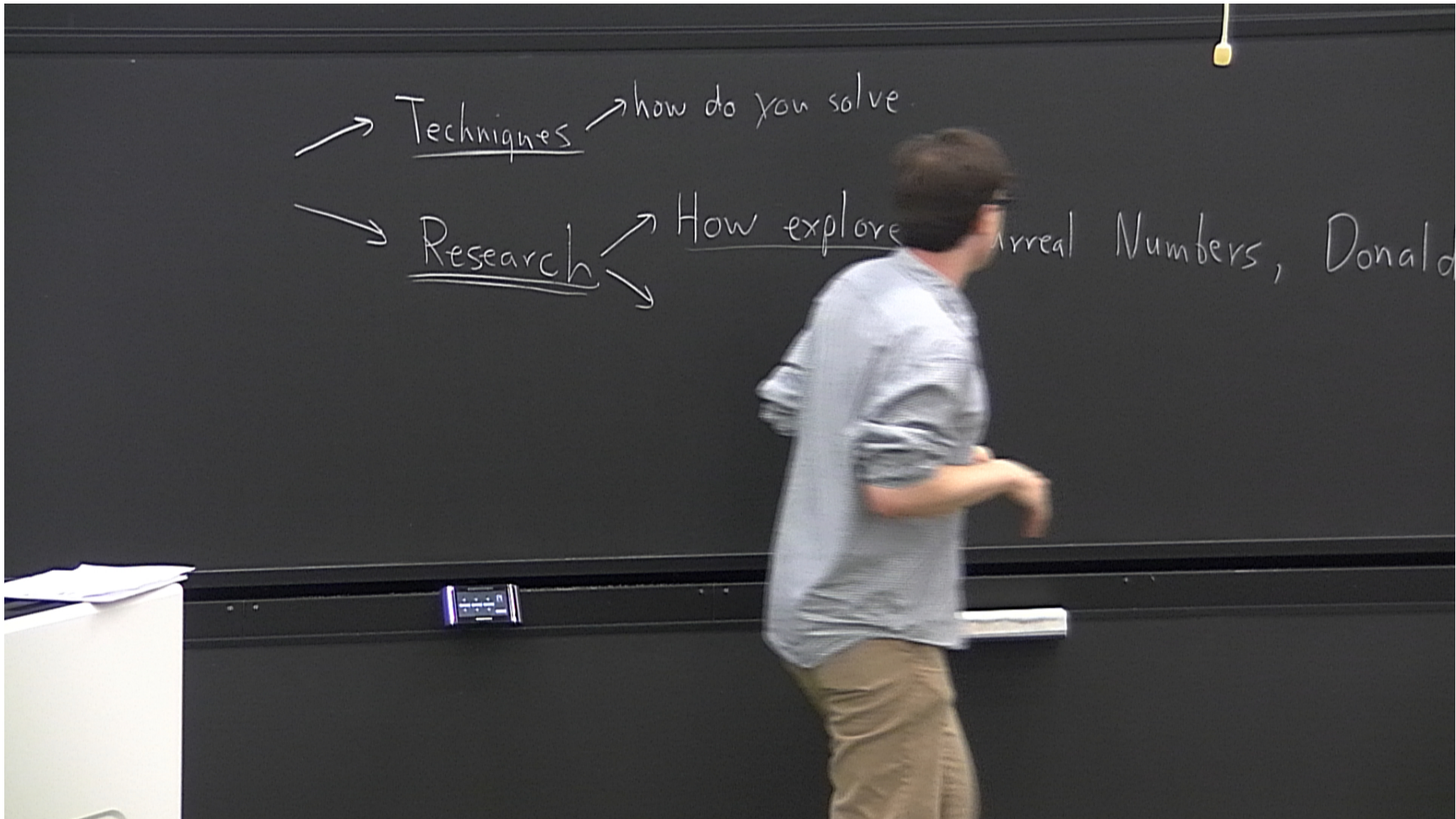


Title: What's interesting these days (with gravity)?

Date: Jul 18, 2013 10:30 AM

URL: <http://pirsa.org/13070033>

Abstract:

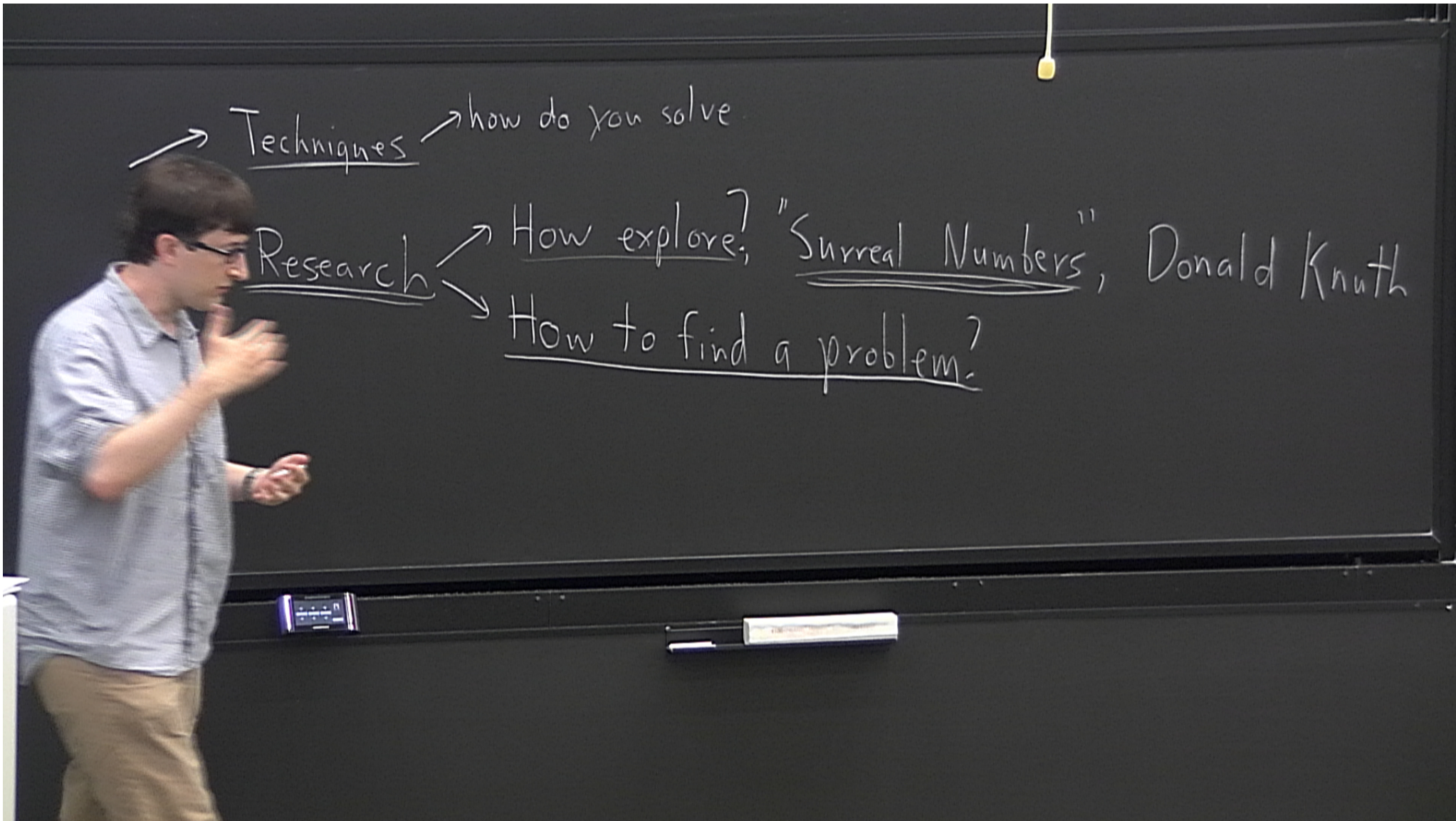


→ Techniques → how do you solve

→ Research → How explore, "Surreal Numbers", Donald Knuth

→ Techniques → how do you solve

→ Research → How ex, "Surreal Numbers", Donald Knuth



→ Techniques → how do you solve

→ Research → How explore? "Surreal Numbers", Donald Knuth
→ How to find a problem? →

→ Techniques → how do you solve

→ Research → How explore? "Surreal Numbers", Donald Knuth

→ How to find a problem? → Einstein, Dirac, ...

