Title: Particle Physics Lecture

Speakers: Junwu Huang

Collection: Particle Physics

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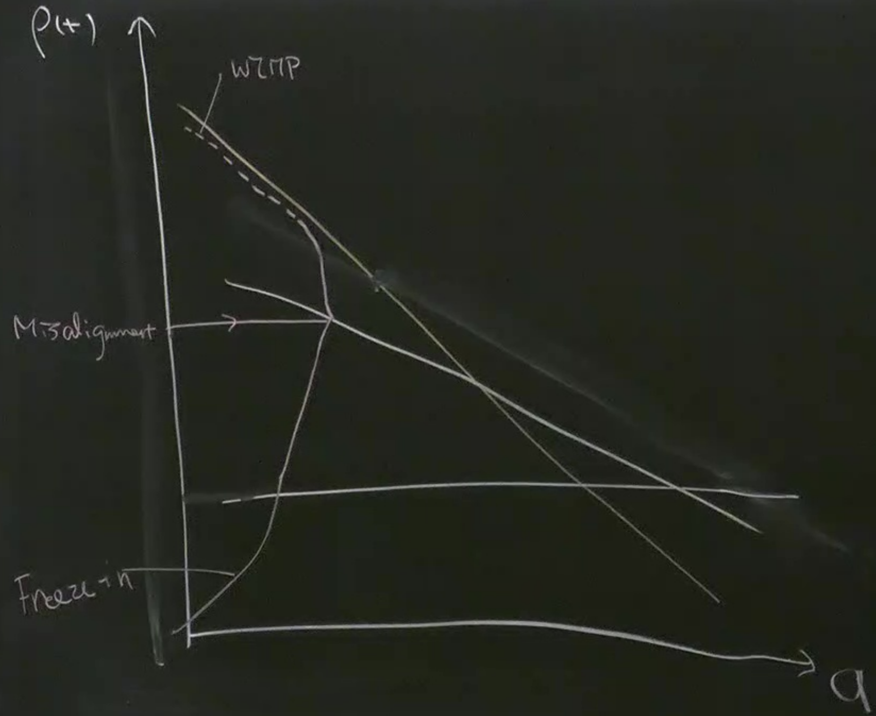


String + DW production.

$$a \to a + 2\pi f_a$$

$$\Phi = (f_a + \rho)\, e^{i a/f_a}$$

U(1) breaking.

$$V \supset \lambda(|\Phi|^2 - f_a^2)^2 + \lambda T^2 \Phi^2$$

$\Rightarrow$ Topological defect. cosmic strings

$\Rightarrow$ DW when $m_a \neq 0$

oduction.

