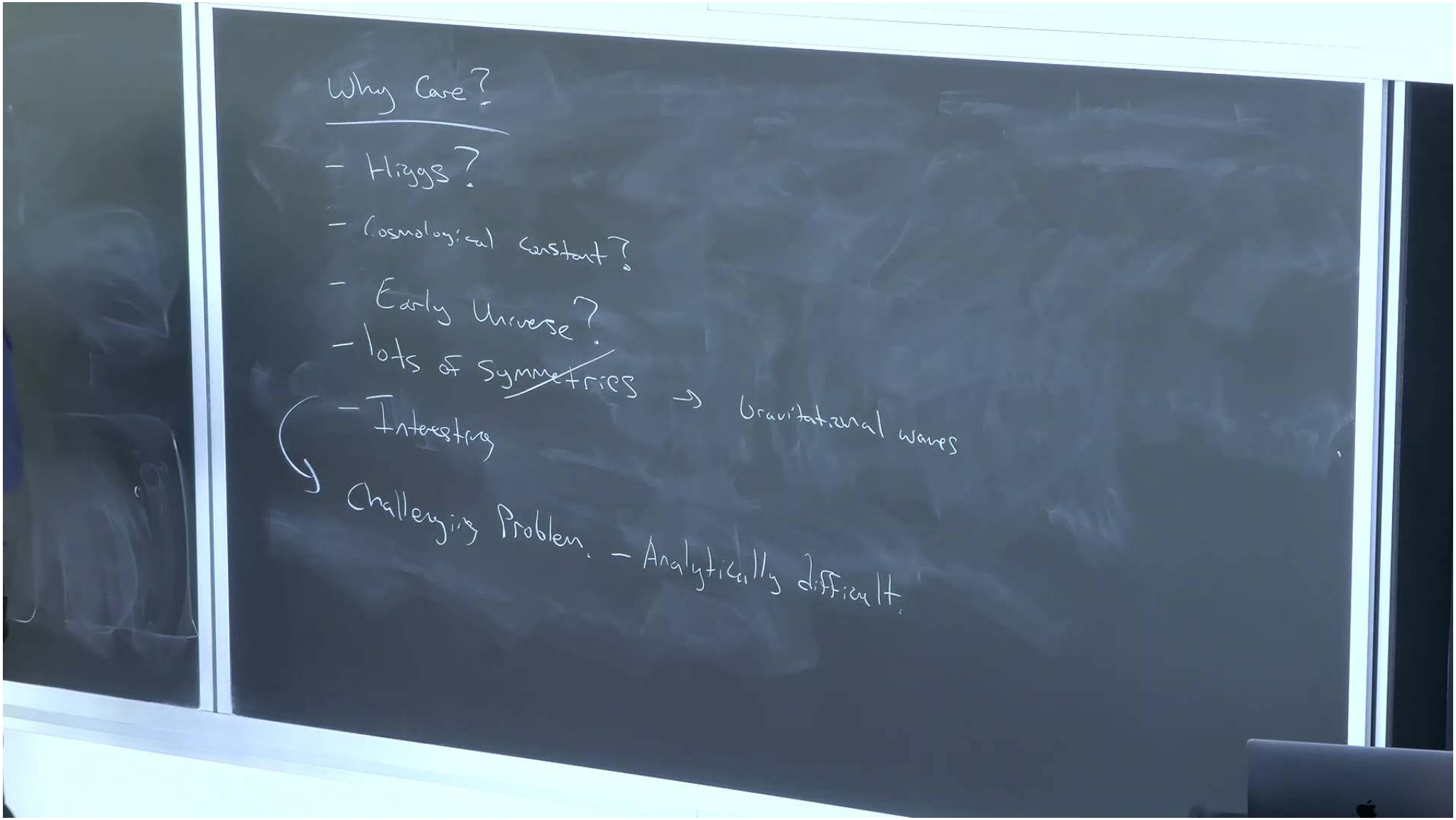


* Classically - Doesn't happen unless put energy in.

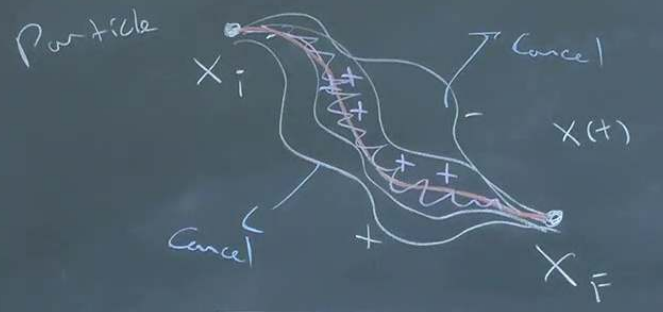
* Quantum - Inevitable!