→ Techniques → how do you solve

→ Research → How to solve? "Surreal Numbers", Donald Knuth

→ How to find a problem?

→ Einstein

→ Dirac

→ von Neumann

→ John Conway

→ Freeman Dyson

Roger Penrose

→ Techniques → how do you solve

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→ Joh

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→ How to find a problem? → Einstein
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→ von Neumann
→ John Conway
→ Freeman Dyson

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→ How to find a problem?

→ Einstein

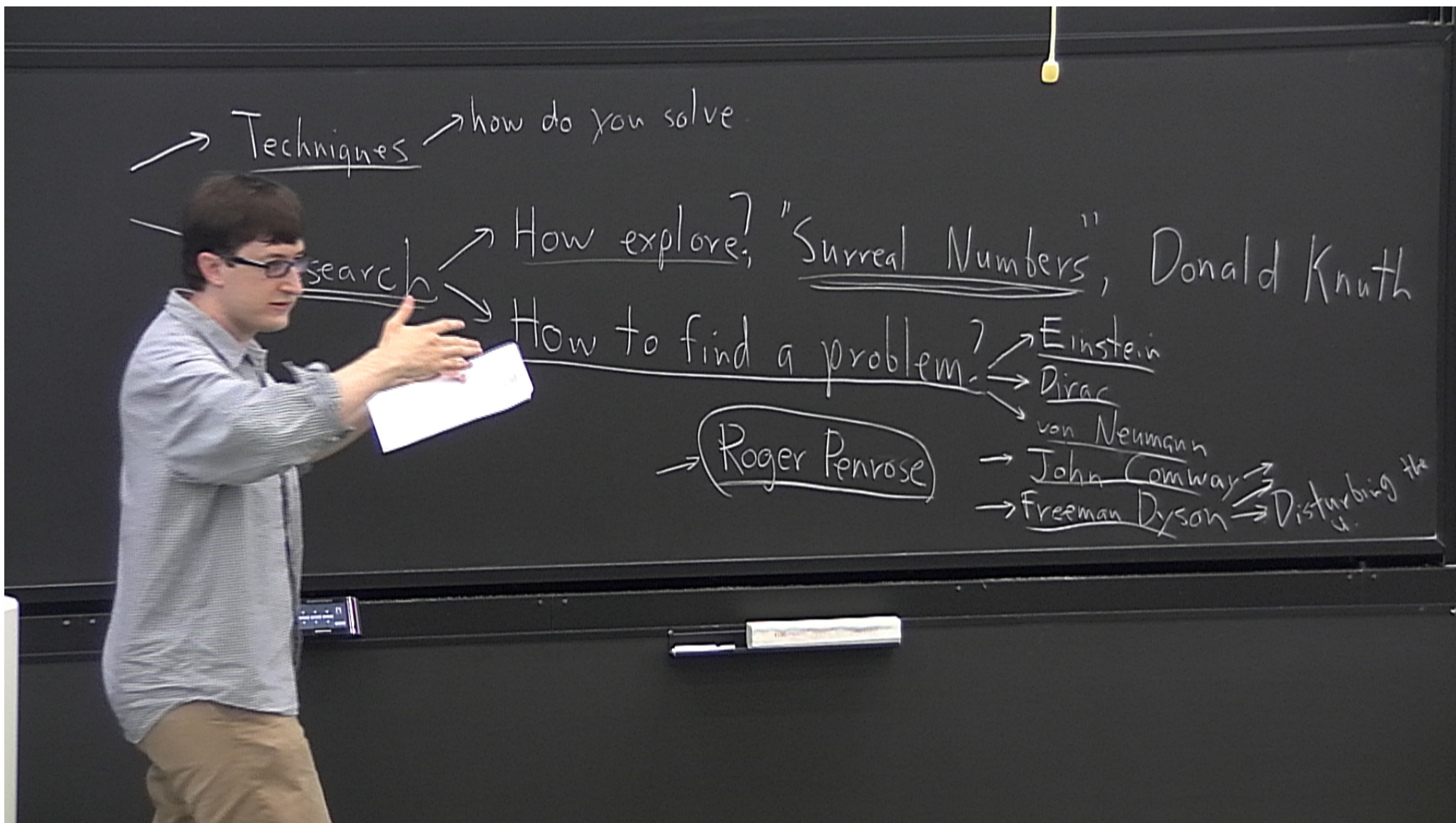
→ Dirac

→ von Neumann

Roger Penrose

→ John Conway

→ Freeman Dyson ⇒ Disturbing the



IGR

Freeman Dyson $\rightarrow$ V.I.S.

IGR

- 1) Dark Matter
- 2) Dark Energy
- 3) Hierarchy Problem
- 4) BH Information Paradox

SM + IGR

8 min
 10^{10} yrs

- 1) Dark Matter
- 2) Dark Energy
- 3) Hierarchy Problem
- 4) BH Information Paradox

→ Freeman Dyson →

SM + IGR

8 min
 10^{10} yrs

- 1) Dark Matter
- 2) Dark Energy
- 3) Hierarchy Problem
- 4) BH Information Paradox

$$\rho \ll m c^2$$

$$\rho \sim \frac{1}{3}$$

→ Freeman Dyson → Disturbed

SM + IGR

8 min
 10^{10} yrs

- 1) Dark Matter
- 2) Dark Energy
- 3) Hierarchy Problem
- 4) BH Information Paradox

$$\rho \ll \frac{mc^2}{V}$$
$$\rho \sim -\frac{1}{3} \frac{mc^2}{V}$$

→ Freeman Dyson → Disturbed

SM + IGR

8 min
 10^{10} yrs

- 1) Dark Matter
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$$\rho \sim \frac{1}{3} \frac{mc^2}{V}$$

→ Freeman Dyson → Disturbed



SM + IGR

8 min
 10^{10} yrs

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→ Freeman Dyson → Disturbed

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 10^{10} yrs

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→ Freeman Dyson → Disturbed

→ Freeman Dyson → Disturbed

SM + IGR

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SM + IGR

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 10^{10} yrs

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$$\rho \sim \frac{1}{3} \frac{m c^2}{V}$$

→ Freeman Dyson → Disturbed

SM + IGR

8 min
 10^{10} yrs

Fawad
Hassan

- 1) Dark Matter
- 2) Dark Energy
- 3) Hierarchy Problem
- 4) BH Information Paradox

$$\rho \sim \frac{mc^2}{V}$$
$$\rho \sim \frac{1}{3} \frac{mc^2}{V}$$

→ Freeman Dyson → Disturbed

m²
SM + IGR
8 min
10¹⁰ yrs
Fawad Hassan

- 1) Dark Matter
- 2) Dark Energy
- 3) Hierarchy Problem
- 4) BH Information Paradox