$e^{i a/f_a}$

$\lambda T^2 \Phi^2$

ect. cosmic strings

$\neq 0$

General Lessons

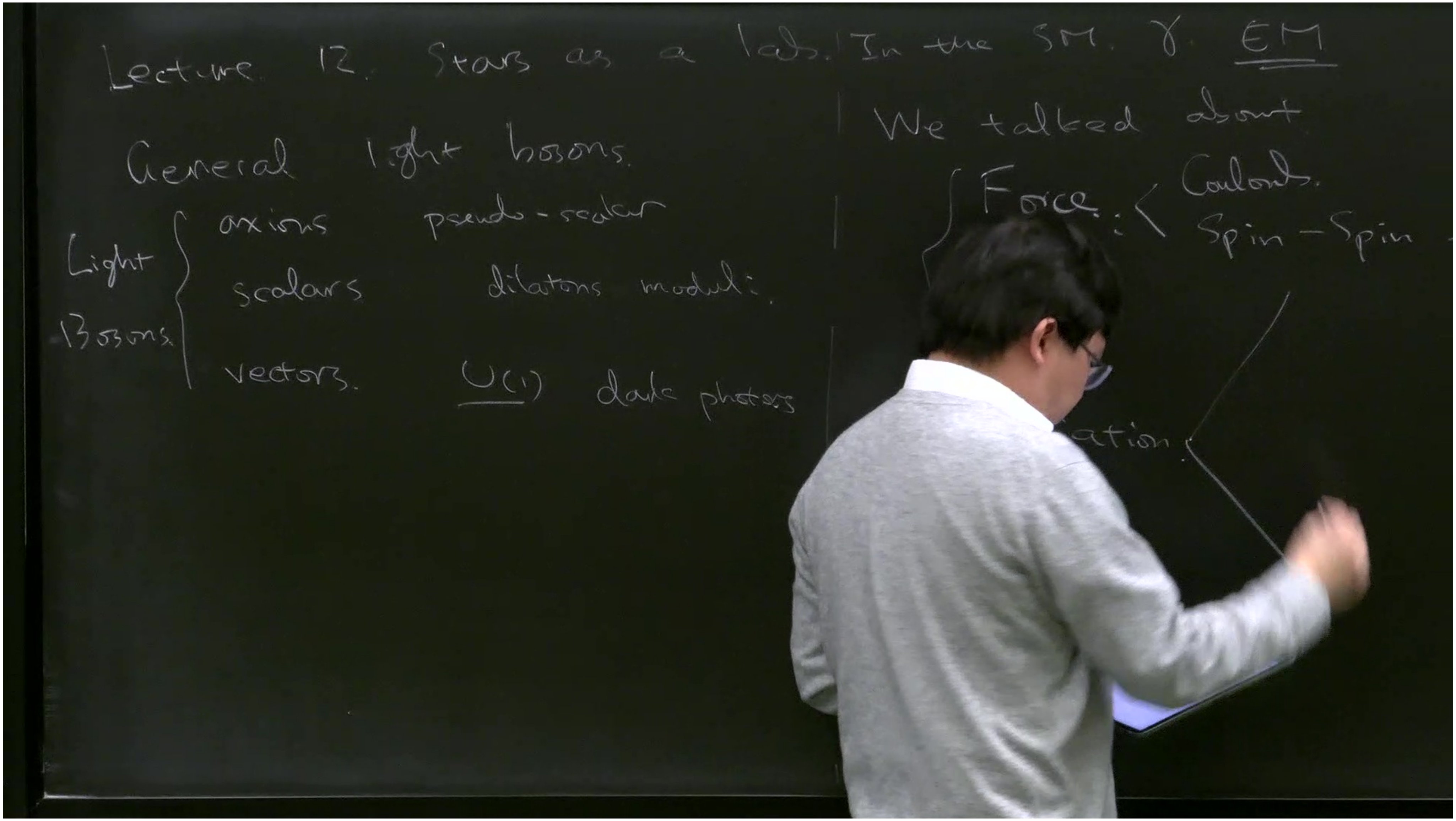
1. Dark Matter Production

- Thermal
  - Freeze-out
  - Freeze-in
- Non-thermal
  - Misalignment
  - Topological defects

$\boxed{m_a} - f_a$ relationship
- QCD
- DM

2. Search

- Thermal: The interaction that leads to the production.
- Non-Thermal: $m_a - f_a$ target.


Lecture 12. Stars as a lab.
In the SM. γ. EM
We talked about
Force: Coulomb.
Spin-Spin
General light bosons.
Light Bosons
axions pseudo-scalar
scalars dilatons moduli.
vectors. U(1) dark photons

...ads. In the SM. γ. EM

...i.

...ters

We talked about

Force: Coulomb.
Spin – Spin . . .

Radiation.

Emit

cosmology (Hot CMB)

Star. γ – Balmer lines.

Lab. Heinrich – Hertz.

Detection.

labs. | In the SM. γ. EM

We talked about

Force: Coulomb. Spin-Spin ...

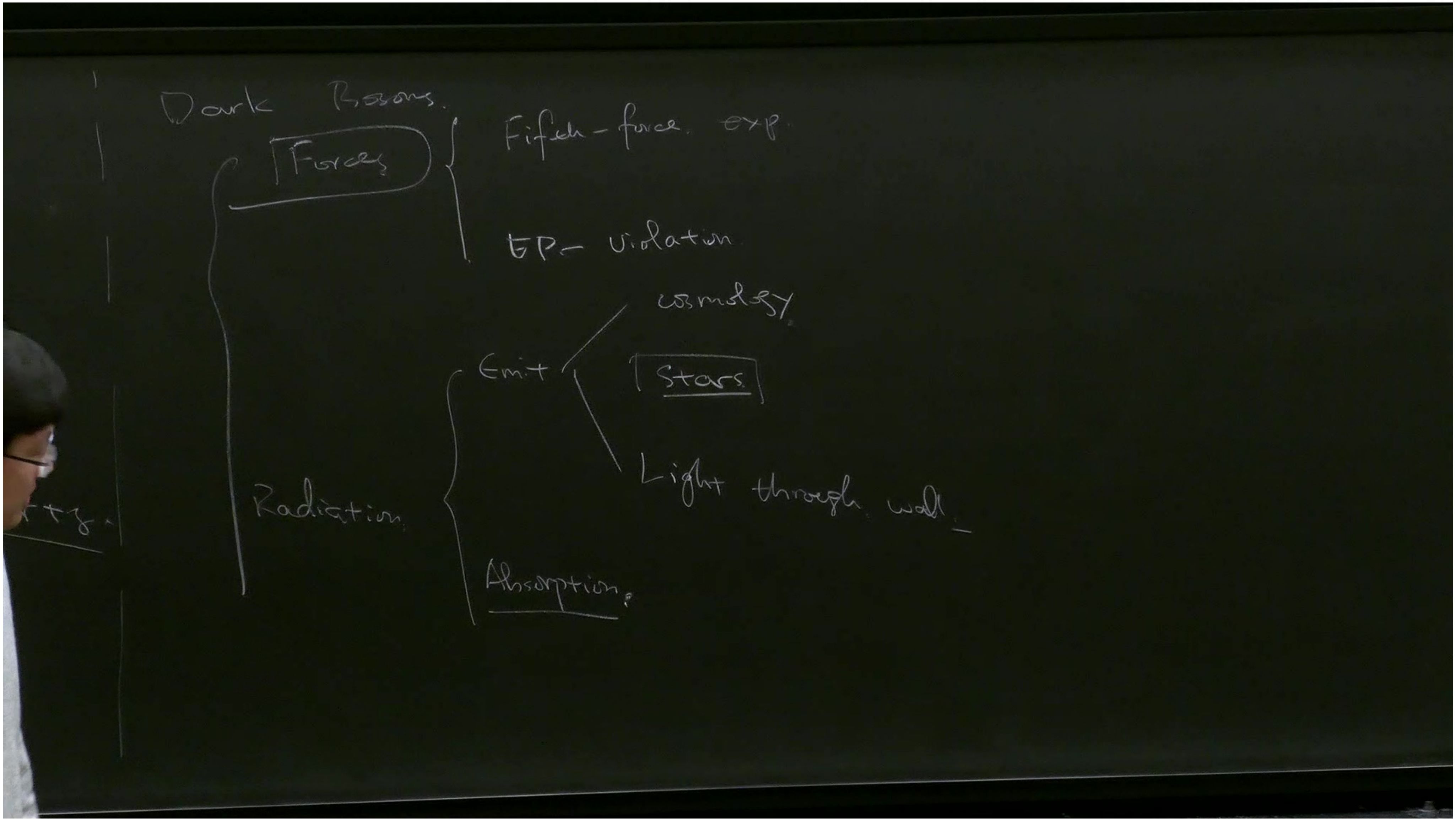
Radiation.