Vacuum Decay




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

Why a hard problem?



Fields - $\varphi(x,t)$

Every possible function.

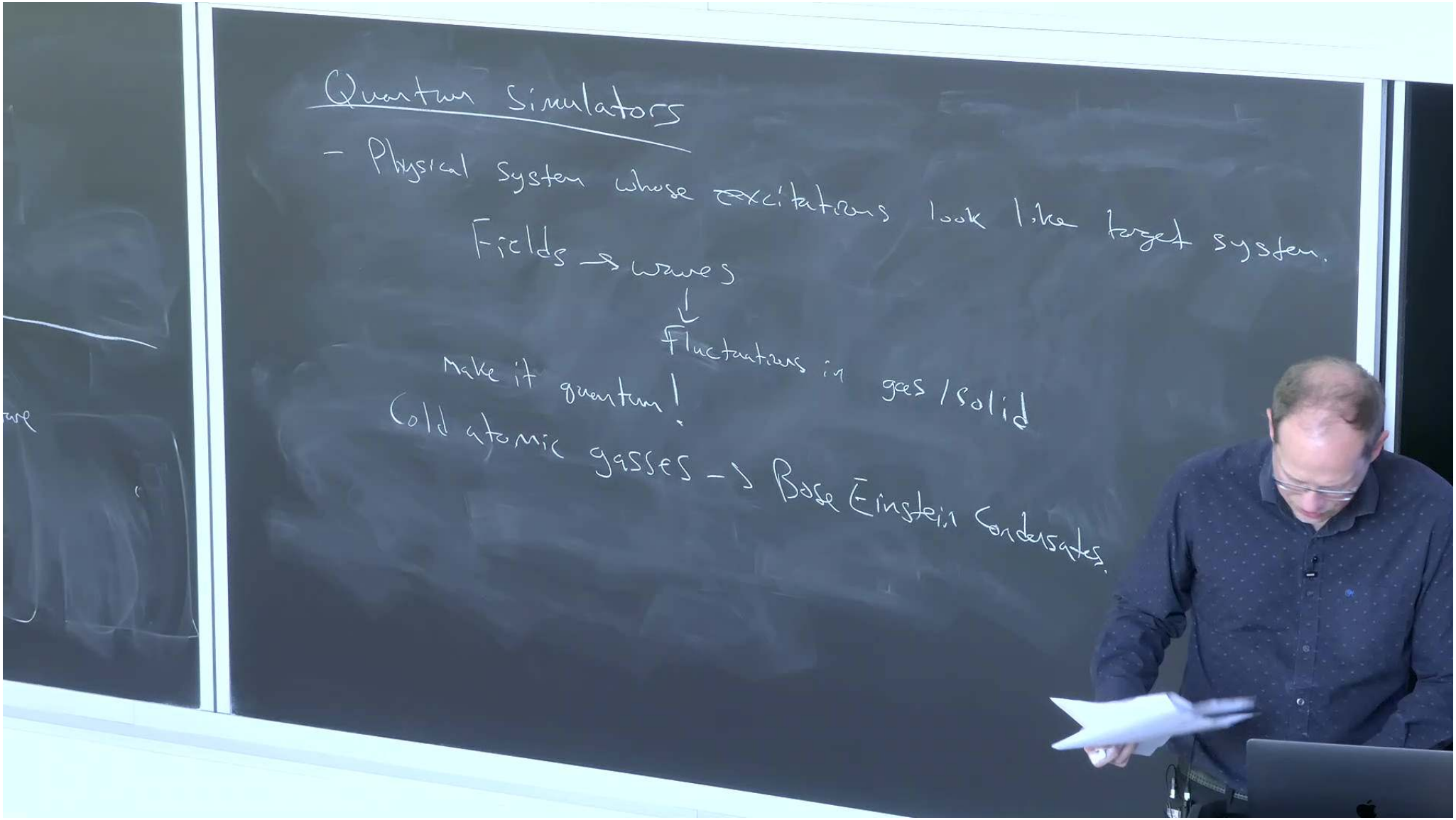
Sampling problem.