$\rho \sim \frac{m^2}{V}$
 $\rho \sim \frac{1}{3} \frac{m^2}{V}$

$m = 125 \text{ GeV}$

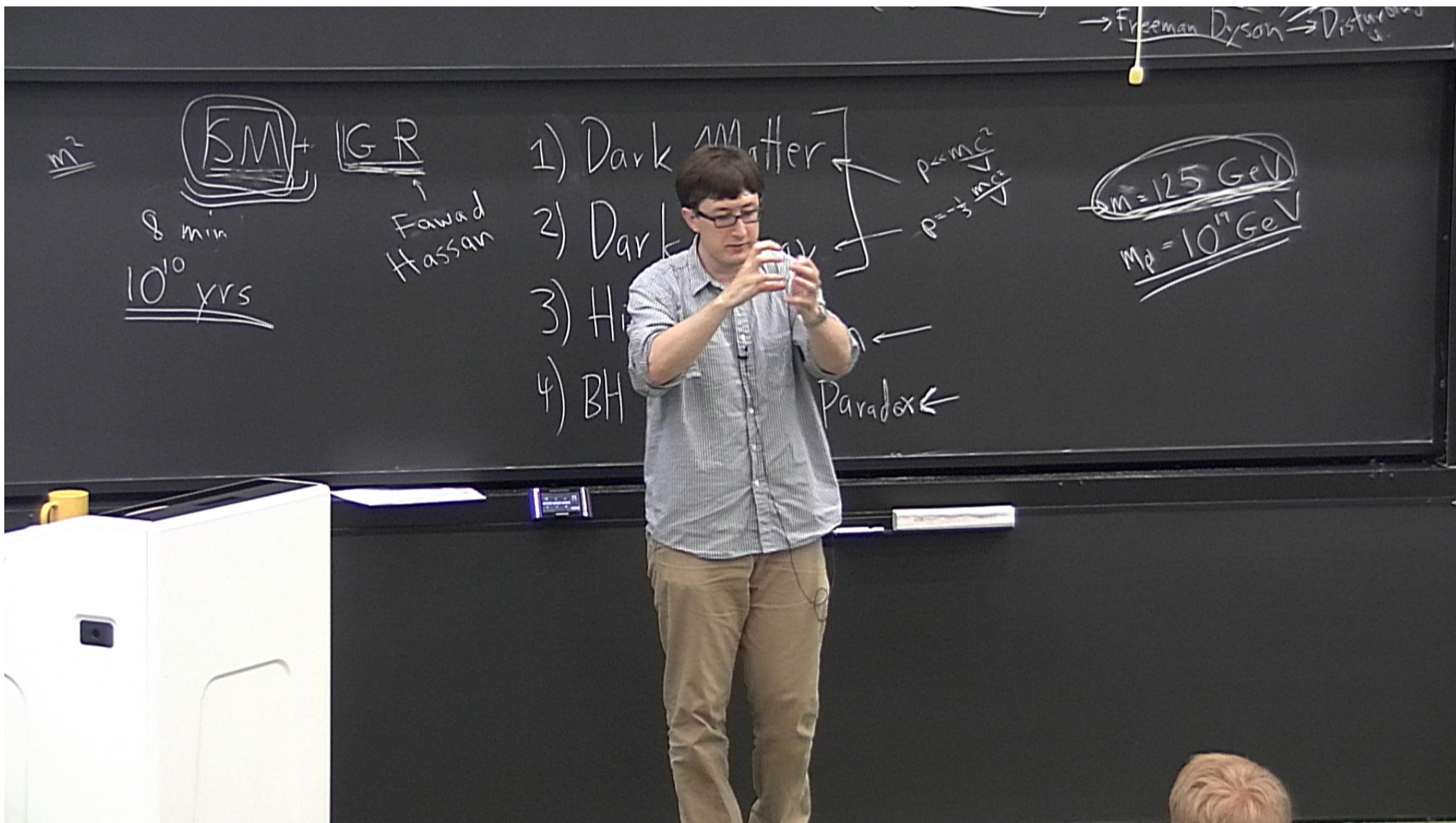
→ Freeman Dyson → Disturbed

m^2
SM + IGR
8 min
 10^{10} yrs
Fawad Hassan

- 1) Dark Matter
- 2) Dark Energy
- 3) Hierarchy Problem
- 4) BH Information Paradox

$$\rho \ll \frac{mc^2}{V}$$
$$\rho = -\frac{1}{3} \frac{mc^2}{V}$$

$m = 125 \text{ GeV}$
 $m_p = 10^{19} \text{ GeV}$



→ Freeman Dyson → Disturbed

m^2
SM + IGR
8 min
 10^{10} yrs
Fawad Hassan

- 1) Dark Matter →
- 2) Dark Energy →
- 3) Hierarchy Problem ←
- 4) BH Information Paradox ←

$$p \ll mc^2$$
$$p \approx \frac{1}{3} mc^2$$

$m = 125 \text{ GeV}$
 $m_p = 10^{19} \text{ GeV}$

→ Freeman Dyson → Disturbed

m^2
SM + IGR
8 min
 10^{10} yrs
Fawad Hassan

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- 2) Dark Energy
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$$\rho \ll \frac{mc^2}{V}$$
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$m = 125 \text{ GeV}$
 $m_p = 10^{19} \text{ GeV}$

→ Freeman Dyson → Disturbance

m^2
SM + IGR
8 min
 10^{10} yrs
Fawad Hassan

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- 2) Dark Energy →
- 3) Hierarchy Problem ←
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→ Freeman Dyson → Disturbance

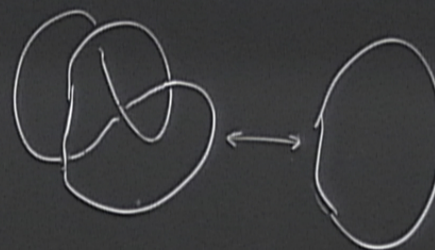
m^2
SM + IGR
8 min
 10^{10} yrs
Fawad Hassan

- 1) Dark Matter →
- 2) Dark Energy →
- 3) Hierarchy Problem ←
- 4) BH Information Paradox ←