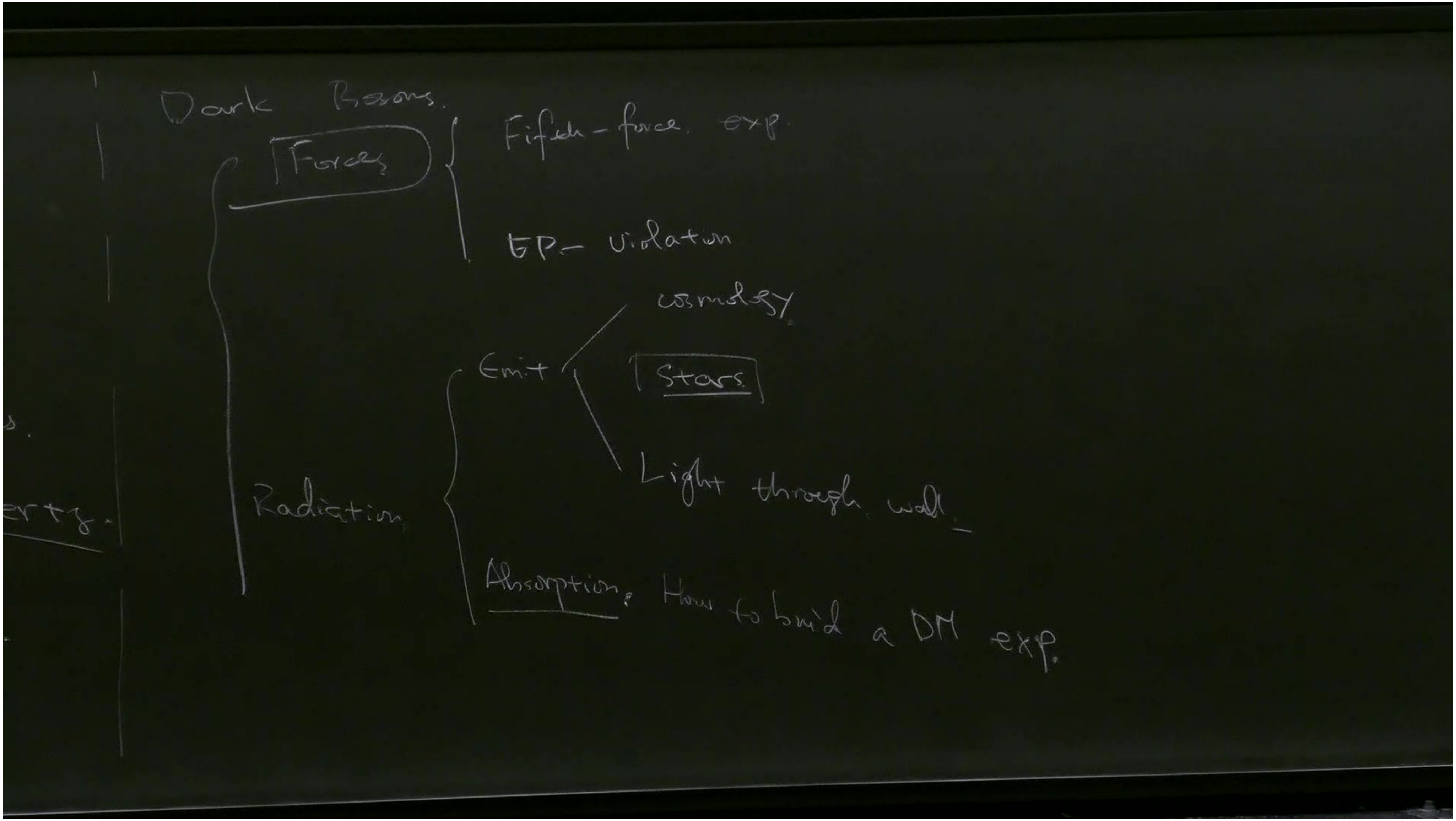
Emit: cosmology (Hot CMB); Star. γ - Balmer lines.; Lab. Heinrich - Hertz.

Detection. Single-photon detectors.

dul:

photons


Dark Bosons.
Forces
Fifth-force exp.
EP-violation
cosmology
Emit
Stars
Light through wall
Radiation
Absorption


Dark Bosons.
Forces
Fifth-force exp.
EP- Violation
Radiation
Emit
cosmology
Stars
Light through wall
Absorption: How to build a DM exp.
erty.

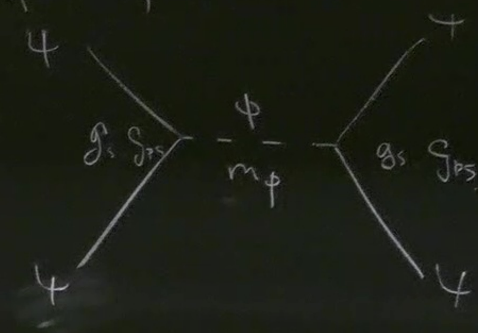
Axion   Moody - Wilczek

$g_s \phi \bar{\Psi}_{SM} \Psi_{SM}$, $g_{PS} (\partial_\mu \phi) \bar{\Psi} \gamma^\mu \gamma^5 \Psi$

scalar.   pseudo-scalars

NR: $g_s \phi \left[\rho_{SM} / m_{SM} \right]$ $\frac{\vec{\nabla}\phi \cdot \vec{S}}{m_\Psi}$

