Title: Particle Physics Lecture - 230329

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Collection: Particle Physics (2022/2023)

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Last Lecture:

Misalignment &

$\theta \to \boxed{\frac{a}{f_a}}$ then

computed $a(t)$

$\underline{H = m_a(T)}$ @ $T \sim T_{QCD}$

Strings & DWs

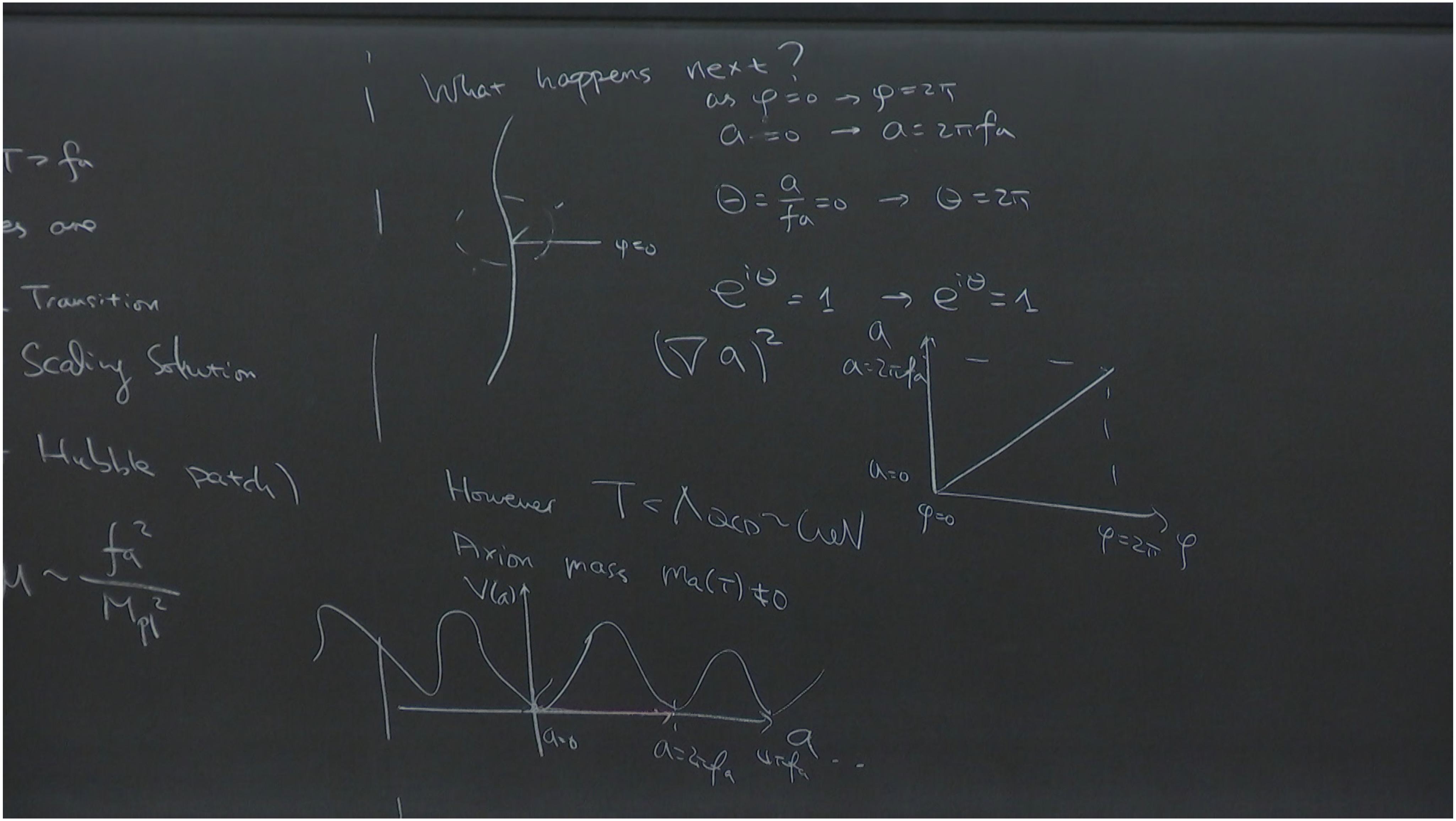
What happens when $T > f_a$

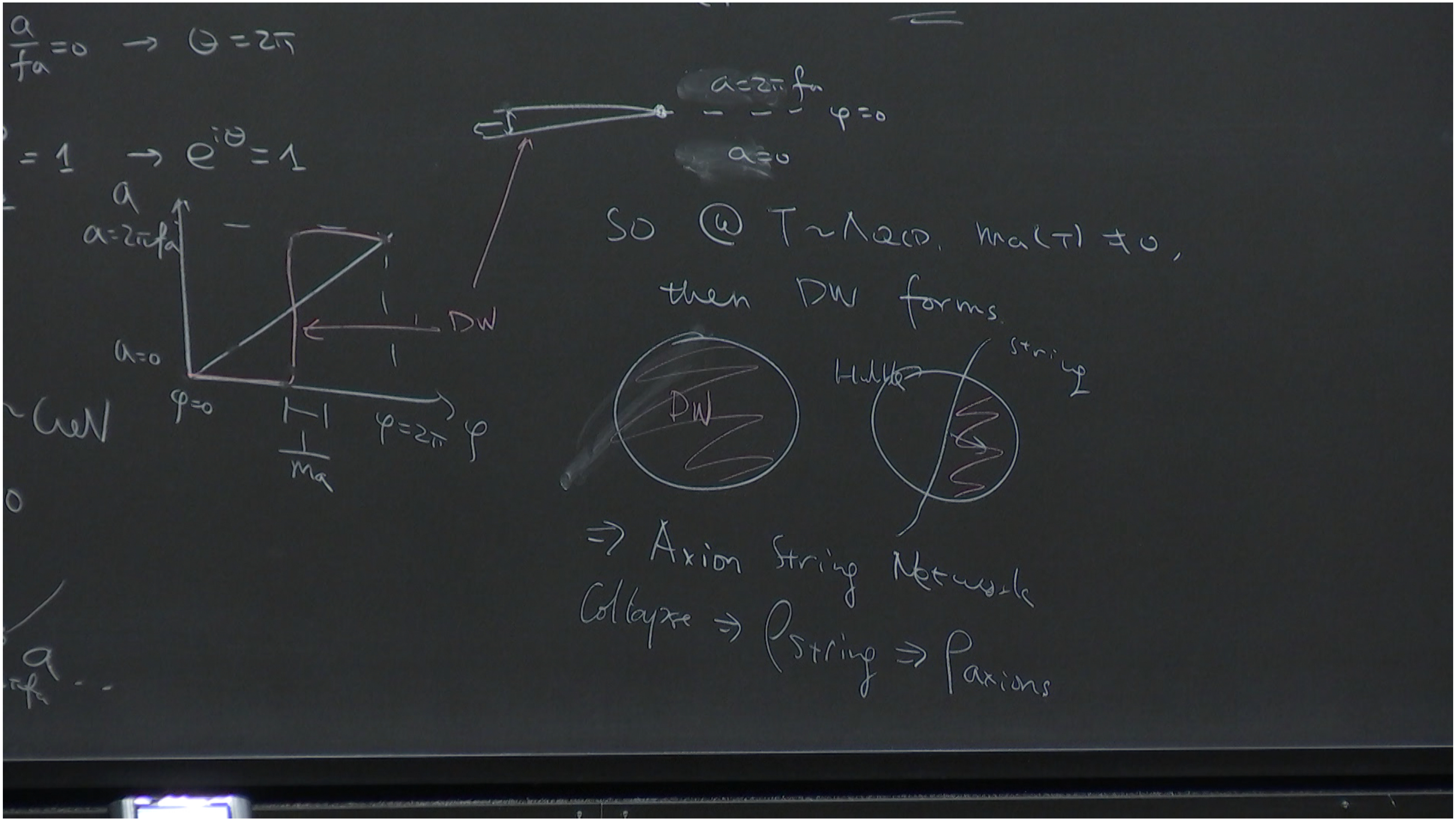
→ High T, symmetries are restored → Phase Transition