$$P \ll \frac{mc^2}{V}$$
$$P \sim \frac{1}{3} \frac{mc^2}{V}$$

$m = 125 \text{ GeV}$
 $m_p = 10^{19} \text{ GeV}$

Group Theory



2010: de Rham, Gabadadze, Tolley

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

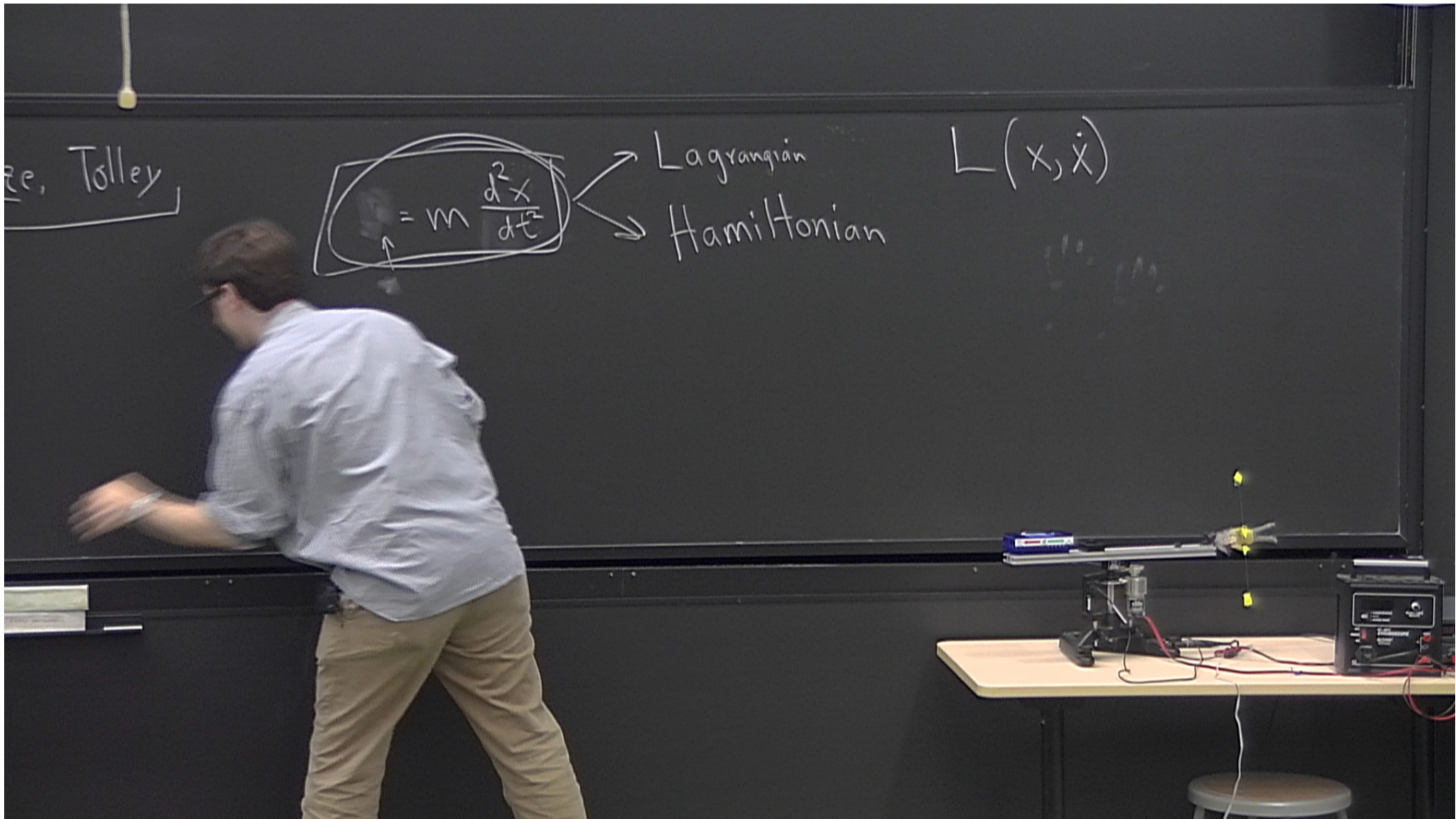
2010: de Rham, Gabadadze, Tolley

$$\boxed{F = m \frac{d^2 x}{dt^2}} \begin{matrix} \nearrow \\ \searrow \end{matrix} \text{Lagrangian}$$

2010: de Rham, Gabadadze, Tolley

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

Lagrangian
Hamiltonian



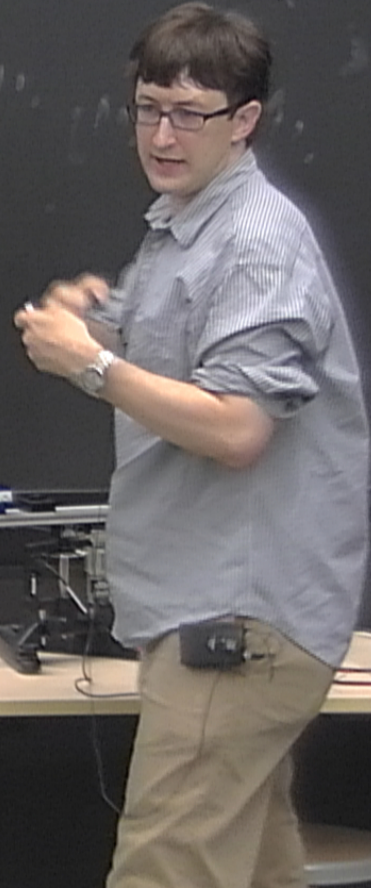
ze, Tolley

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

Lagrangian

Hamiltonian

$$L(x, \dot{x}) = \frac{1}{2} m \left(\frac{dx}{dt} \right)^2 - \frac{1}{2} k x^2$$



re, Tolley

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

Lagrangian

Hamiltonian

$$L(x, \dot{x}) = \frac{1}{2} m \left(\frac{dx}{dt} \right)^2 - \frac{1}{2} kx^2$$

re, Tolley

$$\boxed{-kx = m \frac{d^2x}{dt^2}} \begin{cases} \rightarrow \text{Lagrangian} \\ \rightarrow \text{Hamiltonian} \end{cases}$$

$$L\left(x, \frac{dx}{dt}\right) = \frac{1}{2}m\left(\frac{dx}{dt}\right)^2 - \frac{1}{2}kx^2$$

$\frac{\partial L}{\partial x} =$

re, Tolley

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

Lagrangian

Hamiltonian

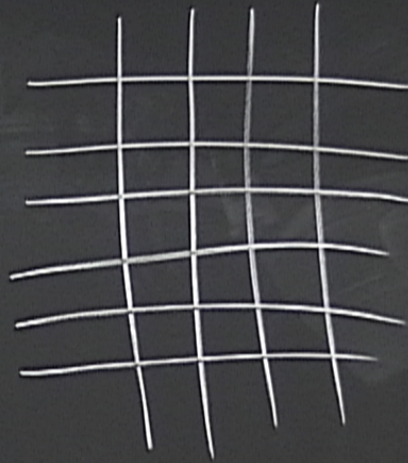
$$L\left(x, \frac{dx}{dt}\right) = \frac{1}{2} m \left(\frac{dx}{dt}\right)^2 - \frac{1}{2} kx^2$$
$$\frac{\partial L}{\partial x} = \frac{d}{dt} \left[\frac{\partial L}{\partial (dx/dt)} \right]$$

re, Tolley

$$\boxed{-kx = m \frac{d^2 x}{dt^2}} \begin{cases} \text{Lagrangian} \\ \text{Hamiltonian} \end{cases}$$

$$L\left(x, \frac{dx}{dt}\right) = \frac{1}{2} m \left(\frac{dx}{dt}\right)^2 - \frac{1}{2} kx^2$$
$$\frac{\partial L}{\partial x} = \frac{d}{dt} \left[\frac{\partial L}{\partial \left(\frac{dx}{dt}\right)} \right]$$
$$-kx = m \frac{d^2 x}{dt^2} = ma$$