Fifth-force



$V @ g^2 \left\{ \begin{array}{l} \frac{g_s^2}{r} e^{-m_\phi r} \\ \\ g_{PS} g_s \frac{\vec{\sigma}}{m} \end{array} \right.$

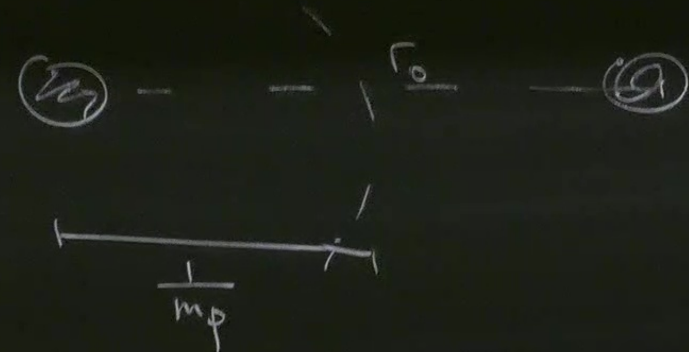
Gain. $N_A^2 \cdot \left(\frac{M_{star}}{m_p}\right)^2$

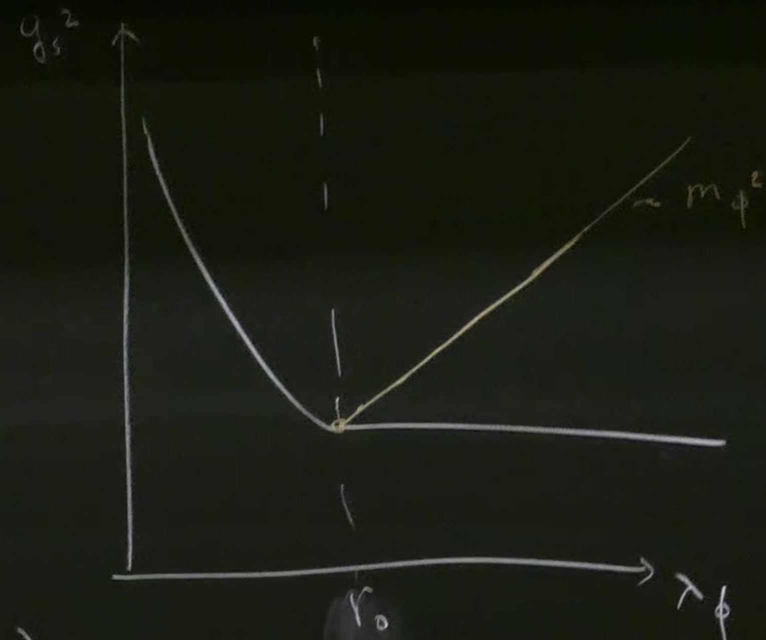
② $\quad$ — — r — —

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

Gain. $N_A^2 \cdot \left\{\frac{-M_{star}}{m_\phi}\right\}^2$

②





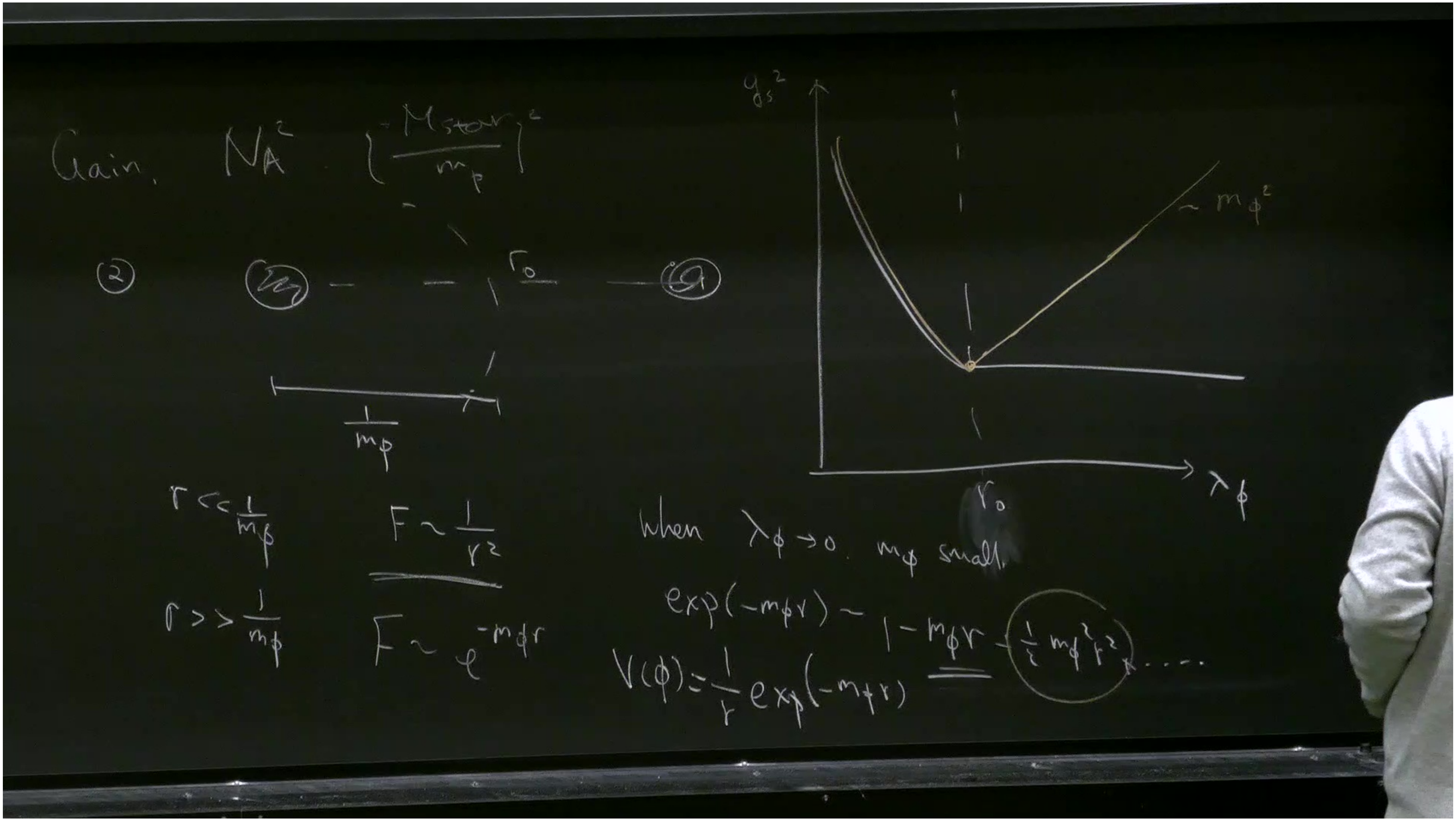
$r \ll \frac{1}{m_\phi}$ $\quad F \sim \frac{1}{r^2}$