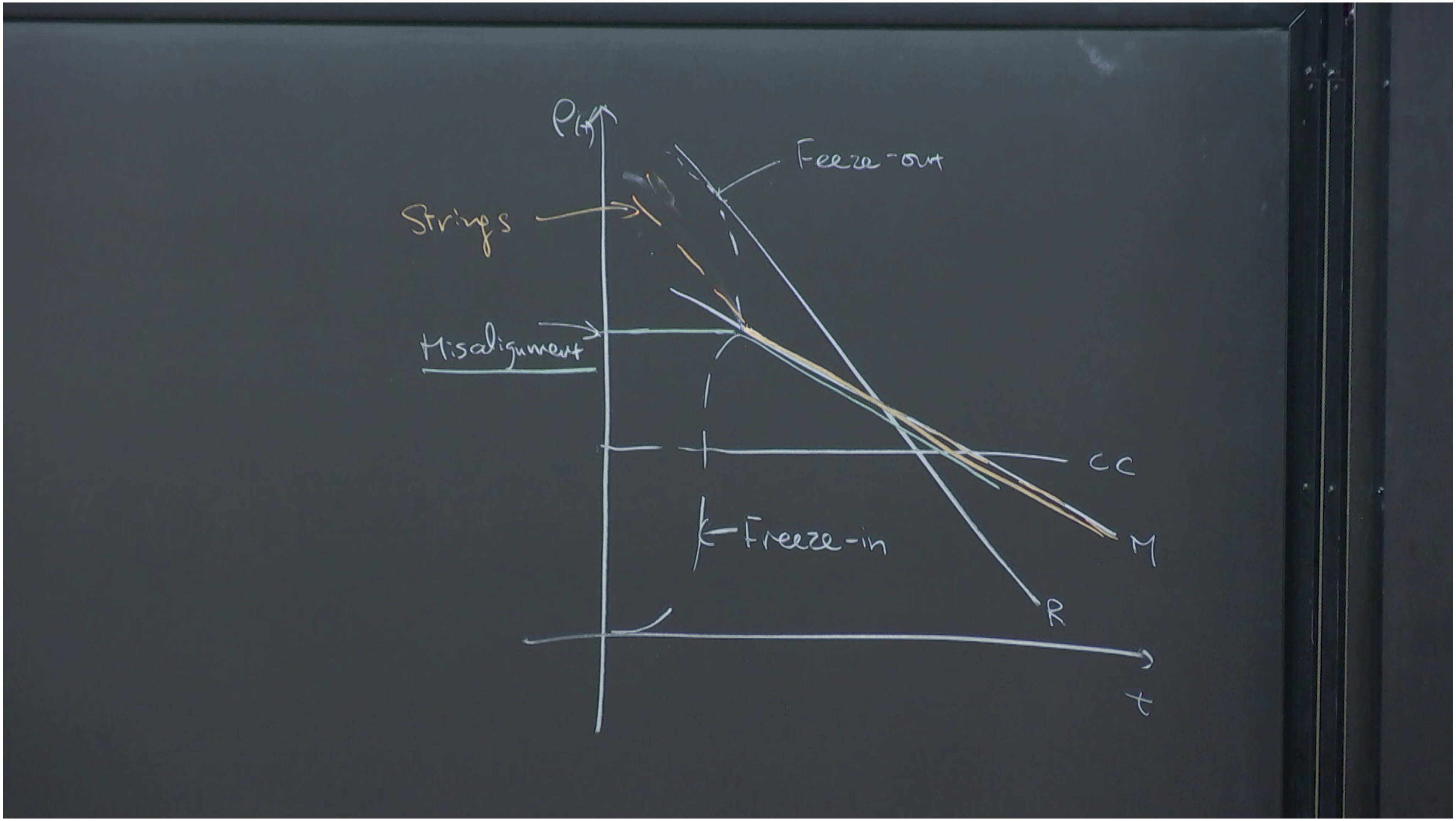
→ Strings & DW → Scaling Solution

($\mathcal{O}(1)$ string per Hubble patch)

* $\frac{\rho_{string}}{\rho_\gamma} = G \cdot \mu \sim \frac{f_a^2}{M_{pl}^2}$


What happens next?
as φ = 0 → φ = 2π
a = 0 → a = 2π fa
Θ = a/fa = 0 → Θ = 2π
e^{iΘ} = 1 → e^{iΘ} = 1
(∇a)^2
φ = 0
a = 2π fa
a = 0
φ = 2π
However T < Λ_QCD ~ GeV
Axion mass m_a(T) ≠ 0
V(a)
a = 0
a = 2π f_a
4π f_a
T > fa
Transition
Scaling Solution
Hubble patch)
μ ~ fa^2 / Mpl^2


a/fa = 0 → Θ = 2π
= 1 → e^{iΘ} = 1
a
a=2πfa
a=0
φ=0
1/ma
φ=2π
φ
DW
~GeV
a=2πfa
φ=0
a=0
SO @ T~ΛQCD, ma(T) ≠ 0,
then DW forms
DW
Hubble
string
⇒ Axion String Network
Collapse ⇒ ρstring ⇒ ρaxions



