

Title: Sequestering Lorentz violation in the Lifshitz sector

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Abstract: Horava's proposal to use Lifshitz propagators for gravitons above certain energy scales may provide a viable theory of quantum gravity without further need of UV completion. In my talk, I will address the question of whether the complete lack of Lorentz invariance above a certain energy scale is a big problem for any realistic construction. I will argue that it is not, provided that the onset of Lifshitz scaling for gravitons occurs at momentum scale much lower than the Planck mass. I will also discuss consequences of combining Lifshitz gravity and supersymmetric matter sector.

Sequestering Lorentz violation (LV) in HL sector.

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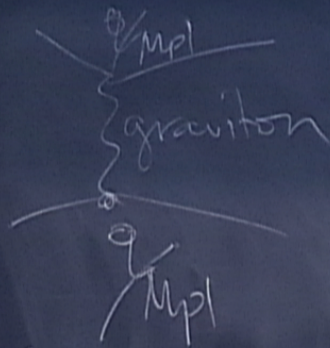
MP, Y Shao 2010

MP, C Tamarit 2013

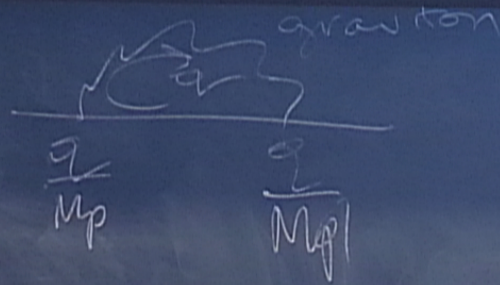
MP, Y Shara 2010
MP, C Tamarit 2013

1. Introduction
2. Preserving LI in matter sector by making $\Lambda_{HI} \ll M_{Pl}$
3. Problems?
Marrying 'Lifshitz to SUSY

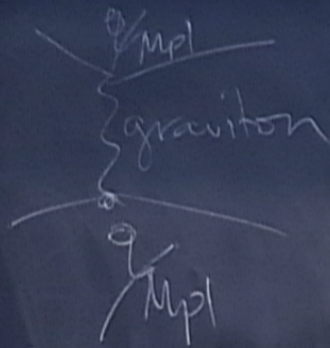
4. Marrying 't Hooft to SUSY



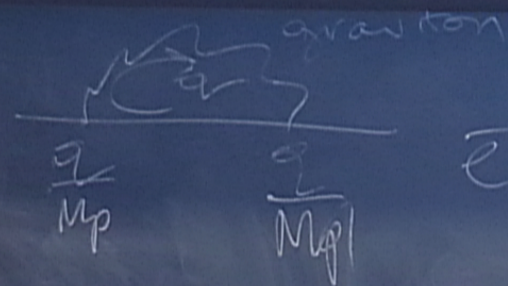
How about



4. Marrying 't Hooft to SUSY



How about

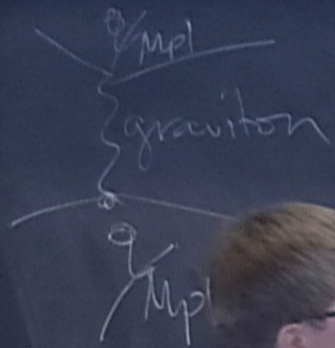


$$\exp\left(1 + \frac{\Lambda_{UV}^2}{M_{Pl}^2}\right)$$

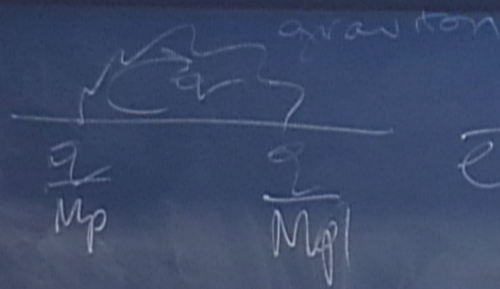
$$\alpha = \frac{1}{16\pi G}$$

= 1000 # of degrees of freedom
 $d=2$ - 451 gauge theory

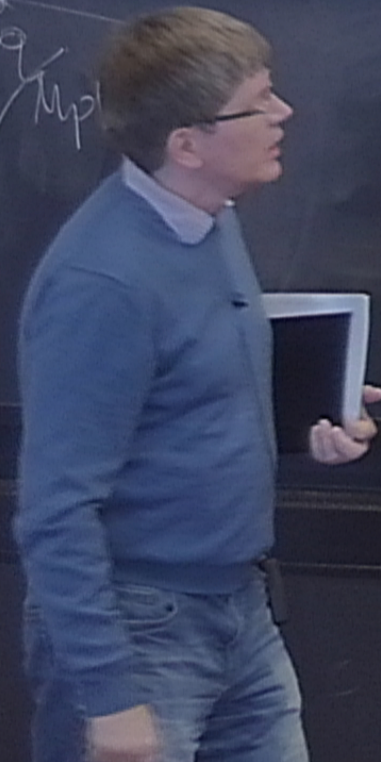
4. Marrying 't Hooft to SUSY



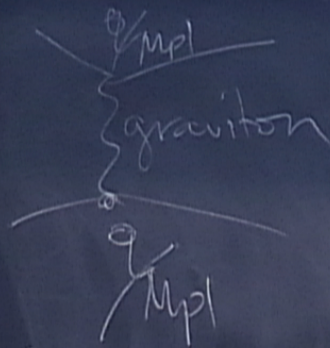
How about



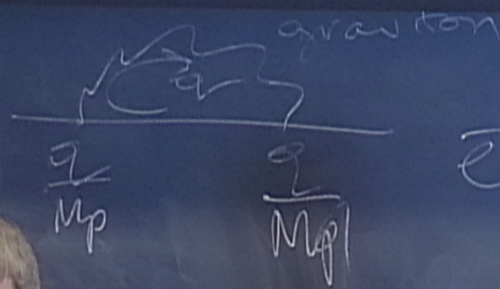
$$\exp\left(1 + \frac{\Lambda_W^2}{M_{Pl}^2} \frac{1}{6\pi^2}\right)$$