$r \gg \frac{1}{m_\phi}$ $\quad F \sim e^{-m_\phi r}$

when $\lambda_\phi \to 0$. m_ϕ small.

$$\exp(-m_\phi r) \sim 1 - m_\phi r + \frac{1}{2} m_\phi^2 r^2 + \dots$$

$$V(\phi) = \frac{1}{r}\exp(-m_\phi r)$$

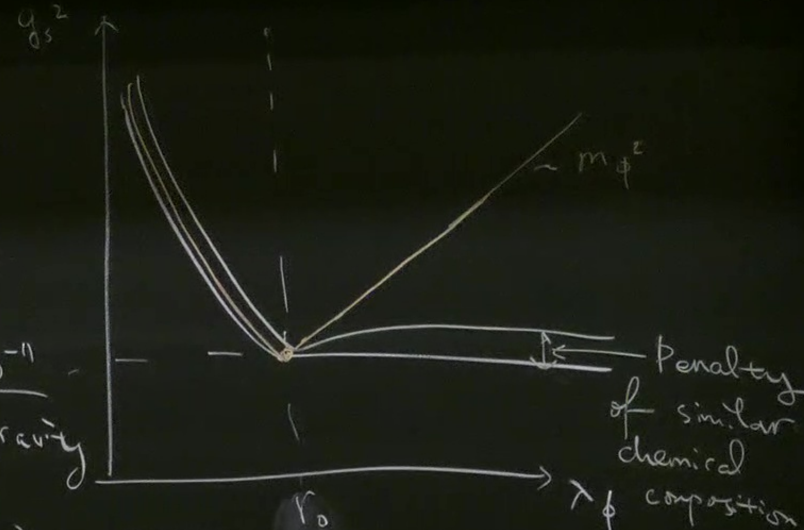

Gain, $N_A^2 \left(\frac{M_{star}}{m_\phi}\right)^2$
②
r_0
$\frac{1}{m_\phi}$
$r << \frac{1}{m_\phi}$ $F \sim \frac{1}{r^2}$
$r >> \frac{1}{m_\phi}$ $F \sim e^{-m_\phi r}$
g_s^2
$\sim m_\phi^2$
r_0
λ_ϕ
when $\lambda_\phi \to 0$. m_ϕ small.
$\exp(-m_\phi r) \sim 1 - m_\phi r + \frac{1}{2} m_\phi^2 r^2 + \dots$
$V(\phi) = \frac{1}{r} \exp(-m_\phi r)$

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

Gain. $N_A^2 \left(\frac{M_{star}}{m_p}\right)^2$

(2) r_0

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



$r \ll \frac{1}{m_\phi}$ $\quad F \sim \frac{1}{r^2}$

$r \gg \frac{1}{m_\phi}$ $\quad F \sim e^{-m_\phi r}$

When $\lambda_\phi \to 0$, m_ϕ small.

$\exp(-m_\phi r) \sim 1 - m_\phi r + \frac{1}{2} m_\phi^2 r^2 + \dots$

$V(\phi) = \frac{1}{r} \exp(-m_\phi r)$

Axion   Moody – Wilczek

$$g \sim \frac{1}{10^{11}\,\mathrm{GeV}}$$

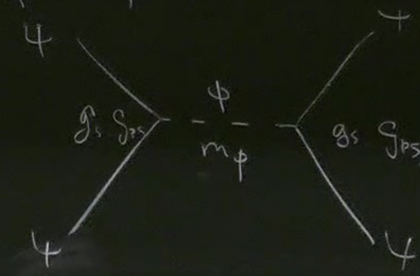
$$g_s \phi \bar{\Psi}_{SM} \Psi_{SM}, \qquad g_{PS} (\partial_\mu \phi) \bar{\Psi} \gamma^\mu \gamma^5 \Psi$$