Classical Computers

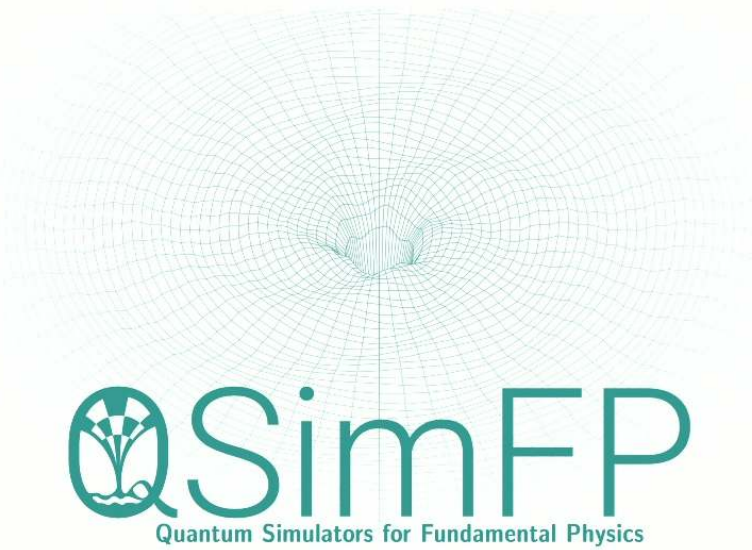
* Trick allowed progress → ± interference → Finite temperature

⇒ 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



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:

$$i\hbar\dot{\psi}_1 = -\frac{\hbar^2\nabla^2}{2m}\psi_1 + \underbrace{g_s\left|\psi_1\right|^2\psi_1 + g_c\left|\psi_2\right|^2\psi_1}_{\text{scattering}} - \underbrace{\nu\psi_2}_{\text{mixing/coupling}}$$

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

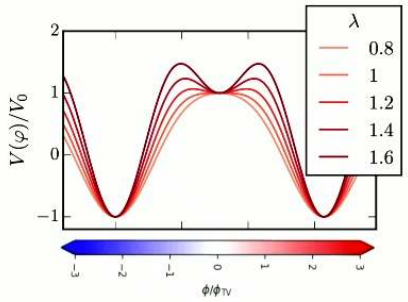
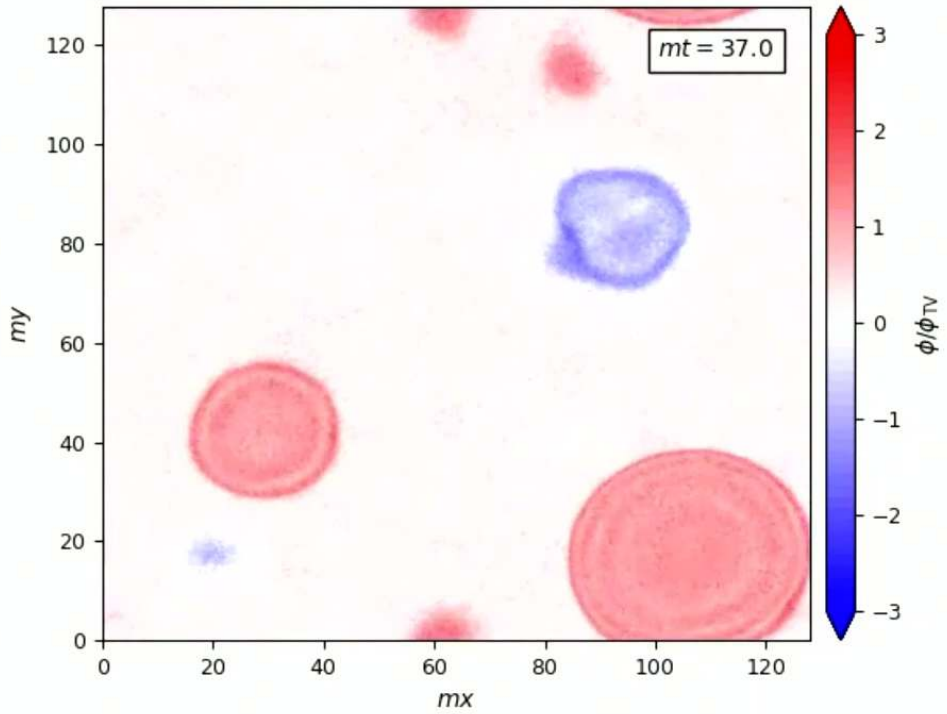
Son & Stephanov; Fialkov et. al.

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

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

See 1712.02356 for details.

Quantum simulators of false vacuum decay



See 1904.07873 for details.