4. Marrying Lifshitz to SUSY



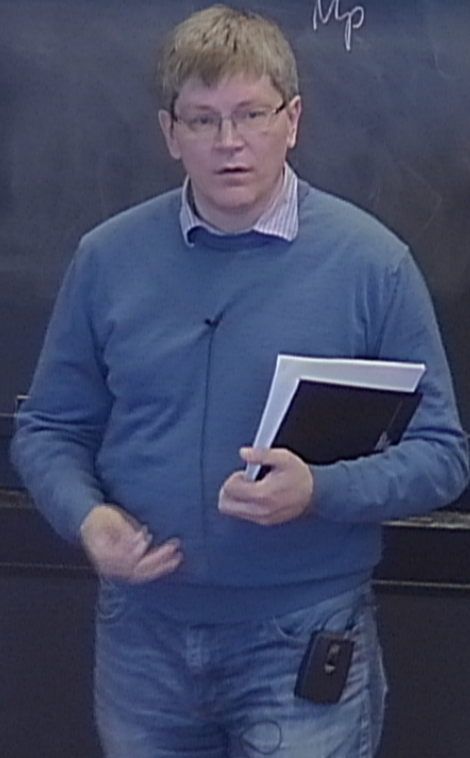
How about



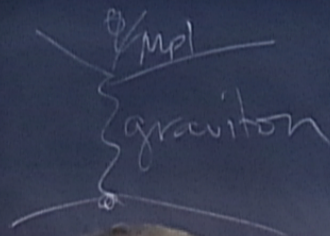
$$\exp\left(1 + \frac{\Lambda_W^2}{M_{Pl}^2} \frac{1}{6\pi^2}\right)$$

z_c

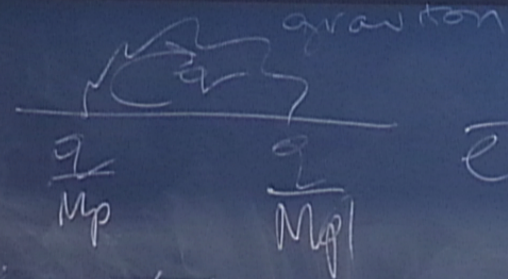
= mass of BPS states in
 $d=2$ SUSY gauge theory



4. Marrying 't Hooft to SUSY



How about

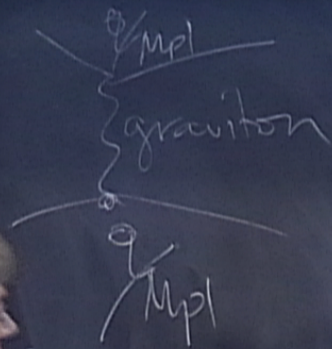


$$\exp\left(1 + \frac{\Lambda_W^2}{M_{Pl}^2} \frac{1}{6\pi^2}\right)$$

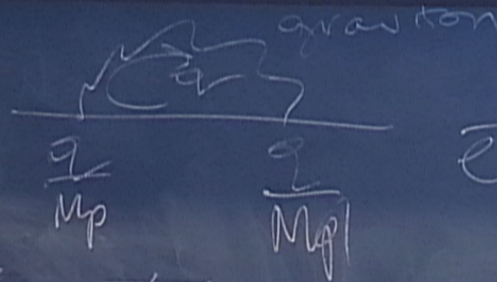
corrections to N law etc

$\neq$ SUSY gauge theory

4. Marrying 't Hooft to SUSY



How about



$$\exp\left(1 + \frac{\Lambda_W^2}{M_{Pl}^2} \frac{1}{6\pi^2}\right)$$

$\Sigma\Sigma$ corrections to N law etc

* Assuming that UV Theory has all same symmetries as IR

What about reduced deg. of symm?
Lattice in space dim + time.

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Lattice in space dim + time.

$$\rightarrow \bar{e} \partial_0 \gamma_0 e + (i a e) \vec{e} \cdot \vec{\gamma} e.$$

What about reduced deg. of symm?

Lattice in space dim + time.

$$\rightarrow \bar{e} \partial_0 \gamma_0 e + (1 + a^2) \bar{e} \vec{\gamma} \vec{\nabla} e.$$

ΔC_r

What about reduced deg. of symm?

Lattice in space dim + time.

$$\rightarrow \bar{e} \partial_0 \gamma_0 e + (1 + a g) \bar{e} \vec{\gamma} \vec{\nabla} e.$$

$$|A(r - c_e)| \lesssim 10^{-12}$$

(aston low energy).

low $\sim 10^{-12}$ ← huge problem
for theories
with broken
LI in the UV.

$(\Delta C_r - C_e) / \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
with broken
LI in the UV.

" $\Lambda_{UV} \ll M_{Pl}$ — if that is the case, then
LV in gravity sector is allowed.

$(\Delta C_r - C_e) / \lesssim 10^{-5}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
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$\Lambda_{UV} \ll M_{Pl}$ — if that is the case, then
" UV in gravity sector is allowed
Horava gravity

$$(\Delta C_r - C_e) \left| \leq 10^{-5} \right. \\ \text{(astro, low energy)}$$

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
with broken
LI in the UV.

Horava gravity
⇒ graviton propagators modified ⇒ better UV behavior.

$$\frac{1}{\omega^2 - k^2} \xrightarrow{H} \frac{1}{\omega^2 - k^2 - \frac{k^6}{\Lambda_{HL}^4}} \left\{ \begin{array}{l} \text{low } k \\ \text{high } k \end{array} \right. \rightarrow \int \frac{d^3 k}{(|\mathbf{k}| + \frac{|\mathbf{k}|^3}{\Lambda^2})}$$

$$|\Delta C_T - C_E| \lesssim 10^{-4}$$

(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem for theories with broken LI in the UV.

Horava gravity
 $\Rightarrow$ graviton propagators modified $\Rightarrow$ better UV behavior

$$\frac{1}{\omega^2 - k^2} \xrightarrow{H} \frac{1}{\omega^2 - k^2 - \frac{k^6}{\Lambda_{HL}^4}} \quad \left(\text{also } \frac{1}{\omega^2 - k^2 - \frac{k^6}{\Lambda_I^4}} \right) \rightarrow \int \frac{d^3 k}{(k^2 + \frac{k^6}{\Lambda^2})} \rightarrow \log \frac{\Lambda_{UV}^2}{\Lambda_{IR}^2}$$

$(\Delta C_r - C_e) \mid \lesssim 10^{-4}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
with broken
LI in the UV.

Horava gravity
⇒ graviton propagators modified ⇒ better UV behavior.

$$\frac{1}{\omega^2 - k^2} \xrightarrow{H} \frac{1}{\omega^2 - k^2 - \frac{k^6}{\Lambda_{HL}^4}} \quad \left(\text{with } \frac{d^3 k}{\omega^2 - k^2 - \frac{k^6}{\Lambda_{HL}^4}} \right) \rightarrow \int \frac{d^3 k}{(|k| + \frac{|k|^3}{\Lambda_{HL}^2})} \rightarrow \log \frac{\Lambda_{UV}^2}{\Lambda_{PL}^2}$$

$(\Delta C_r - C_e) \sim 10^{-10}$
 (astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
 for theories
 with broken
 LI in the UV.

$$\frac{1}{k_{\mu}^2 - \frac{(k_{\mu}^3)^2}{\Lambda_{UV}^2}} \rightarrow \frac{1}{k^2} - \frac{1}{k^2 - \Lambda_{HL}^2}$$

$(\Delta C_r - C_e) \sim 10^{-10}$
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$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
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$$\frac{1}{(k_{UV}^2 - \frac{(k_{UV}^2)^2}{\Lambda_{UV}^2})} \rightarrow \frac{1}{k^2} - \frac{1}{k^2 - \Lambda_{UV}^2}$$

$(AC_r - C_e) \left| \leq 10^{-10} \right.$
 (astro, low energy).