ρ(t)
Freeze-out
Strings
Misalignment
CC
Freeze-in
M
R
t

$\lesssim \Lambda_{QCD}$

$(\nabla a)^2 + V(a)$

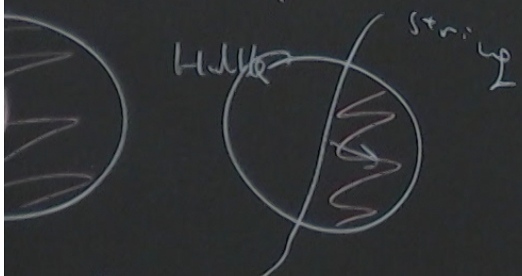
$a = 2\pi f_a$

$\varphi = 0$

$a = 0$

@ $T \sim \Lambda_{QCD}$, $m_a(T) \neq 0$,

en DW forms.



on String Network

$\Rightarrow \rho_{string} \Rightarrow \rho_{axions}$

ρ_{string} @ $T = \Lambda_{QCD}$

$\underline{H = m_a}$ $\quad \dfrac{\rho_s}{\rho_\gamma} \simeq \dfrac{f_a^2}{M_{pl}^2}$

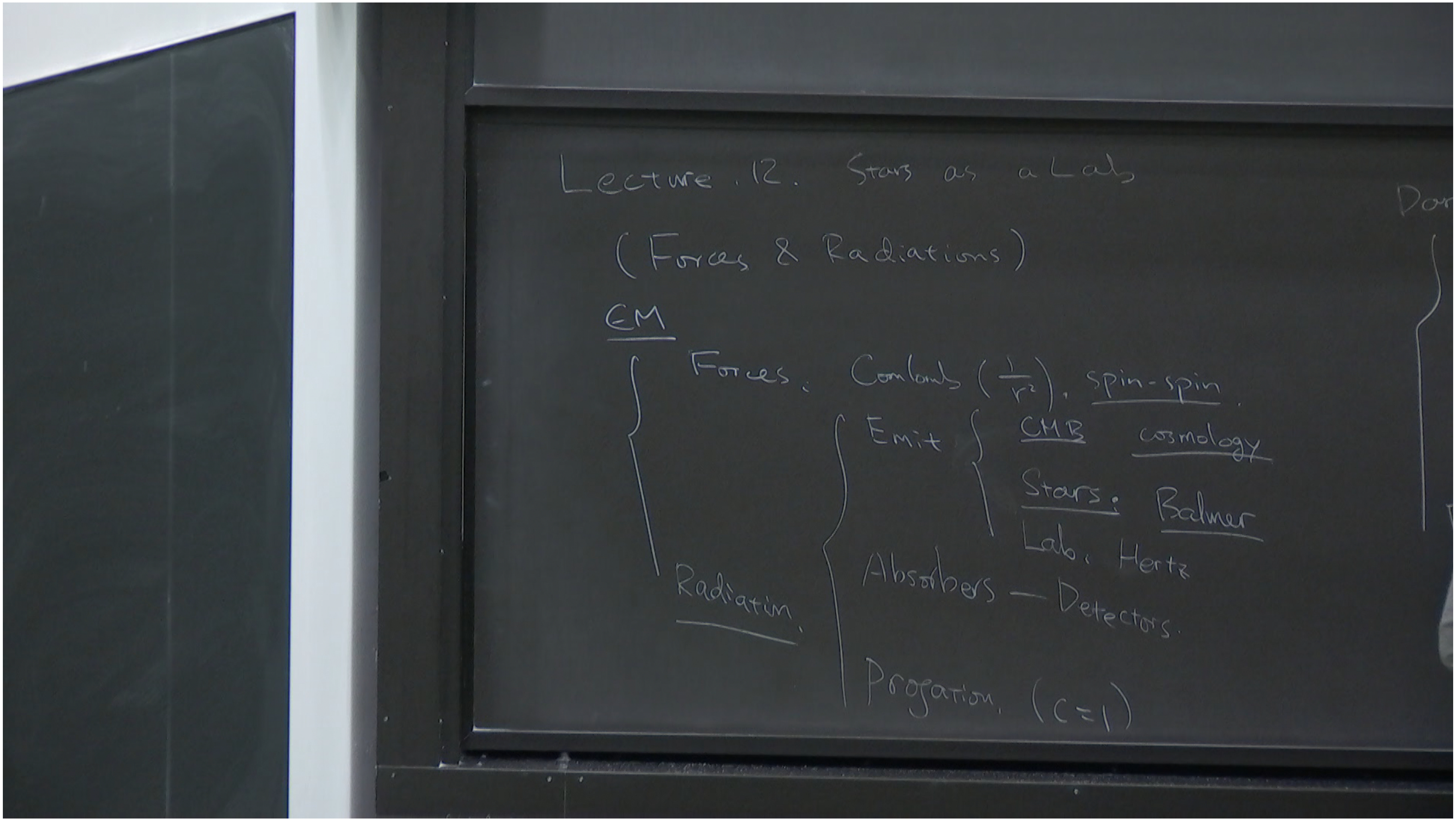
$$\rho_a \simeq \frac{f_a^2}{M_{pl}^2} \cdot \underbrace{m_a^2 M_{pl}^2}_{} \simeq m_a^2 f_a^2 \qquad (\rho_\gamma)$$