scalar   pseudo-scalars

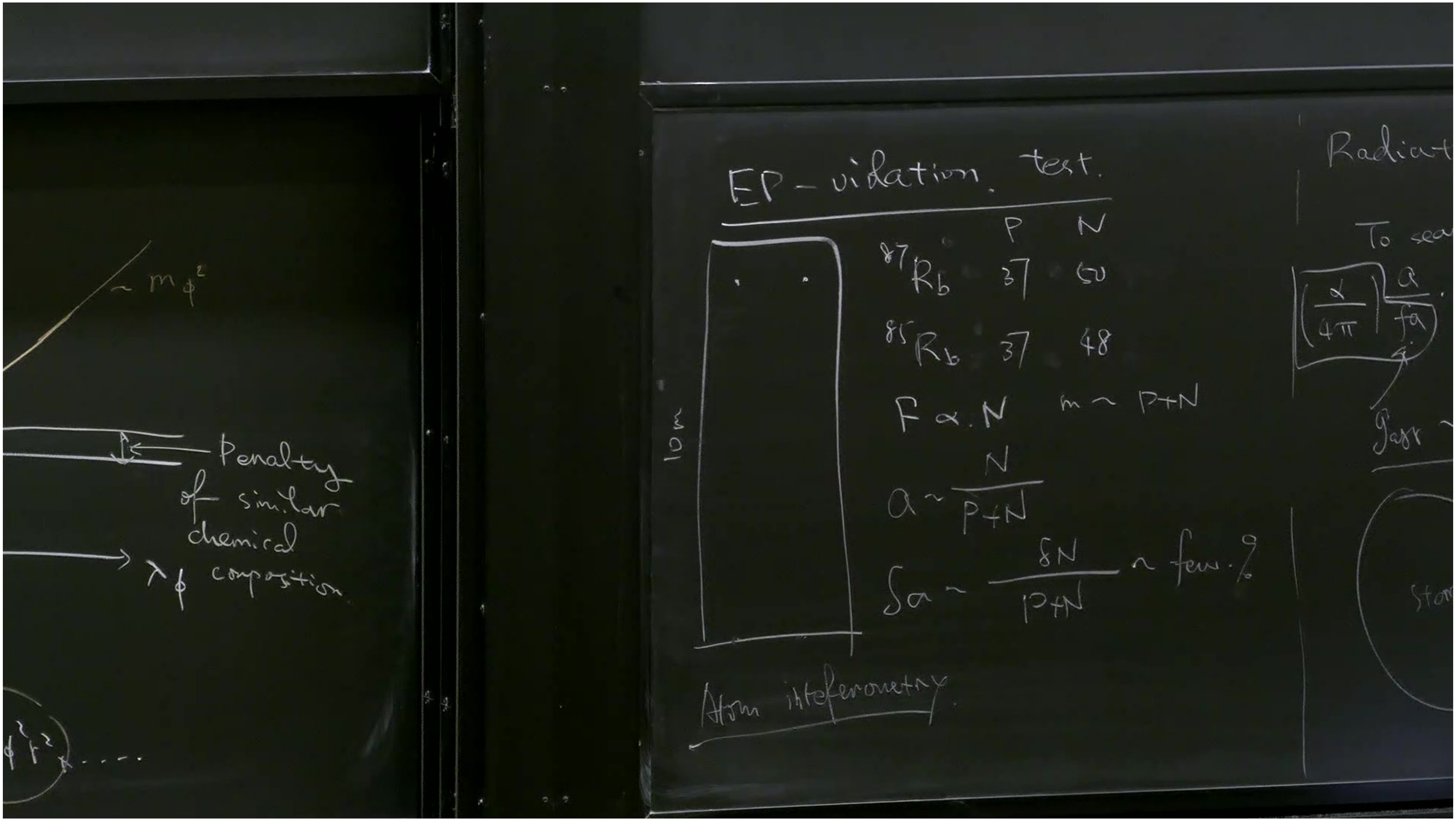
NR:

$$\underline{g_s \phi \left[\rho_{SM}/m_{SM}\right]} \qquad \frac{\vec{\nabla}\phi \cdot \vec{S}}{m_\psi}$$

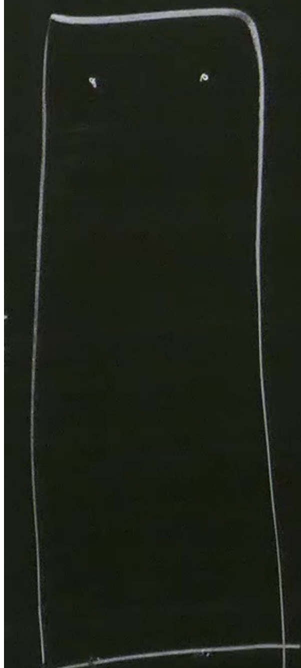
Fifth-force



$$V @ g^2 \begin{cases} \dfrac{g_s^2}{r} e^{-m_\phi r} \quad \Leftarrow \\[2ex] g_{PS}\, g_s \dfrac{\vec{\sigma}\cdot\hat{r}}{m_\psi} \left(\dfrac{1}{r^2} + \dfrac{m_\phi}{r}\right) \end{cases}$$


~ mφ²
Penalty
of similar
chemical
composition
EP-violation test.
P N
⁸⁷Rb 37 50
⁸⁵Rb 37 48
F ∝ N m ~ P+N
a ~ N / (P+N)
δa ~ δN / (P+N) ~ few %
10 m
Atom interferometry
Radiat
To sea

EP-violation test.



	P	N
^{87}Rb	37	50
^{85}Rb	37	48

$F \propto N \qquad m \sim P+N$

$$a \sim \frac{N}{P+N}$$

$$\delta a \sim \frac{\delta N}{P+N} \sim \text{few } \%$$

Atom interferometry.