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$$\frac{1}{(k_{\mu}^2 - \frac{(k_{\mu}^2)^2}{\Lambda^2})} \rightarrow \frac{1}{k^2} - \frac{1}{k^2 - \Lambda^2}$$

* Q: Can we take HL proposal (with "UV behavior")
 seriously despite the fact of 100% consistency?

$(\Delta C_r - C_e) \left| \leq 10^{-10} \right.$
 (astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
 for theories
 with broken
 LI in the UV.

$$\frac{1}{(k_\mu^2 - \frac{(k_\mu^3)^2}{\Lambda_{UV}^2})} \rightarrow \frac{1}{k^2} - \frac{1}{k^2 - \Lambda_{UV}^2}$$

* Q: Can we take HL proposal ("good" UV behavior of gravity)
 seriously despite the fact of 100% LV in gravity
 sector?

$(\Delta C_r - C_e) \sim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
with broken
LI in the UV.

$$\frac{1}{(k_{\mu}^2 - \frac{(k_{\mu}^3)^2}{\Lambda_{UV}^2})} \rightarrow \frac{1}{k^2} - \frac{1}{k^2 - \Lambda_{UV}^2}$$

* Q: Can we take HL proposal ("good" UV behavior of gravity)
(semi-)seriously despite the fact of 100% LV in gravity sector?

3. Problems?

4. Marrying 'Lifshitz to SUSY

$\mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{gravity}}$

↑
maintain
normal
propagators

↑
go to
Lifshitz
scaling at $\Lambda_H \ll M_{\text{pl}}$.

3. Problems?

4. Marrying 'Lifshitz to SUSY

$\mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{gravity}}$

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$$\mathcal{L}_{\text{matter}} = (\partial_\mu \Phi \partial^\mu \Phi)^2 - \frac{1}{4} F_{\mu\nu}^2.$$

3. Problems?

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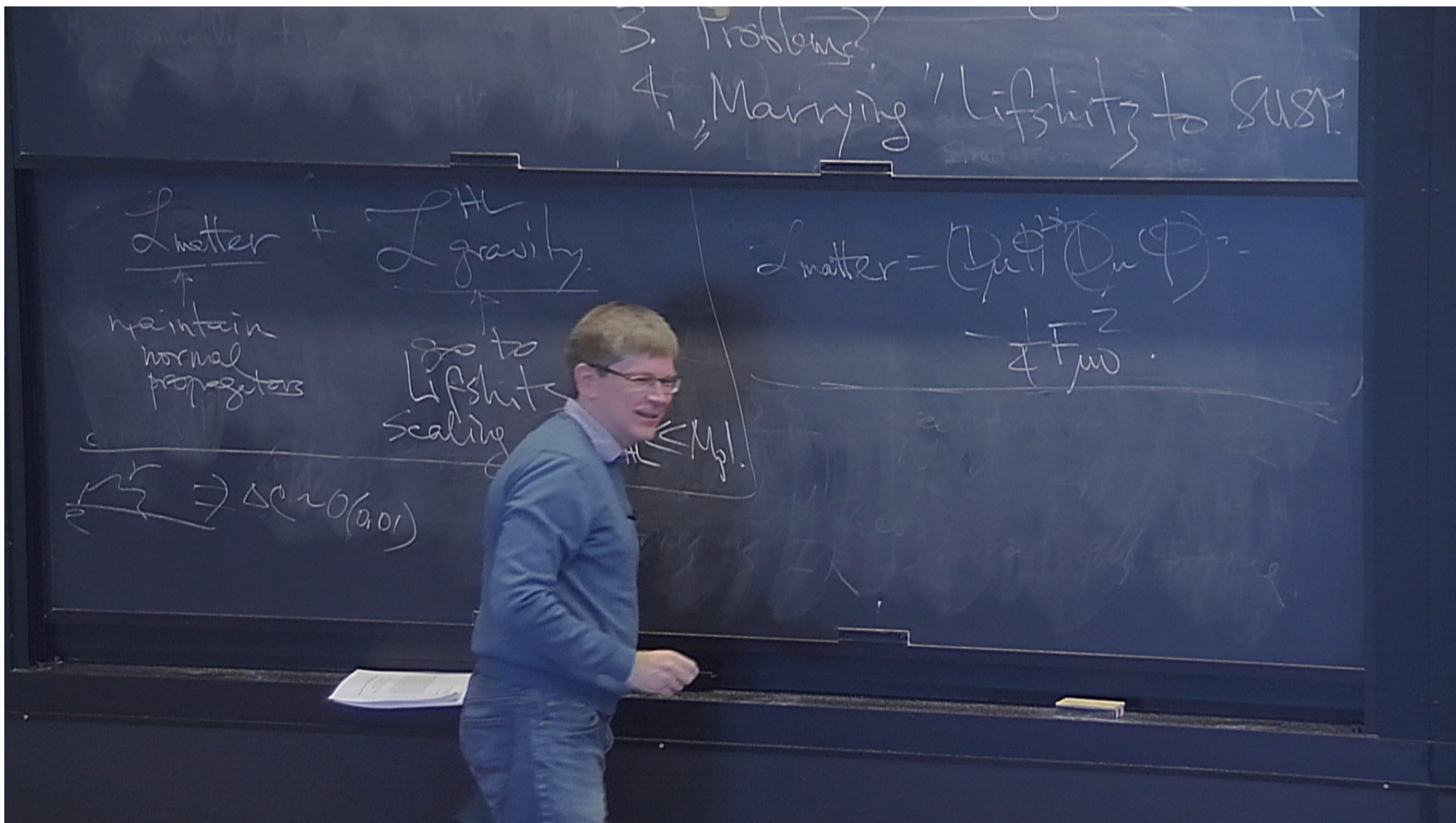
$\mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{gravity}}$

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$$\mathcal{L}_{\text{matter}} = (\partial_\mu \Phi^\dagger \partial_\mu \Phi)^2 - \frac{1}{4} F_{\mu\nu}^2.$$

$$\frac{1}{\Lambda^2} \Rightarrow \Delta C \sim O(0.01)$$



3. Problems?
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$\mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{gravity}}^{\text{HL}}$