For QCD axion

$\underset{\text{Misalignment}}{\underline{10\,\mu eV}} \lesssim m_a \lesssim \underset{\text{String \& DW}}{\underline{100\,\mu eV}}$ (meV)

$10^{10}\,GeV \lesssim f_a \lesssim 10^{12}\,GeV$

cm [mm] $\lesssim \lambda_a \lesssim$ meter.


Lecture. 12. Stars as a Lab
(Forces & Radiations)
EM
Forces: Coulomb (1/r²), spin-spin.
Emit
CMB cosmology
Stars: Balmer
Lab: Hertz
Radiation.
Absorbers — Detectors.
Propagation. (c=1)

axions

Dark Matter:

- Forces
  - Fifth Forces
  - EP violation test ①
- Radiation
  - Cosmology
    - Freeze-in DM
    - DR.
  - Stars. ②
  - Light through wall Exp
  - Absorbers Main Topic of L13

Forces: (Moody–Wilczek)

Scalar-like

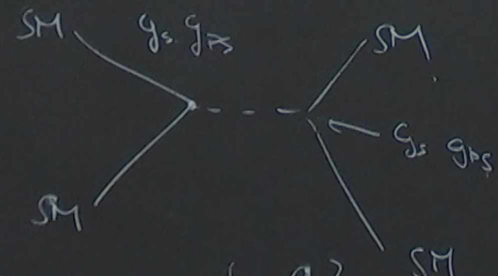
$g_s \phi \bar{\psi}_{SM} \psi_{SM}$

Pseudo-scalar like

$g_{PS} (\partial_\mu \phi) \bar{\psi} \gamma^\mu \gamma^5 \psi$

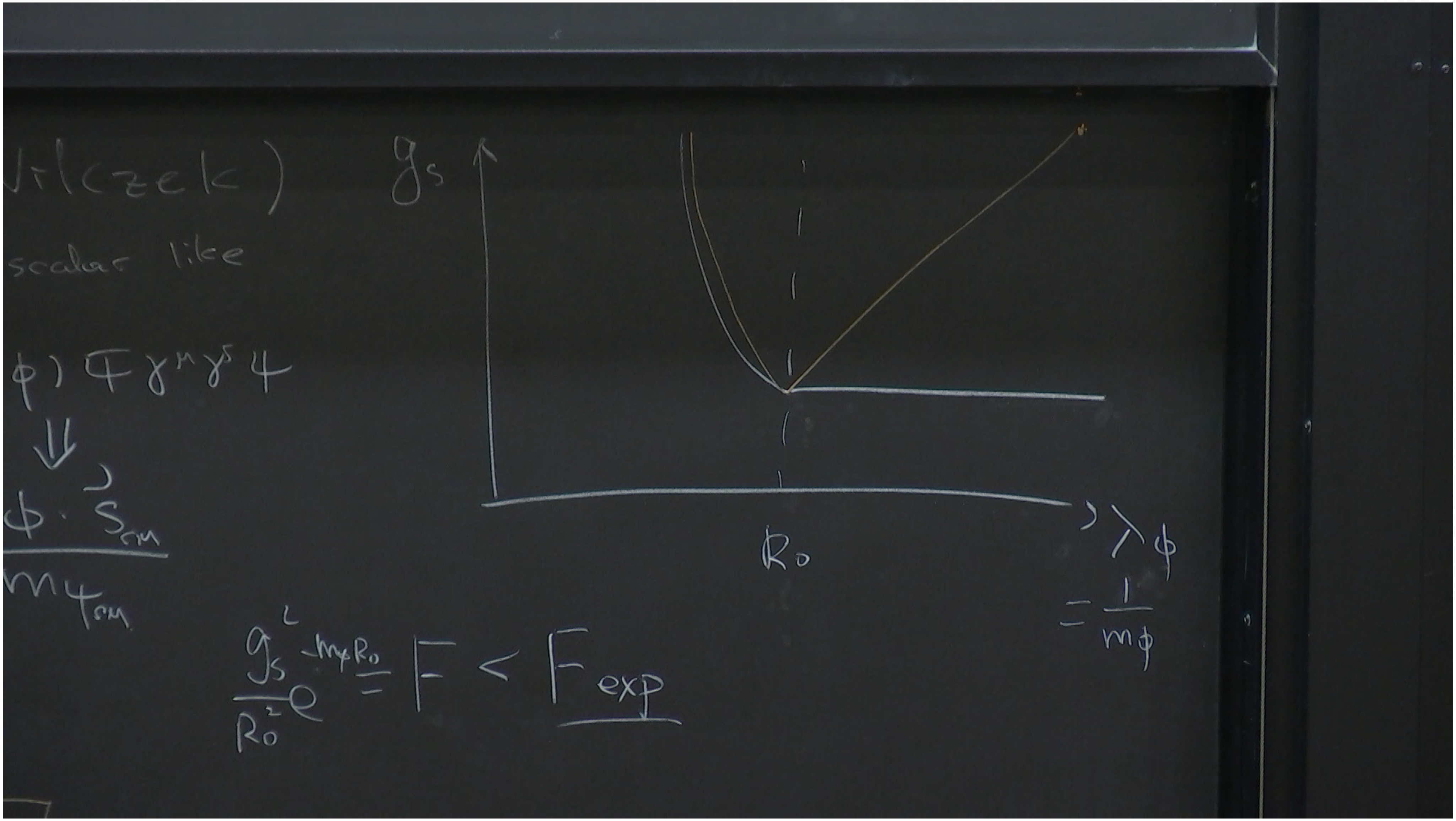
$\Downarrow$

$$\frac{\vec{\nabla} \phi \cdot \vec{S}_{SM}}{m_{\psi_{SM}}}$$



$V @ g^2$

$$\begin{cases} \dfrac{g_s^2}{r} e^{-m_\phi r} \propto N_A^2 \\ g_{PS} \cdot g_s \ \dfrac{\vec{\sigma} \cdot \hat{r}}{m_\psi} \left(\dfrac{1}{r^2} + \dfrac{m_\phi}{r} \right) e^{-m_\phi r} \end{cases}$$



scalar like
g_s
R_0
$\lambda_\phi = \frac{1}{m_\phi}$
$\frac{g_s^2}{R_0^2} e^{-m_\phi R_0} = F < F_{exp}$