GR + SM



2010: de Rham, Gabadadze, Tolley

$$L(x, \frac{dx}{dt})$$
$$\downarrow$$
$$L + \delta L$$

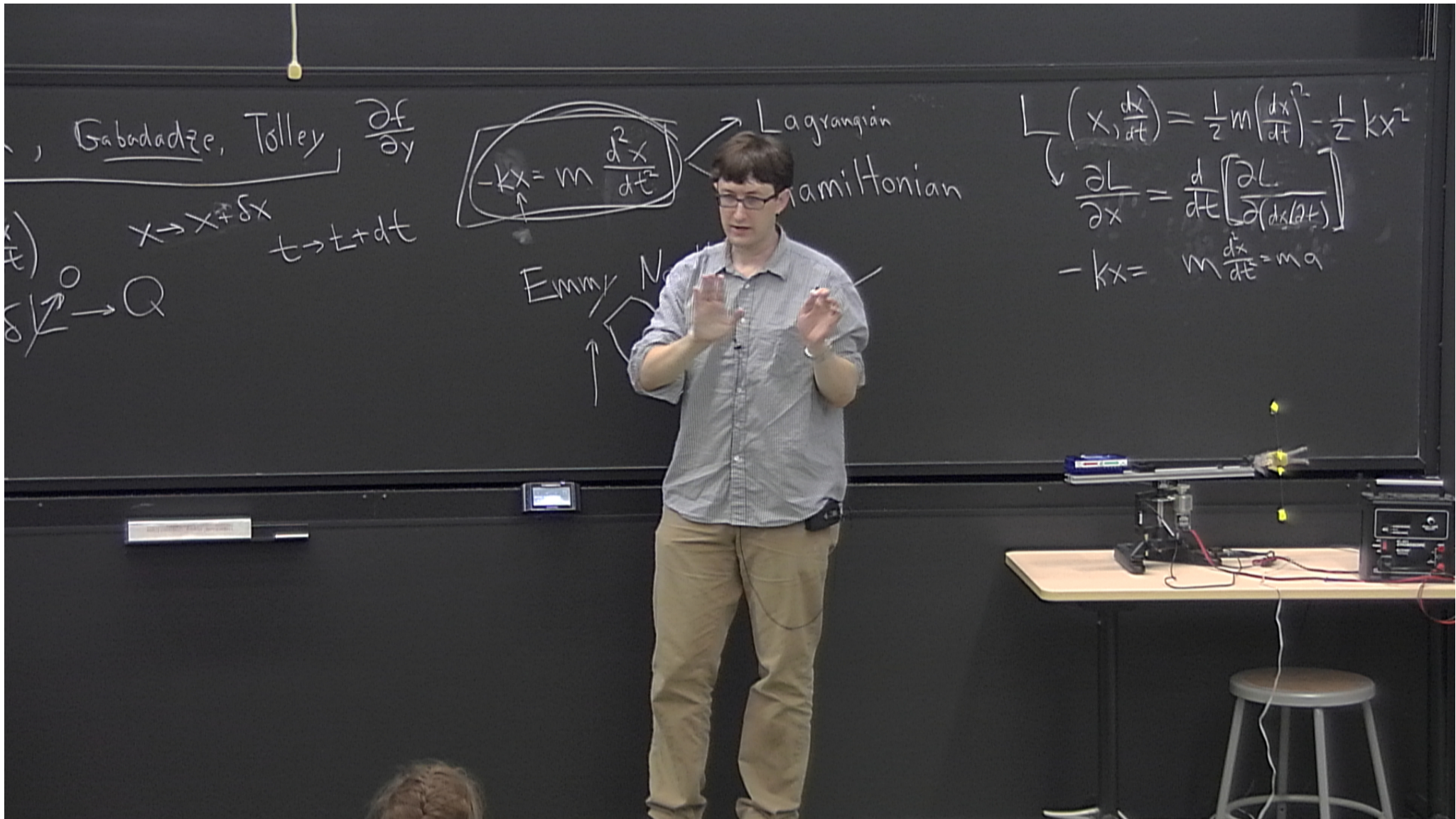
$$x \rightarrow x + \delta x$$

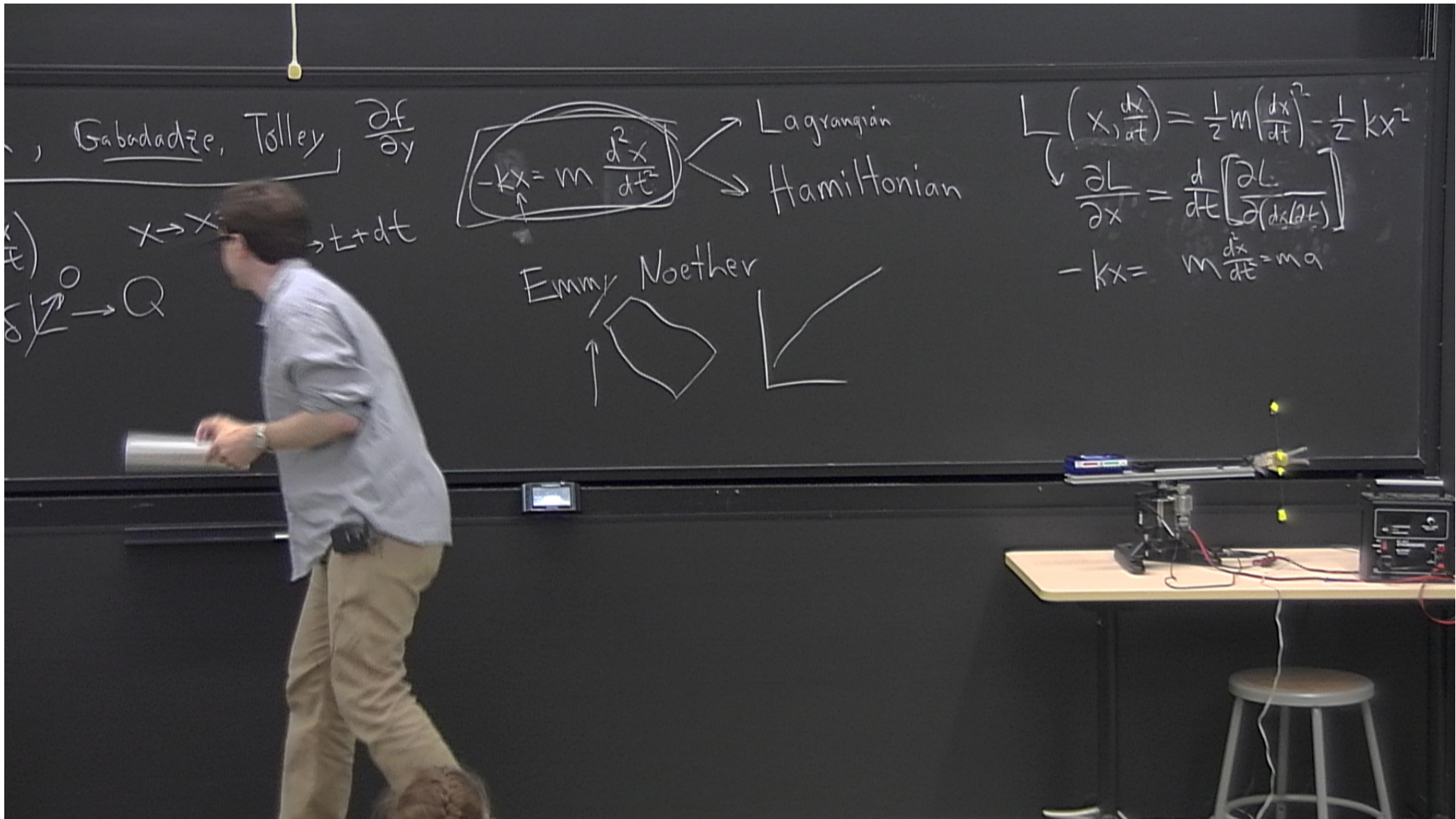
$$-kx = m \frac{d^2 x}{dt^2}$$

Lagrangian

Hamiltonian

Emmy Noether





Gabadadze, Tolley

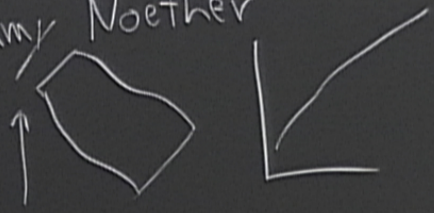
$x \rightarrow x + \delta x$
 $t \rightarrow t + dt$
 $\delta \mathcal{L} \rightarrow Q$