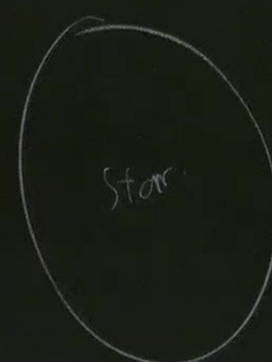
Radiation. Stars.

To search for. PS. interactions.

$$\boxed{\left(\frac{\alpha}{4\pi}\right)\frac{a}{f_a}} \cdot F^{\mu\nu}\tilde{F}_{\mu\nu} \quad (\vec{E}\cdot\vec{B})$$

$g_{a\gamma\gamma} \sim 10^{-10}\,\text{GeV}^{-1}$

Stellar cooling.



axion with $g_{a\gamma\gamma} \sim 10^{-10}\,\text{GeV}^{-1}$ can cool the sun about 10~30% the amount the photon cools.

EP - violation test.

	P	N
^{87}Rb	37	50
^{85}Rb	37	48

10 m

$F \propto N \quad m \sim P+N$

$a \sim \frac{N}{P+N}$

$\delta a \sim \frac{\delta N}{P+N} \sim$ few %

Atom interferometry.

Radiation. Stars.

To search for. PS. interactions.

$$\boxed{\frac{\alpha}{4\pi}} \frac{a}{f_a} \cdot \underline{F^{\mu\nu}\tilde{F}_{\mu\nu}} \quad (\vec{E}\cdot\vec{B})$$

$$\underline{g_{a\gamma\gamma} \sim 10^{-10}\,\mathrm{GeV}^{-1}}$$

stellar cooling

Star
$T \gtrsim$ keV

axion with $g_{a\gamma\gamma} \sim 10^{-10}\,\mathrm{GeV}^{-1}$ can cool the sun about 10~30% the amount the photon cools.

where doe

optical e

Thomson cro

$\sigma \sim \frac{\alpha^2}{m_e^2}$

$L \sim \frac{1}{m_e}$

$R_\odot \sim 1\,s$

$L/R_\odot \sim 10$

where does γ we see from the sun come from?

Optical depth:

Thomson cross-section

$$\sigma \sim \frac{\alpha^2}{m_e^2} \qquad n_e \sim \mathrm{keV}^3$$

$$L \sim \frac{1}{n_e \sigma} \simeq \frac{\mathrm{MeV}^2}{\mathrm{keV}^3 \cdot (0.01)^2} \sim \mathrm{nm} \cdot 10^{10} \sim 10\,\mathrm{m}$$