$$\Downarrow$$

$$\frac{\vec{\nabla}\phi \cdot \vec{S}_{SM}}{m_{\psi_{SM}}}$$

$$\boxed{A^2}$$

R_0

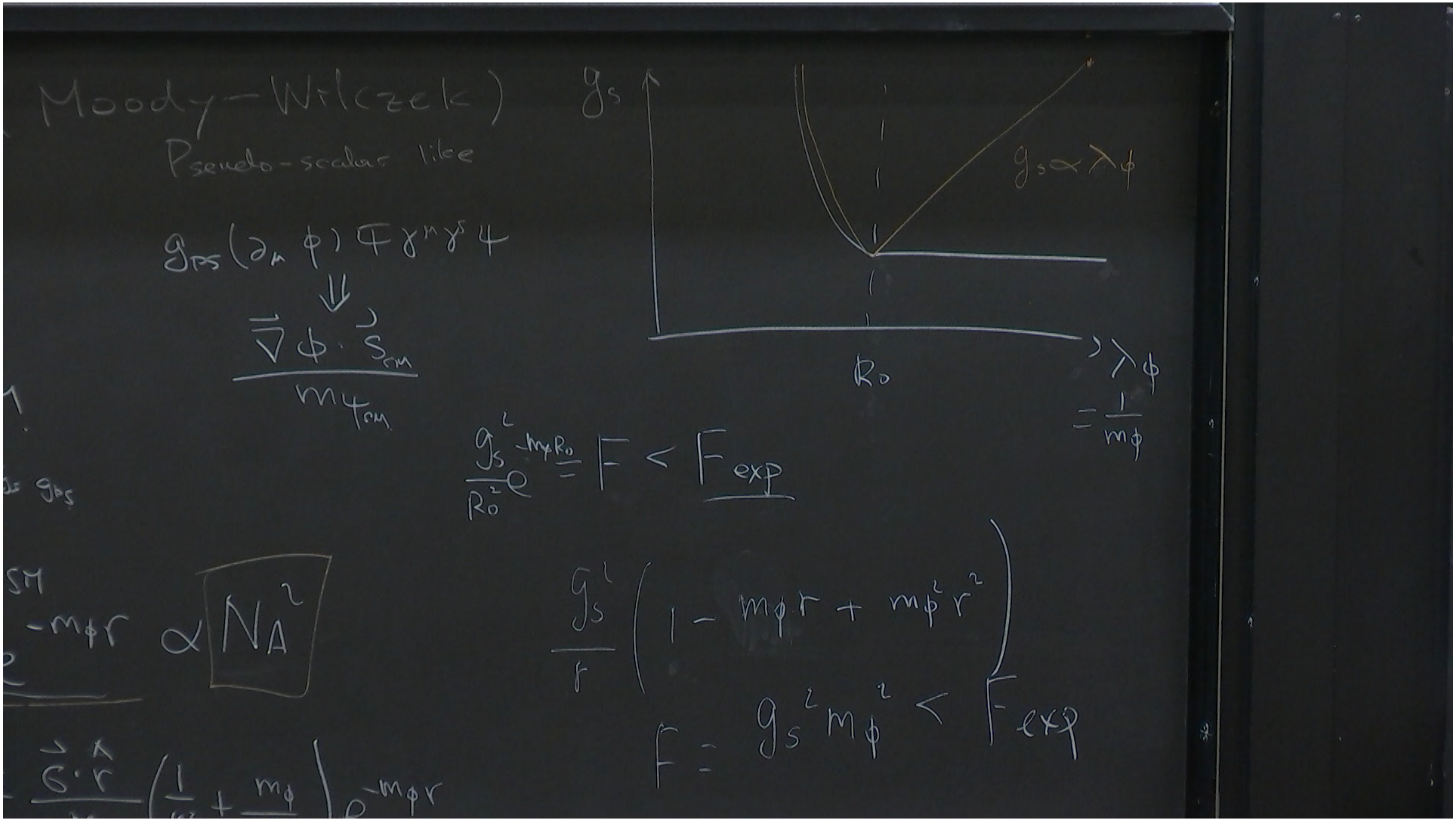
$\lambda_\phi = \frac{1}{m_\phi}$

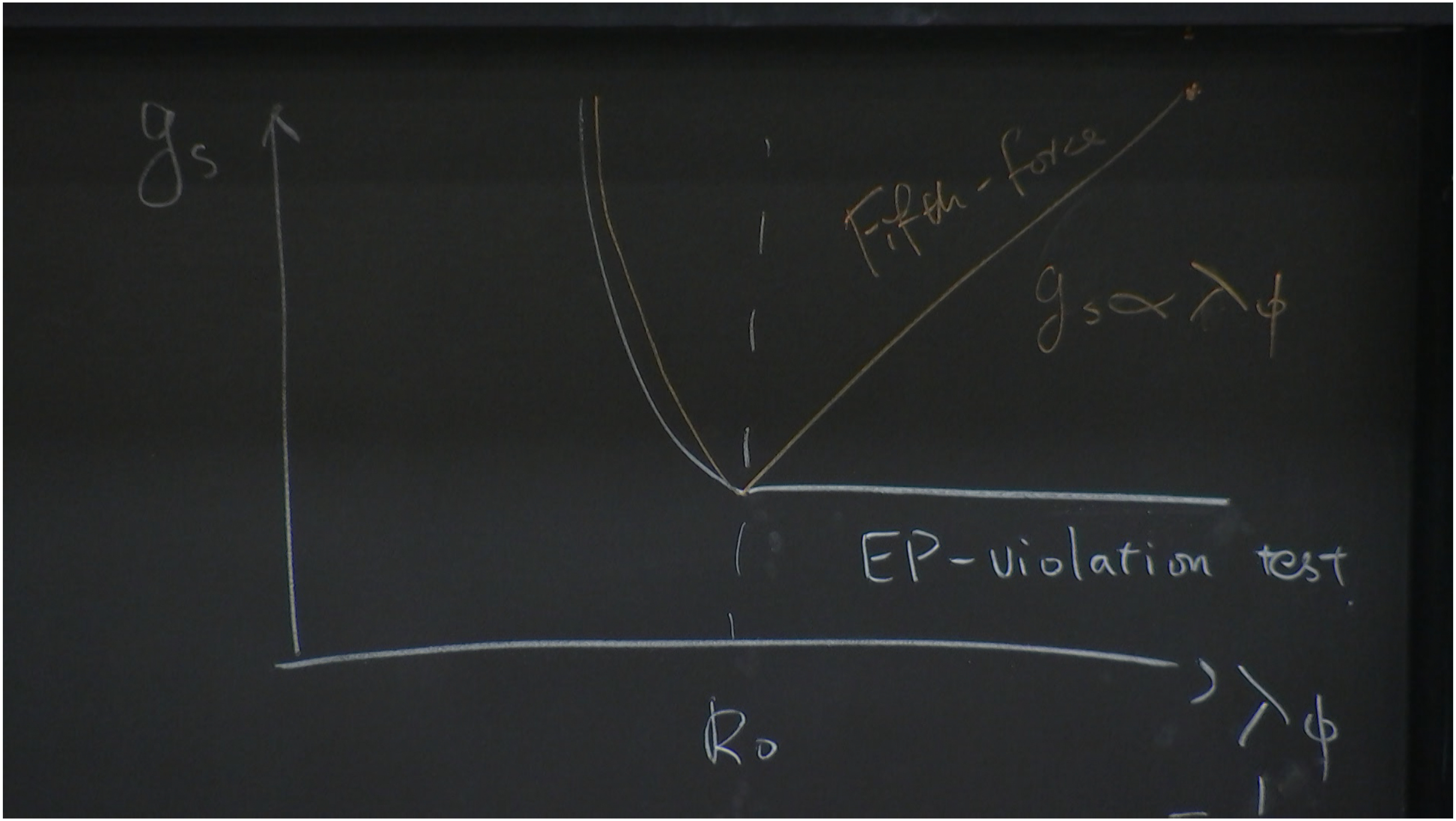
$$\frac{g_s^2}{R_0^2} e^{-m_\phi R_0} = F < \underline{F_{exp}}$$

$$\frac{g_s^2}{r}\left(1 - m_\phi r + m_\phi^2 r^2\right)$$

$$F = g_s^2 m_\phi^2$$

$$m_\phi \Big) e^{-m_\phi r}$$


Moody-Wilczek)
Pseudo-scalar like
$g_{PS}(\partial_\mu \phi)\bar{\Psi}\gamma^\mu\gamma^5\Psi$
$\frac{\vec{\nabla}\phi\cdot\vec{S}_{SM}}{m_{\Psi_{SM}}}$
g_s
$g_s \propto \lambda_\phi$
R_0
$\lambda_\phi = \frac{1}{m_\phi}$
$\frac{g_s^2}{R_0^2}e^{-m_\phi R_0} = F < F_{exp}$
$\frac{g_s^2}{r}\left(1 - m_\phi r + m_\phi^2 r^2\right)$
$F = g_s^2 m_\phi^2 < F_{exp}$
$\propto N_A^2$



g_s
Fifth-force
$g_s \propto \lambda_\phi$
EP-violation test
R_0
λ_ϕ

$\boxed{B-L}$ gauge boson

	n	p	e^-	H
B	1	1	0	1
L	0	0	1	1
$B-L$	1	1	0	0

	p
^{87}Rb	37
^{85}Rb	37

$B-L$: n → M/m_n; H → 0

$$F_{Earth \cdot H} = F_G$$

$$F_{Earth \cdot neutron} - F_{Earth \cdot H} = F_{B-L}$$

$$F_{Earth \cdot neutron} = F_G + F_{B-L}$$

	p	n	$B-L/m$
^{87}Rb	37	50	$50/87$
^{85}Rb	37	48	$48/85$

$$\delta \sim 1\% \cdot \frac{1}{GeV}$$

$$\ldots H = F_{B-L}$$