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

Lagrangian

Hamiltonian

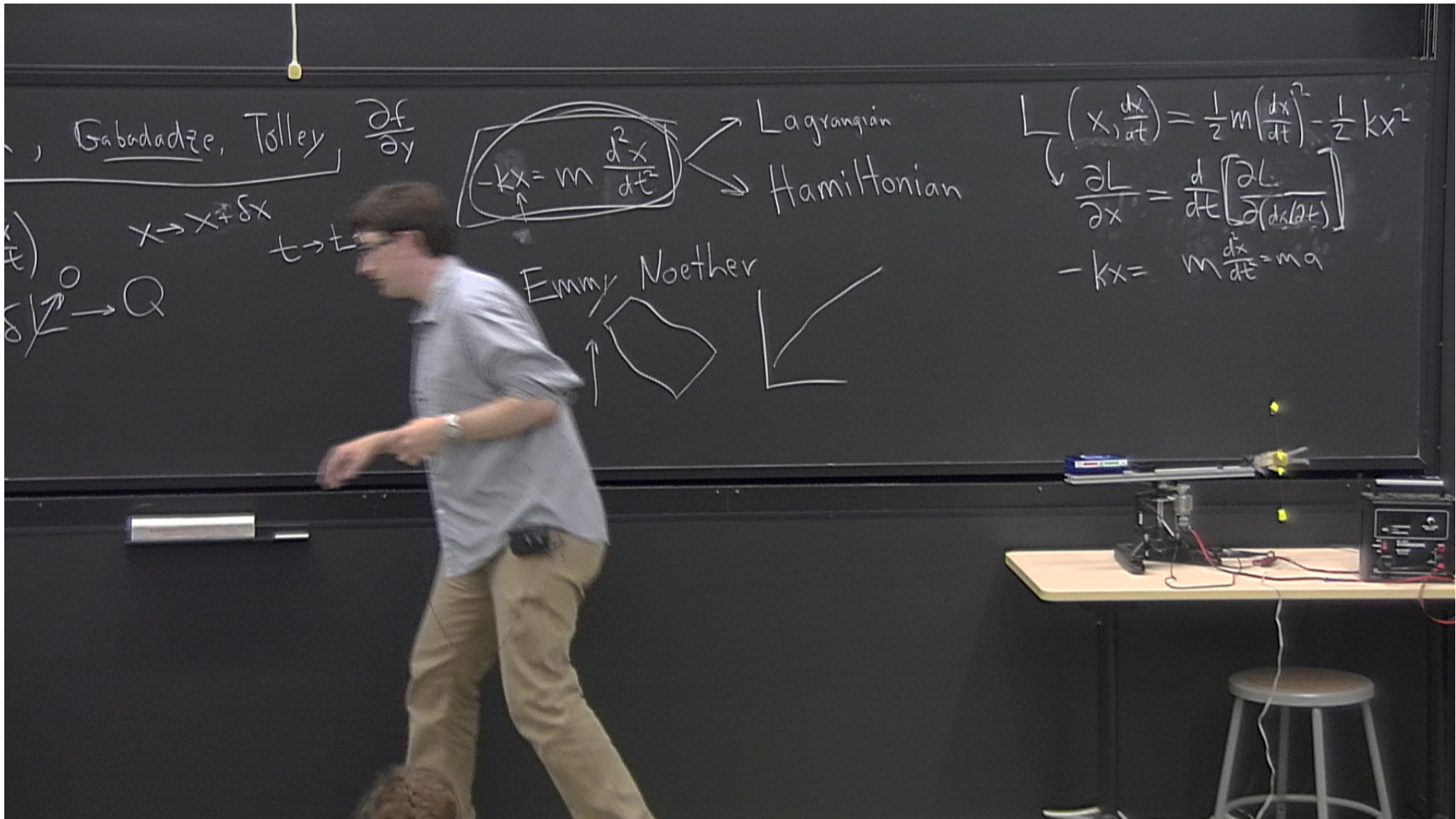
Emmy Noether



$$L\left(x, \frac{dx}{dt}\right) = \frac{1}{2} m \left(\frac{dx}{dt}\right)^2 - \frac{1}{2} kx^2$$

$$\frac{\partial L}{\partial x} = \frac{d}{dt} \left[\frac{\partial L}{\partial \left(\frac{dx}{dt}\right)} \right]$$

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



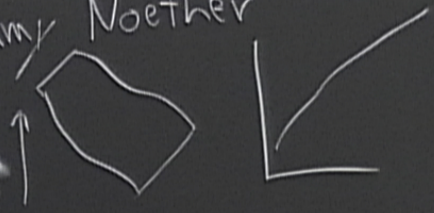
, Gabadadze, Tolley, $\frac{\partial f}{\partial y}$

$x \rightarrow x + \delta x$
 $t \rightarrow t$
 $\delta \mathcal{L} \rightarrow Q$

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

→ Lagrangian
→ Hamiltonian

Emmy Noether



$$L\left(x, \frac{dx}{dt}\right) = \frac{1}{2} m \left(\frac{dx}{dt}\right)^2 - \frac{1}{2} k x^2$$
$$\frac{\partial L}{\partial x} = \frac{d}{dt} \left[\frac{\partial L}{\partial \left(\frac{dx}{dt}\right)} \right]$$
$$-kx = m \frac{d^2 x}{dt^2} = m a$$

$\underline{GR} + \underline{SM}$
Poincare + $SU(3) \times SU(2) \times U(1)$

	$SU(3)$	$SU(2)$	$U(1)$
q_L			
u_R			
d_R			
l_L			
ν_R			
e_R			

Scal

GR + SM

Poincare + SU(3) × SU(2) × U(1)

	SU(3)	SU(2)	U(1)
q_L			
u_R			
d_R			
l_L			
ν_R			
ϕ			
h			

scalar $\rightarrow h$
 fermions
 gauge bosons

GR + SM

Poincare + SU(3) × SU(2) × U(1)