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$$\mathcal{L}_{\text{matter}} = (\partial_{\mu} \Phi)^2 - \frac{1}{4} F_{\mu\nu}^2$$

$$\frac{1}{\Lambda^2} \Rightarrow \Delta C \sim O(0.01)$$

2, 1, 0
 φ
 3, 1, 0
 $\varphi - \varphi$

3. Problems?

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$\mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{gravity}}^{\text{HL}}$

↑
maintain
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↑
go to
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scaling at $\Lambda_{\text{H}} \ll M_{\text{Pl}}$

$$\mathcal{L}_{\text{matter}} = (\partial_{\mu}\Phi)^2 - \frac{1}{4}F_{\mu\nu}^2$$

$$\Rightarrow \Delta\mathcal{L} \sim \mathcal{O}(a_0)$$

$$2, 1, 0$$

$$3, 1$$

$$C_{\mu} - C_{\nu}$$

3. Problems?

maintain
normal
propagators

go to
Lifshitz
scaling at $\lambda_H \ll M_p$

$\frac{2, 1, 0}{\text{---}}$
 $\frac{3, 1, 0}{\text{---}}$

$(\Delta C - C) \lesssim 10^{-6}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
with broken
LI in the UV.

2,0 $\Delta C \sim \frac{\Lambda_{HL}^2}{M_{Pl}^2} \left(\frac{1}{16\pi^2} \right) \log \frac{\Lambda_{UV}^2}{\Lambda_{HL}^2} \quad \left(\text{using } Z=3 \right)$

→ $\Lambda_{HL} \lesssim 10^{-10} M_{Pl}$ UV
seriously deprecate the fact of 100% UV gravity
sector.

$(\Delta C - C) \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
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2,0 $\Delta C \sim \frac{\Lambda_{HL}^2}{M_{Pl}^2} \left(\frac{1}{16\pi^2} \right) \log \frac{\Lambda_{UV}^2}{\Lambda_{HL}^2}$ (using $z = \frac{2}{3}$)

1 $\Delta C \sim \frac{\Lambda_{UV}^2}{M_{Pl}^2} \frac{1}{16\pi^2}$ $\Lambda_{HL} \lesssim 10^{-10} M_{Pl}$ UV low energy
sector gravity

$(\Delta C - C) \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
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2, 0 $\Delta C \sim \frac{\Lambda_{HL}^2}{M_{Pl}^2} \left(\frac{1}{16\pi^2} \right) \log \frac{\Lambda_{UV}^2}{\Lambda_{HL}^2}$ (using $z = \frac{2}{3}$)

1 $\Delta C \sim \frac{\Lambda_{UV}^2}{M_{Pl}^2} \frac{1}{16\pi^2}$ $\Lambda_{HL} \lesssim 10^{-10} M_{Pl}$
because of the non-L propagators for "g" γ

$(\Delta C - C) \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
with broken
LI in the UV.

2, 0 $\Delta C \sim \frac{\Lambda_{HL}^2}{M_{Pl}^2} \left(\frac{1}{16\pi^2} \right) \log \frac{\Lambda_{UV}^2}{\Lambda_{HL}^2}$ (using $Z=3$)

1 $\Delta C \sim \frac{\Lambda_{UV}^2}{M_{Pl}^2} \frac{1}{16\pi^2}$ $\Lambda_{HL} \lesssim 10^{-10} M_{Pl}$

Either Λ_{UV} is the
the highest physical
scale or modify
proposal to cure spin 1 propagators

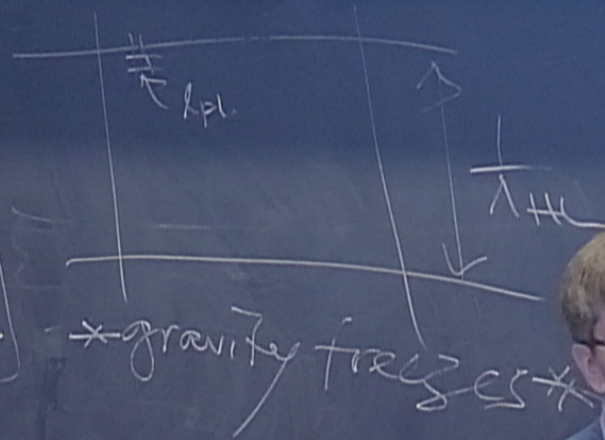
because of the non-L propagators for "g" "g"

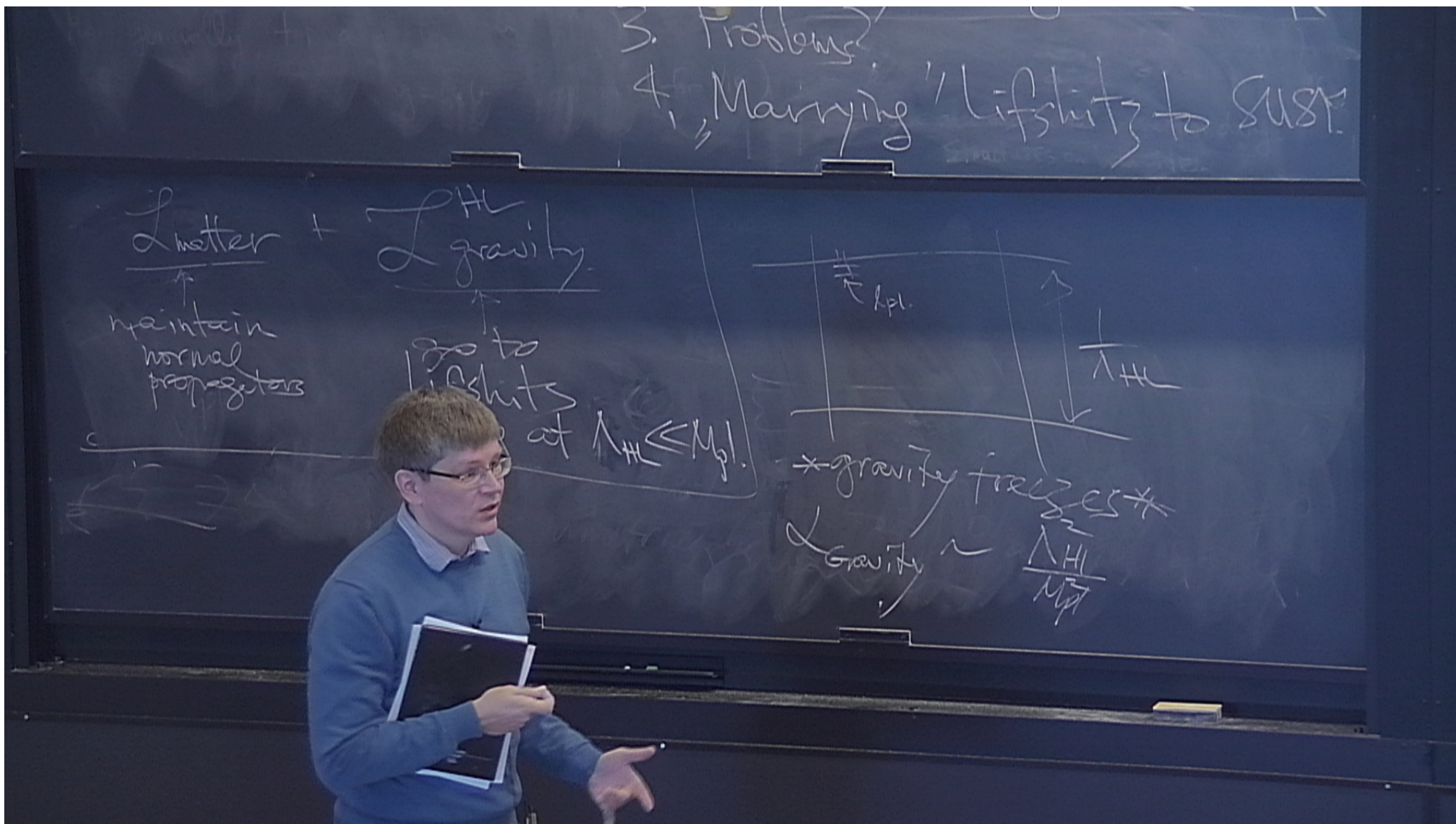
3. Problems?
 4. "Marrying" Lifshitz to SUSY