$$R_\odot \sim 1\,\mathrm{s} \sim 10^9\,\mathrm{m}$$

$$L/R_\odot \sim 10^{-8} \quad @\ T \sim 6000\,\mathrm{K}$$

$10^{10}\,\mathrm{GeV}^{-1}$

about

the photon

Total emission

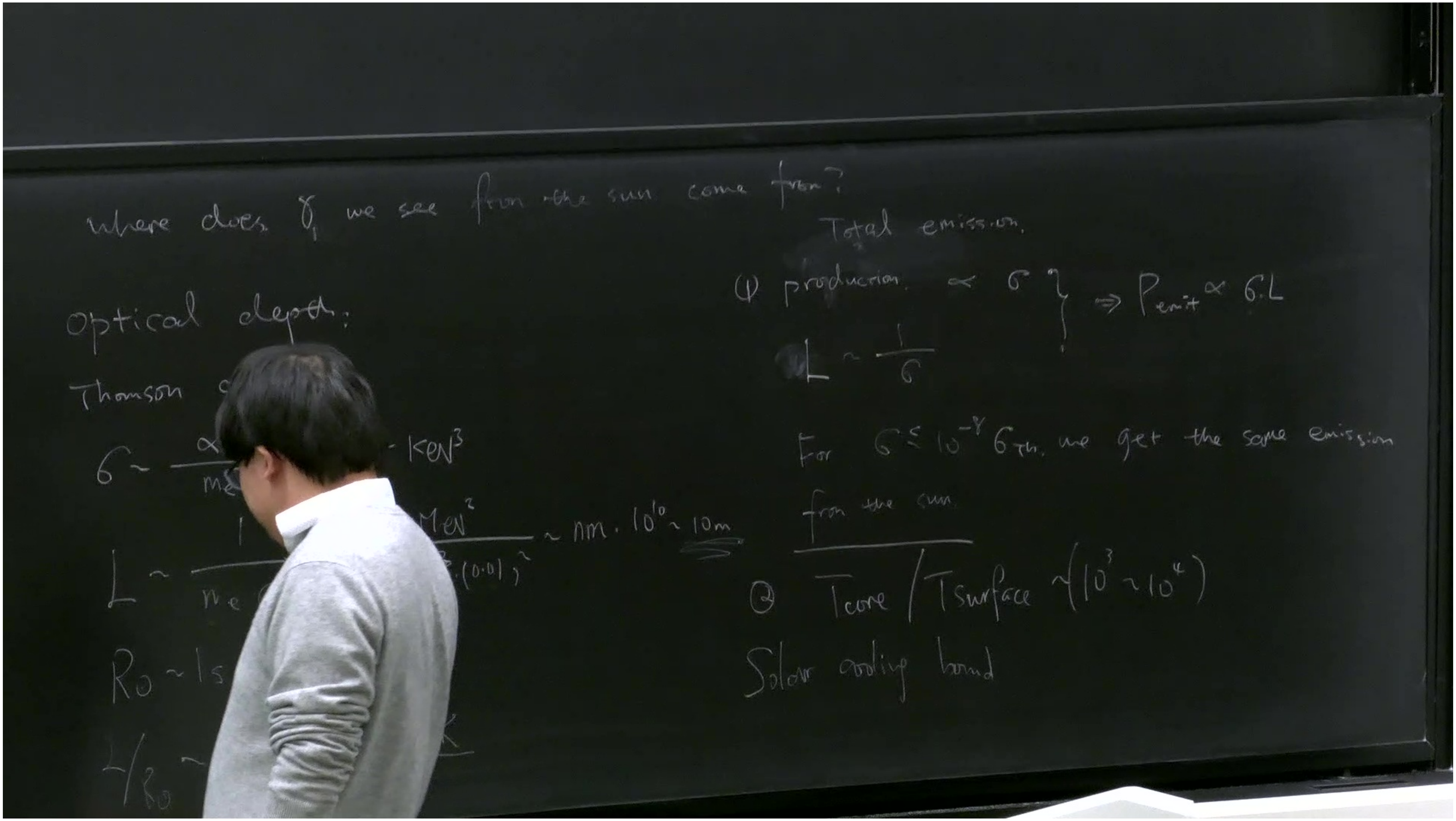
(1) production $\propto \sigma$

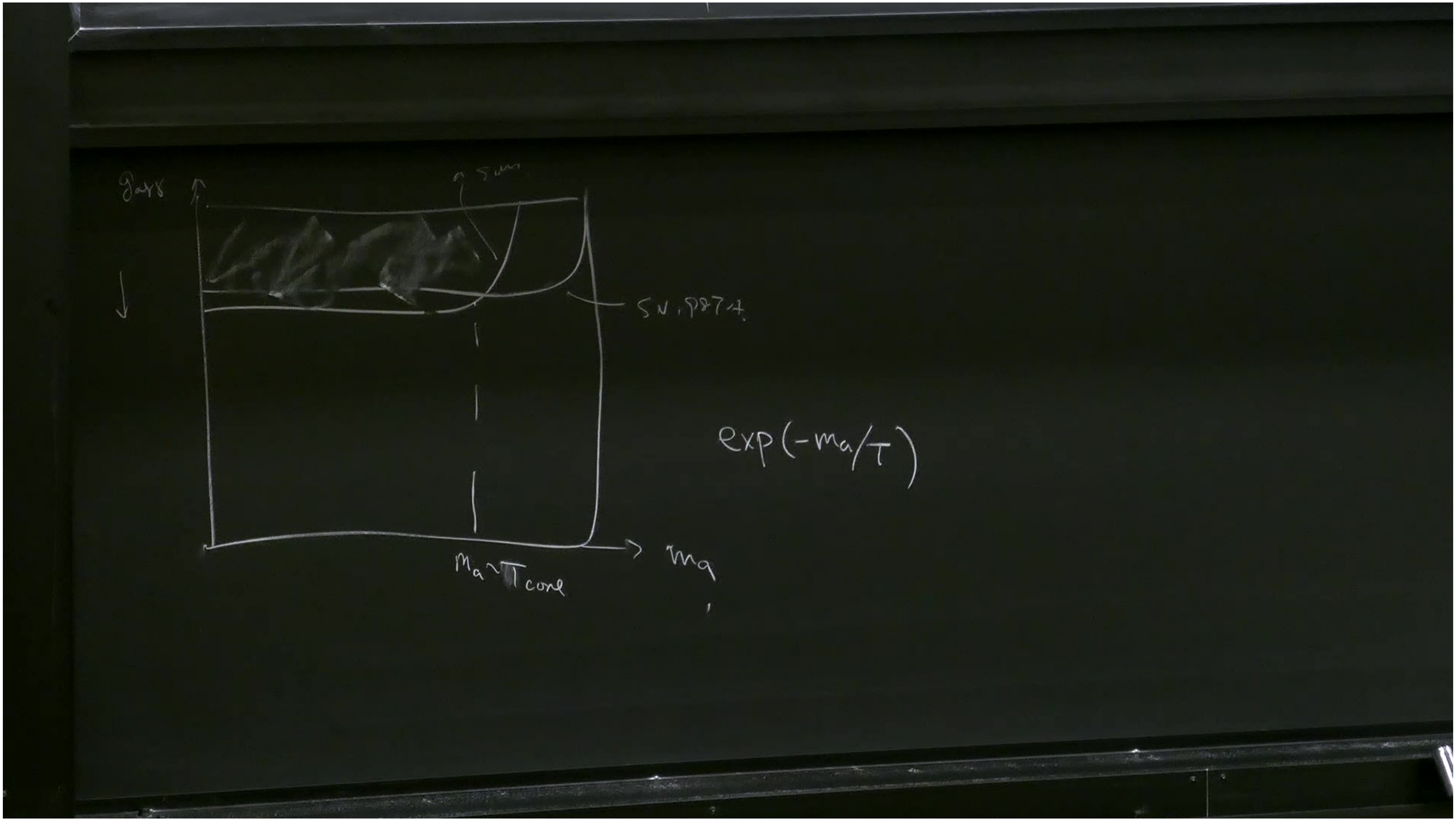
$L \sim \frac{1}{\sigma}$

$\Rightarrow P_{emit} \propto \sigma \cdot L$

For $\sigma \lesssim 10^{-8}\,\sigma_{Th}$, we get the same emission from the sun.

(2)


where does γ we see from the sun come from?
Total emission.
optical depth:
Thomson
① production ∝ σ } ⇒ P_emit ∝ σ·L
L ~ 1/σ
For σ ≲ 10^-8 σ_Th, we get the same emission from the sun.
~ nm · 10^10 ~ 10m
② Tcore / Tsurface ~ (10^3 ~ 10^4)
Solar cooling bound


exp(-ma/T)
ma ~ Tcore
ma