	SU(3)	SU(2)	U(1)
q_L			
u_R			
d_R			
l_L			
ν_R			
ϕ			
h			

scalar $\rightarrow h$
fermions
gauge bosons

$\hbar$

$$G_N = 6.67 \times 10^{-11}$$

GR + SM

Poincare + $SU(3) \times SU(2) \times U(1)$

	$SU(3)$	$SU(2)$	$U(1)$
q_L			
u_R			
d_R			
l_L			
ν_R			
e_R			
h			

scalar $\rightarrow h$
fermions
gauge bosons

$\hbar$
OK

$G_F = 6.67 \times 10^{-5}$

GR + SM

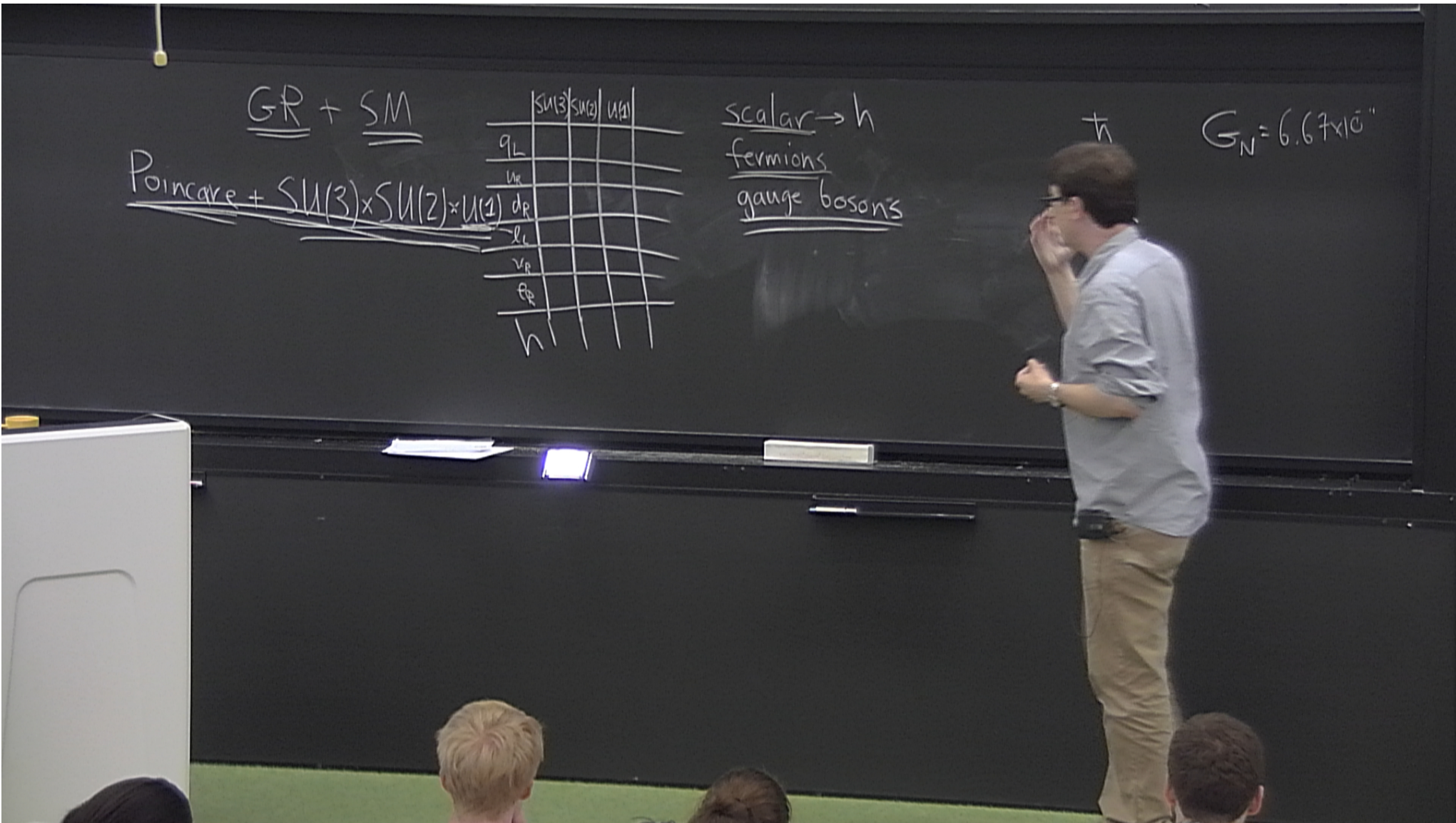
Poincare + SU(3) × SU(2) × U(1)

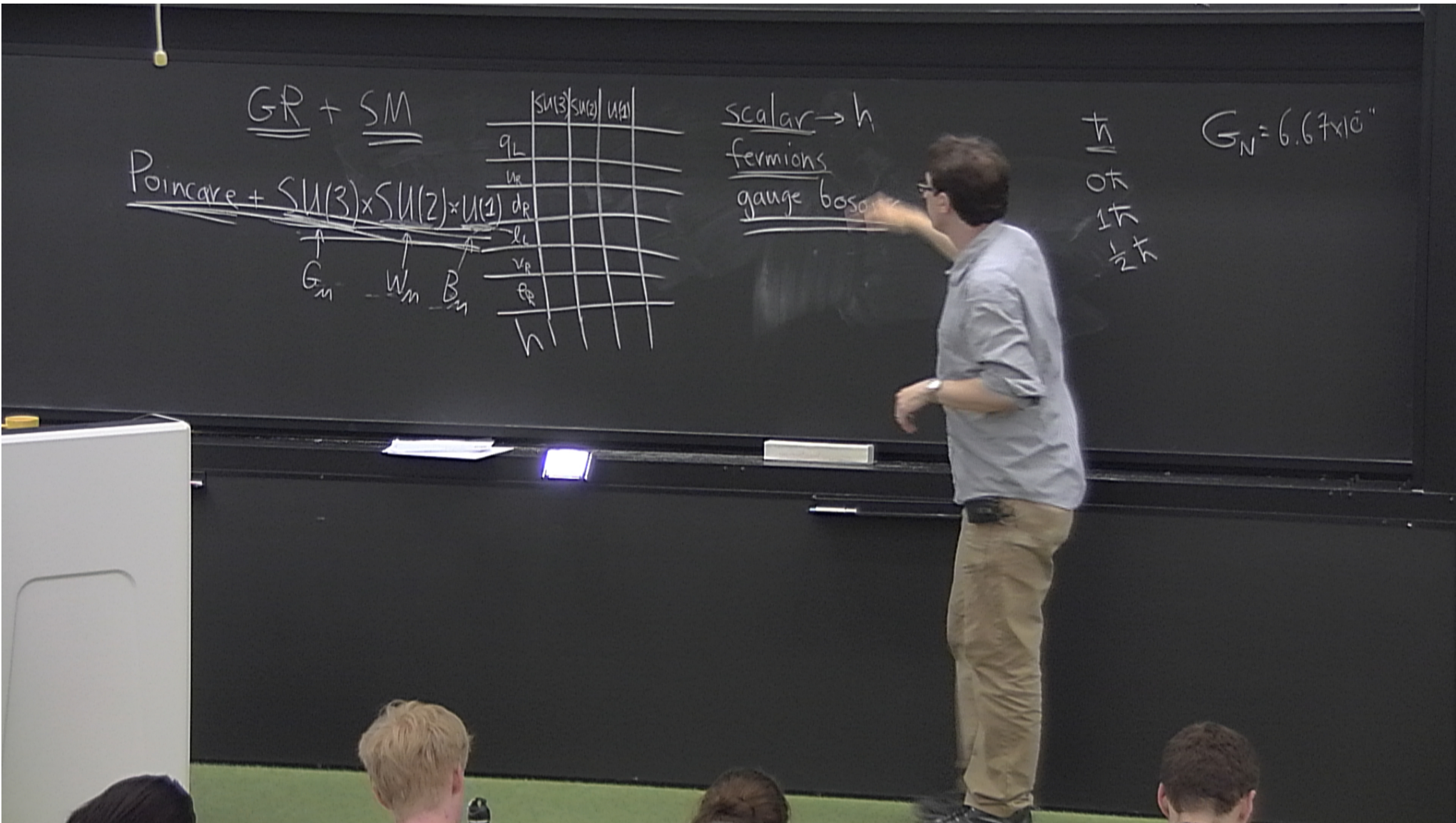
	SU(3)	SU(2)	U(1)
q_L			
u_R			
d_R			
l_L			
ν_R			
ϕ			
h			

scalar → h
 fermions
gauge bosons

$\hbar$
 OK
 1K

$$G_N = 6.67 \times 10^{-11}$$





GR + SM

Poincare + SU(3) × SU(2) × U(1)