$\mathcal{L}_{\text{matter}}$ + $\mathcal{L}_{\text{gravity}}^{\text{HL}}$

↑
 maintain
 normal
 propagators

↑
 go to
 Lifshitz
 scaling at $\Lambda_{\text{HL}} \ll M_{\text{Pl}}$



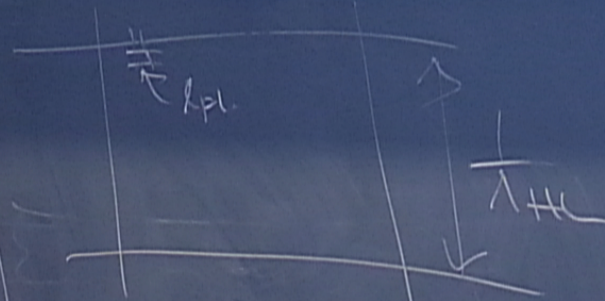


3. Problems?
 4. "Marrying" Lifshitz to SUSY

$L_{\text{matter}} + L_{\text{gravity}}$

maintain
 factors

go to
 Lifshitz
 scaling at $\Lambda_H \ll M_{\text{Pl}}$



gravity freezes

$$L_{\text{gravity}} \sim \frac{\Lambda_H^2}{M_{\text{Pl}}^2} \ll 1$$

$(\Delta C_r - C_e) \mid \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim 10^{14}$

← huge problem
for theories
with broken
LI in the UV.

What is the origin of LI in the matter sector?
($\mu_{pl} \rightarrow 0$ limit)

A:



$(\Delta C_T - C_e) \mid \lesssim 10^{-10}$
(astros, low energy).

$\Lambda_{UV} \sim 10^{16}$ ← huge problem
for theories
with broken
LI in the UV.

What is the origin of LI in the matter sector?

A: Susy.

$\bar{\Psi} \partial_\mu \Psi$

($\partial \rightarrow$ limit)
dim 4 (3).

$(\Delta C_r - C_e) \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
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LI in the UV.

What is the origin of LI in the matter sector?

A: Susy.

$\bar{\Psi} \partial_\mu \Psi$

($\alpha_{pl} \rightarrow 0$ limit)

$\int d^4\theta \Phi^\dagger \Phi + \text{dim } 4(3).$

$(\Delta C_r - C_e) \mid \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
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LI in the UV.

What is the origin of LI in the matter sector?
($\alpha_{pl} \rightarrow 0$ limit)

A: Susy.

$$\bar{\Psi} \partial_0 \Psi \quad + \quad \dim 4 (3).$$

$$\int d^4 \theta \quad \bar{\Phi}_1 \Phi_2 \quad \rightarrow \quad \int d^4 \theta \quad \bar{\Phi}_1 \Phi_2$$

$(\Delta C_r - C_e) \lesssim 10$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$

← huge problem
for theories
with broken
LI in the UV.

What is the origin of LI in the matter sector?

A: Susy.

$\bar{\Psi} \partial_\mu \Psi$

($\alpha_{Pl} \rightarrow \infty$ limit)

$\int d^4\theta \Phi^\dagger \Phi$ + dim 4 (3).
 $\Rightarrow m_{\text{soft}}^2$ dim 3 A,
dim 5,6

$(\Delta C_r - C_e) \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$ ← huge problem
for theories
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LI in the UV.

What is the origin of LI in the matter sector?
($\alpha_{pl} \rightarrow \infty$ limit)

A: Susy.

$\int d^4\theta \Phi^\dagger \Phi$
+ dim 4 (3).

$\text{dim}_{5,6} \Rightarrow m_{\text{soft}}^2 \sim m_{3/2}^2$
 $m_{\text{soft}}^2 \ll \Lambda_{UV}^2$

$(\Delta C_r - C_e) \mid \lesssim 10^{-10}$
(astro, low energy).

$\Lambda_{UV} \sim M_{Pl}$

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What is the origin of LI in the matter sector?

A: Susy.

$\bar{\Psi} \partial_\mu \Psi$

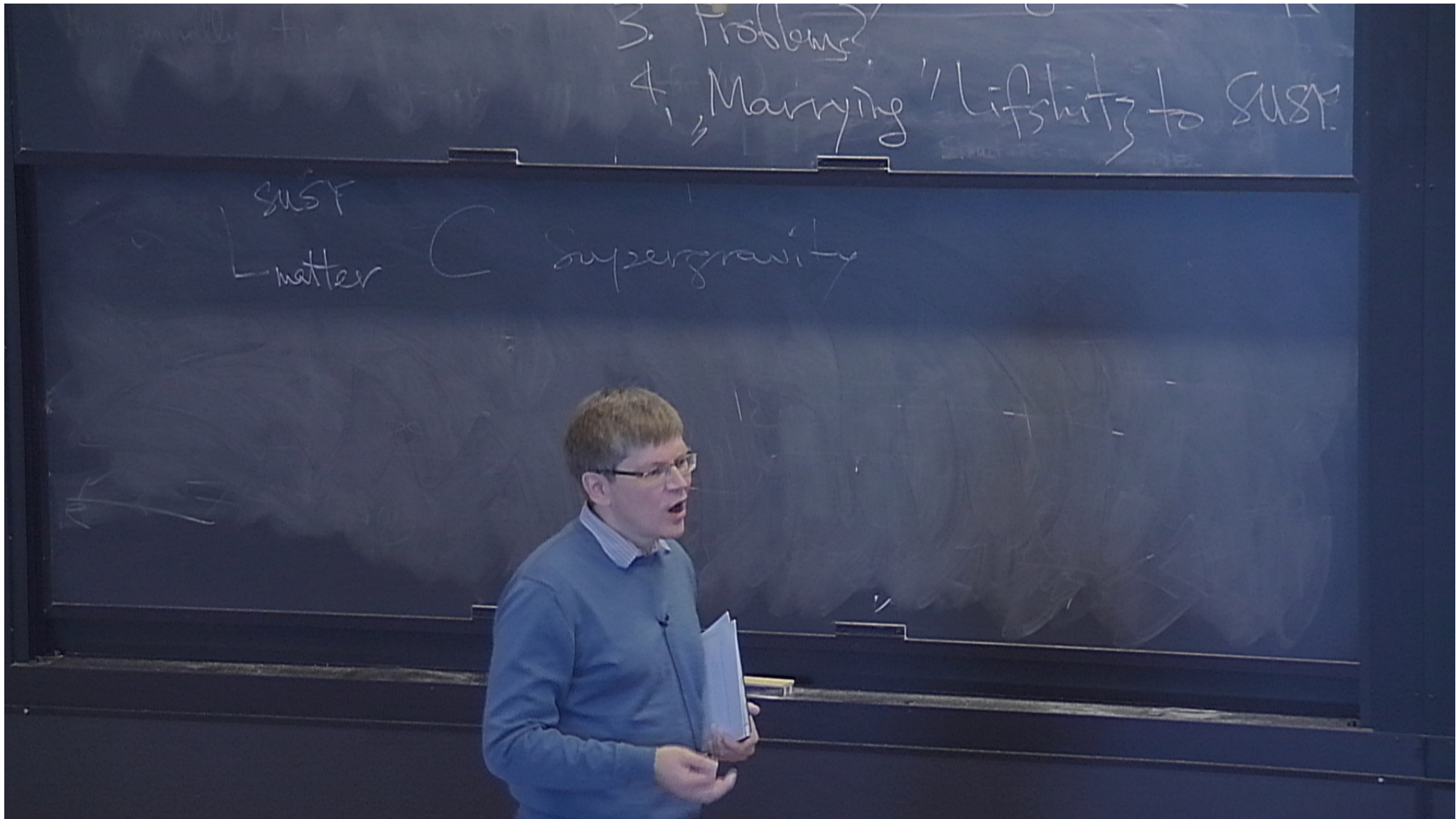
($\alpha_{pl} \rightarrow \infty$ limit)

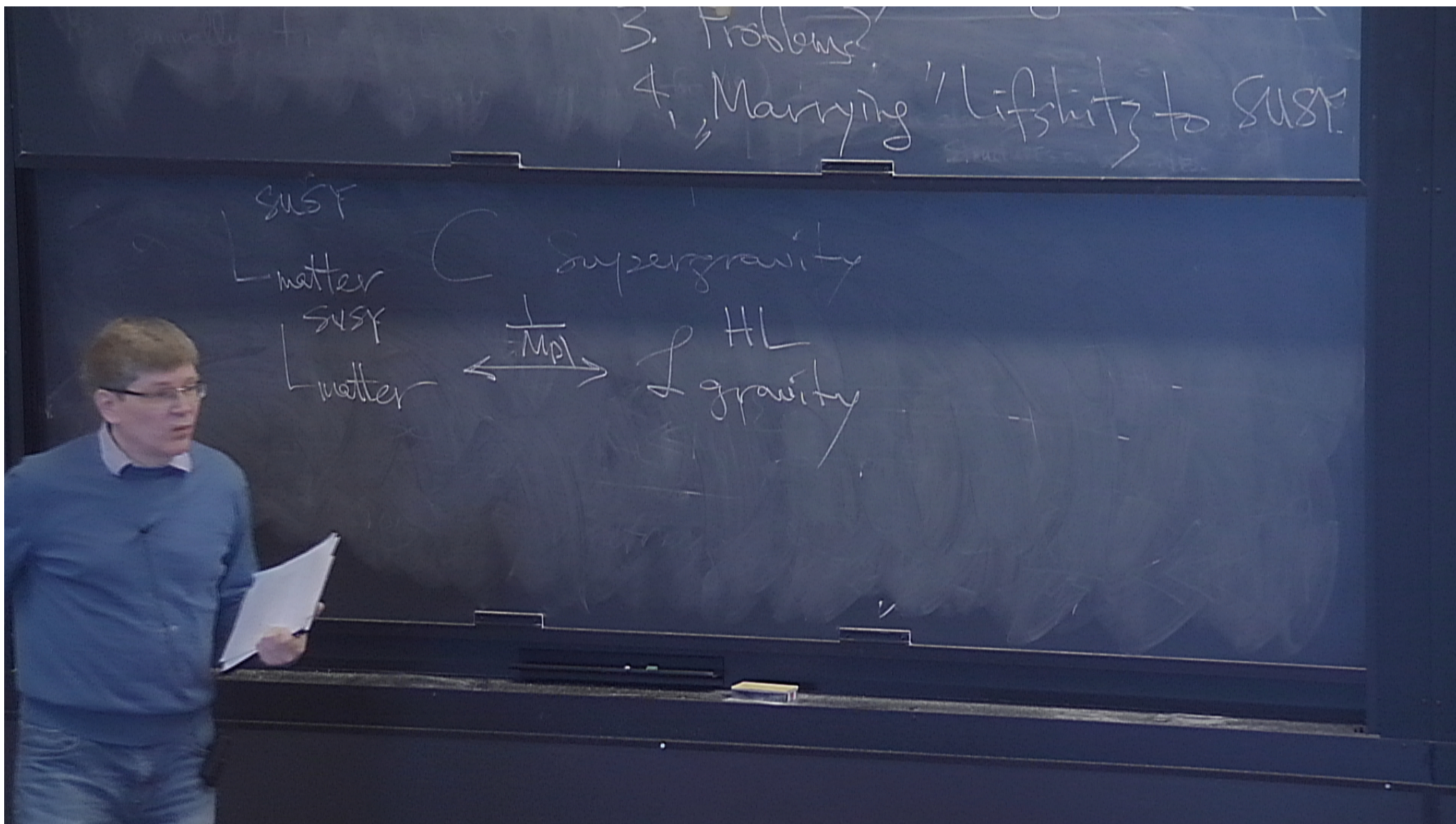
$\int d^4 \theta \Phi^\dagger \Phi + \text{dim } 4(3)$