$\uparrow$ $\uparrow$ $\uparrow$
 G_m W_m B_m

	SU(3)	SU(2)	U(1)
q_L			
u_R			
d_R			
l_L			
ν_R			
e_R			
h			

scalar → h
fermions
gauge bosons

GR + SM

Poincare + SU(3) × SU(2) × U(1)

$\uparrow$ $\uparrow$ $\uparrow$
 G_m W_m B_m

	SU(3)	SU(2)	U(1)
q_L	3	2	$+\frac{1}{6}$
u_R	3	1	$+\frac{2}{3}$
d_R	3	1	$-\frac{1}{3}$
ℓ_L	1	2	$+\frac{1}{2}$
ν_R	1	1	0
e_R	1	1	-1
h	1	2	$+\frac{1}{2}$

scalar → h
fermions
gauge bosons

GR + SM

Poincare + SU(3) × SU(2) × U(1)

$\uparrow$ $\uparrow$ $\uparrow$
 G_m W_m B_m

	SU(3)	SU(2)	U(1)
q_L	3	2	$+\frac{1}{6}$
u_R	3	1	$+\frac{2}{3}$
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l_L	1	2	$-\frac{1}{2}$
ν_R	1	1	0
e_R	1	1	-1
h	1	2	$+\frac{1}{2}$

scalar → h
fermions
gauge bosons

GR + SM

Poincare + SU(3) x SU(2) x U(1)

$\uparrow$ $\uparrow$ $\uparrow$
 G_m W_m B_m

	SU(3)	SU(2)	U(1)
q_L	3	2	$+\frac{1}{6}$
u_R	3	1	$+\frac{2}{3}$
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l_L	1	2	$-\frac{1}{2}$
ν_R	1	1	0
e_R	1	1	-1
h	1	2	$+\frac{1}{2}$

scalar $\rightarrow h$
fermions
gauge bosons

$L =$

GR + SM

Poincare + SU(3) × SU(2) × U(1)

$\uparrow$ $\uparrow$ $\uparrow$
 G_m W_m B_m

	SU(3)	SU(2)	U(1)
q_L	3	2	$+\frac{1}{6}$
u_R	3	1	$+\frac{2}{3}$
d_R	3	1	$-\frac{1}{3}$
ℓ_L	1	2	$-\frac{1}{2}$
ν_R	1	1	0
e_R	1	1	-1
h	1	1	$+\frac{1}{2}$

scalar $\rightarrow h$
fermions
gauge bosons

$\mathcal{L}(B_m, G_m, W_m, h, q_L, \ell_L, u_R, d_R, e_R, \nu_R)$

$\hbar$

$G_N = 6.67 \times 10^{-11}$

0 $\hbar$

1 $\hbar$

$\frac{1}{2} \hbar$

GR + SM

Poincare + SU(3) x SU(2) x U(1)
 $\uparrow \quad \quad \uparrow \quad \quad \uparrow$
 $G_m \quad W_m \quad B_m$

	SU(3)	SU(2)	U(1)
q_L	3	2	$+\frac{1}{6}$
u_R	3	1	$+\frac{2}{3}$
d_R	3	1	$-\frac{1}{3}$
ℓ_L	1	2	$-\frac{1}{2}$
ν_R	1	1	0
e_R	1	1	-1
h	1	1	$+\frac{1}{2}$

scalar $\rightarrow h$
fermions
gauge bosons

$\hbar$

$$G_N = 6.67 \times 10^{-11}$$

OK

$1\hbar$

$\frac{1}{2}\hbar$

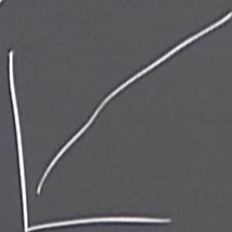
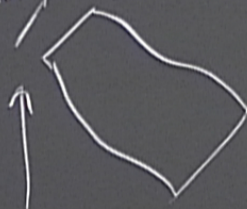
$L(B_m, G_m, W_m, h, q_L, \ell_L, u_R, d_R, e_R, \nu_R)$

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

Lagrangian

Hamiltonian

Emmy Noether



$$x \rightarrow x + \delta x \quad L \rightarrow L + \delta L^0$$

$$L\left(x, \frac{dx}{dt}\right) = \frac{1}{2} m \left(\frac{dx}{dt}\right)^2 - \frac{1}{2} kx^2$$

$$\downarrow \frac{\partial L}{\partial x} = \frac{d}{dt} \left[\frac{\partial L}{\partial (dx/dt)} \right]$$

$$-kx = m \frac{dx}{dt} = ma$$

$$L = \frac{1}{2}(Dh)^{\dagger}(Dh) + i[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R]$$



$$L = \frac{1}{2}(Dh)^{\dagger}(Dh) + i[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R + \bar{\nu}_L \not{D} \nu_L]$$

$$\begin{aligned}
 L = & \frac{1}{2} (Dh)^\dagger (Dh) \\
 & + i \left[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R + \bar{\nu}_L \not{D} \nu_L \right] \\
 & - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W_{\mu\nu} W^{\mu\nu} - \frac{1}{4} G_{\mu\nu} G^{\mu\nu}
 \end{aligned}$$

$$x \rightarrow x + \delta x \quad L \rightarrow L + \delta L$$

$$\begin{aligned}
 L = & \frac{1}{2} (Dh)^\dagger (Dh) \\
 & + i [\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R + \bar{\nu}_L \not{D} \nu_L] \\
 & - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W_{\mu\nu} W^{\mu\nu} - \frac{1}{4} G_{\mu\nu} G^{\mu\nu} \\
 & - m^2 (h^\dagger h) - \lambda (h^\dagger h)^2 \leftarrow \\
 & - [\bar{q}_L \gamma_\mu u_R \tilde{h} + \bar{q}_L \gamma_\mu d_R h + \bar{l}_L \gamma_\mu \nu_R \tilde{h} + \bar{l}_L \gamma_\mu e_R h + \text{c.c.}] - \nu_R^T M \nu_R
 \end{aligned}$$

$$x \rightarrow x + \delta x \quad L \rightarrow L + \delta L$$

$$\begin{aligned}
 L = & \frac{1}{2} (Dh)^\dagger (Dh) \\
 & + i [\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R + \bar{\nu}_L \not{D} \nu_L] \\
 & - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W_{\mu\nu} W^{\mu\nu} - \frac{1}{4} G_{\mu\nu} G^{\mu\nu} \\
 & - m^2 (h^\dagger h) - \lambda (h^\dagger h)^2 \leftarrow \\
 & - [\bar{q}_L \gamma_\mu u_R \hat{h} + \bar{q}_L \gamma_\mu d_R h + \bar{l}_L \gamma_\mu \nu_R \hat{h} + \bar{l}_L \gamma_\mu e_R h + c.c.] - \underline{\underline{\nu_R^T M \nu_R}}
 \end{aligned}$$

$$\frac{R}{16\pi G_N}$$