$\frac{1}{\Lambda_{UV}^2} \text{dim } 6$

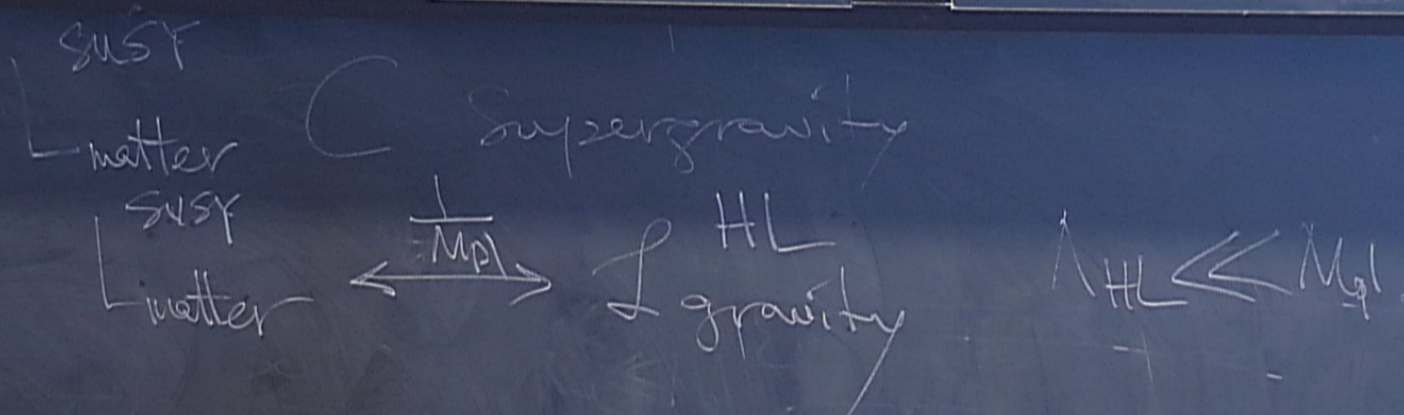
$\Rightarrow m_{\text{soft}}^2$

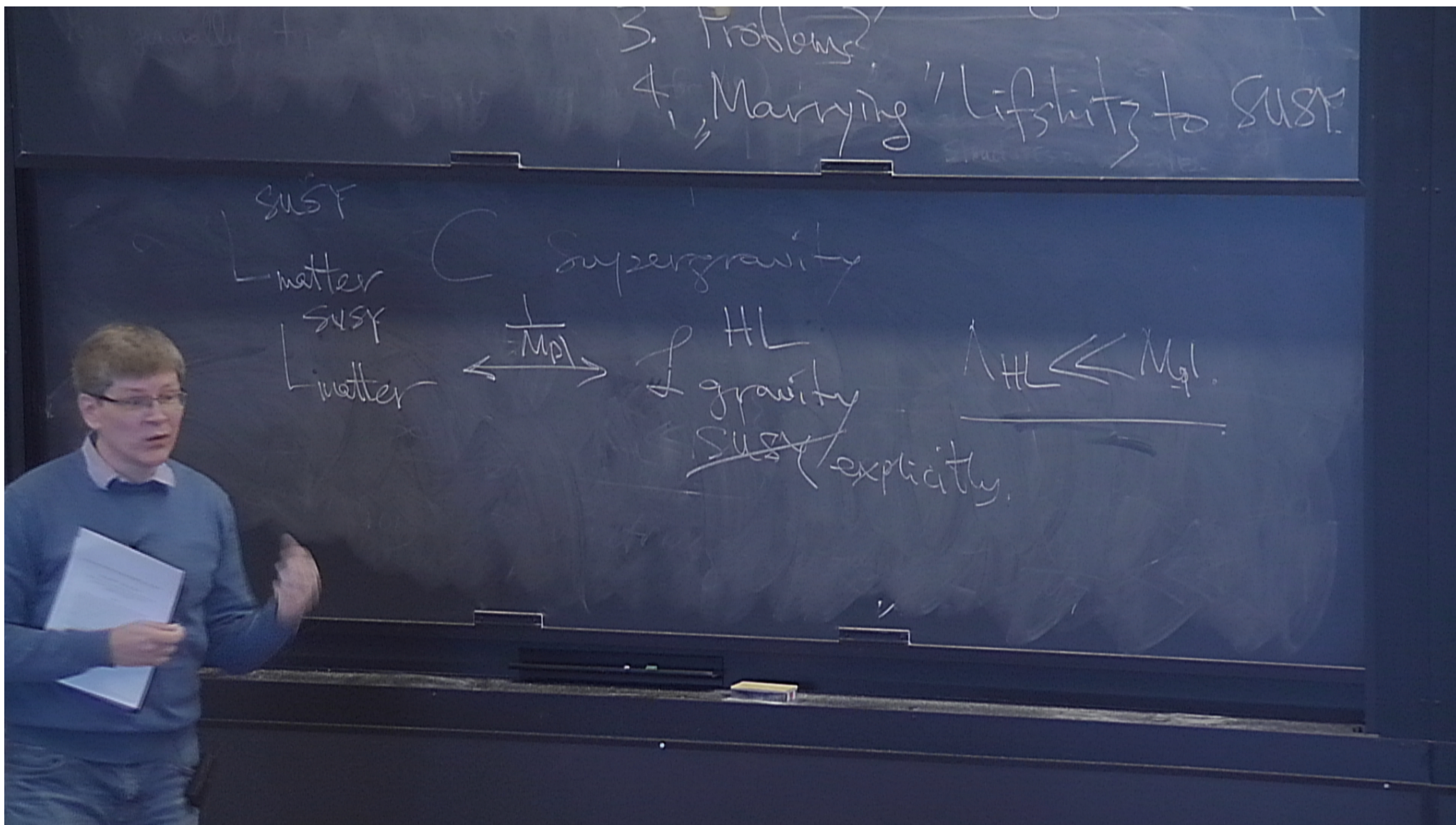
$m_{\text{soft}}^2 \ll \Lambda_{UV}^2$





3. Problems?
4. 'Marrying' Lifshitz to SUSY





3. Problems?
4. Marrying 'Lifshitz to SUSY

$$\mathcal{W} = m^2 \varphi^2 + \underbrace{M}_{\tilde{\Lambda}_{UV}} \bar{\Phi}^2 + \lambda \varphi \bar{\Phi}^2$$

3. Problems?
 4. Marrying Lifshitz to SUSY

$$W = \overset{\substack{\text{SM-like} \\ \text{setb}}}{m^2 \varphi^2} + M \Phi \bar{\Phi}^2 + \lambda \varphi \Phi \bar{\Phi}^2$$

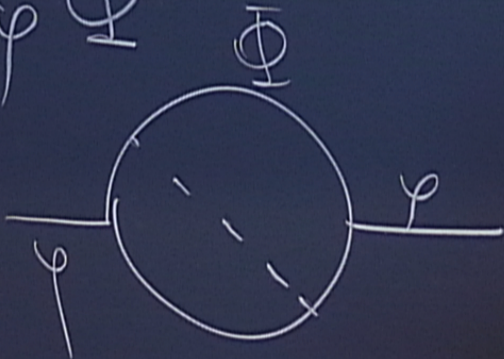
$\searrow \quad \nearrow$
 Λ_W

$\mathcal{L}_{\text{matter}}$
 $\mathcal{L}_{\text{gravity}} = \frac{\kappa}{M_{\text{Pl}}} T_{\mu}^{\mu}$

3. Problems?
 4. Marrying Lifshitz to SUSY

$$W = \overset{\text{SM-like set}}{m^2 \varphi^2} + M \Phi^2 + \lambda \varphi \Phi^2$$

$\int \text{matter} \text{ \& gravity} = \frac{1}{M_{\text{Pl}}^2} \int d^4x \sqrt{-g} T_{\mu\nu}$



Λ_{UV}

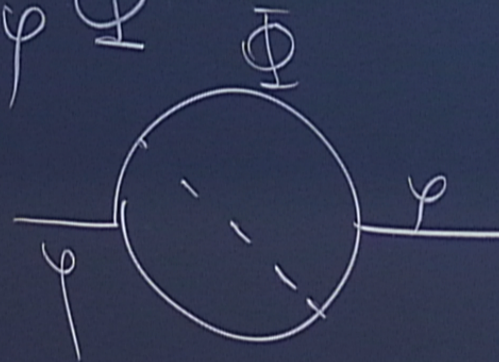
3. Problems?

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$$W = \overset{\text{SM-like set}}{m^2 \varphi^2} + M \Phi^2 + \lambda \varphi \Phi^2$$

$$\mathcal{L}_{\text{gravity}} = \frac{1}{M_{\text{Pl}}^2} T_{\mu\nu}$$

$$\mathcal{L}_{\text{grav}} = \dots \frac{\chi \Delta \chi}{\Lambda_{\text{HL}}^4}$$



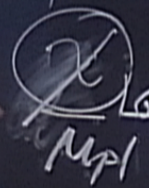
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$$W = m^2 \varphi^2 + M \Phi^2 + \lambda \varphi \Phi^2$$

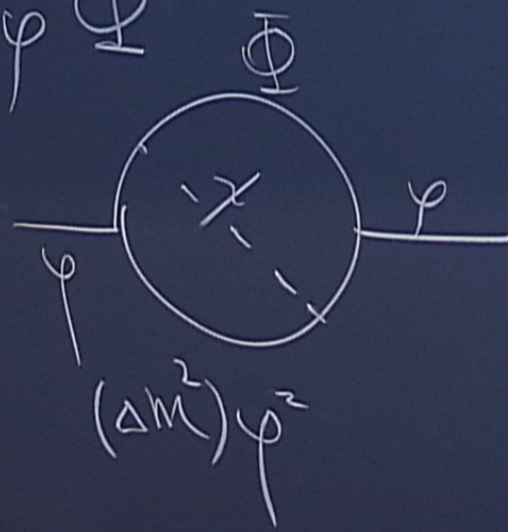
SM-like
 sets

Λ_{UV}

$\mathcal{L}_{\text{mat}}$
 $\mathcal{L}_{\text{grav}}$



$$\dots \frac{\chi \Delta \chi}{\Lambda_{\text{HL}}^4}$$



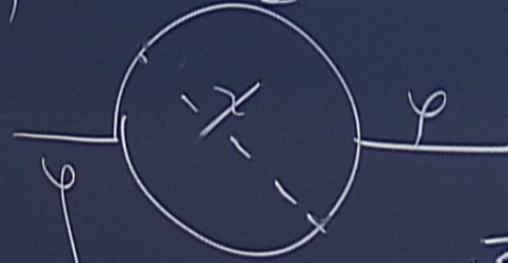
3. Problems?

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$$W = \overset{\text{SM-like set}}{m^2 \varphi^2} + M \Phi^2 + \lambda \varphi \Phi^2$$

$$\mathcal{L}_{\text{gravity}} = \frac{1}{M_{\text{Pl}}^2} T_{\mu\nu}$$

$$\mathcal{L}_{\text{grav}} = \dots \frac{\chi \Delta \chi}{\Lambda_{\text{HL}}^4}$$



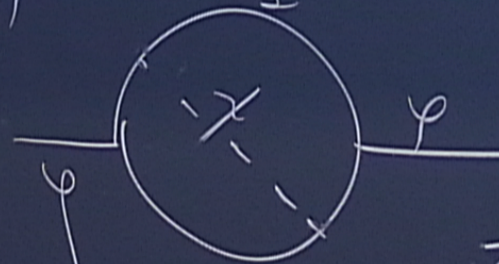
$$(\Delta m^2) \varphi^2 \simeq \frac{\lambda_{\text{HL}}^2}{M_{\text{Pl}}^2} M^2$$

3. Problems?
 4. Marrying Lifshitz to SUSY

$$W = \overset{\text{SM-like set}}{m^2 \varphi^2} + M \Phi^2 + \lambda \varphi \Phi^2$$

$$\mathcal{L}_{\text{gravity}} = \frac{1}{M_{\text{Pl}}^2} T_{\mu\nu}$$

$$\mathcal{L}_{\text{grav}} = \dots \frac{\chi \Delta \chi}{\Lambda_{\text{HL}}^4}$$



$$(\Delta m^2)_{\phi\phi} \simeq \frac{\lambda_{\text{HL}}^2}{M_{\text{Pl}}^2} M^2$$

3. Problems?
 4. Marrying Lifshitz to SUSY

$$W = \overset{\text{SM-like set}}{m^2 \Phi^2} + M \Phi^2 + \lambda \varphi \Phi^2$$

$\mathcal{L}_{\text{matter}} = \frac{1}{M_{\text{Pl}}} \chi T \chi$
 $\mathcal{L}_{\text{grav}} = \dots \frac{\chi \Delta \chi}{\Lambda_{\text{HL}}^4}$

$\frac{d^3 k}{(2\pi)^3}$
 $\frac{\Lambda_{\text{HL}}^3}{M^2}$

(ΔM^2)