

Title: PSI 2015/2016 Quantum Gravity - Lecture 15

Date: Mar 11, 2016 10:15 AM

URL: <http://pirsa.org/16030053>

Abstract:

Marc Geiller

- Immirzi parameter
and self-dual formulation
of LQG.

Bianca Dittrich

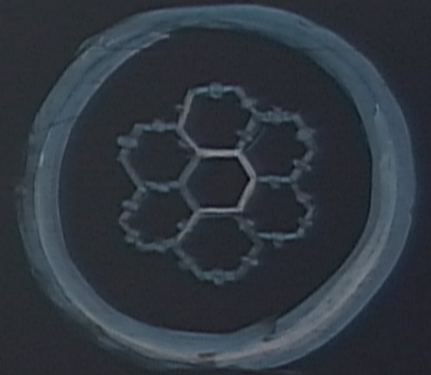
- Renormalization of SF.

Aldo Riello

- Amplitudes and semi-classical limit

Laurent Freidel

- General questions...



Tutorial

Wolfgang Wieland

SF, Plebanski primals
and Wilson line actions.

Barbero - Immingi - parameter



Barbero-Immirzi parameter

i) Starting $\text{Lie}(\text{SO}(1,3)) \ni \omega^{\underline{IJ}} \leftarrow \frac{\epsilon^{0,1,2,3}}{i}$

$$\pm \omega^i = \frac{1}{2} \epsilon^i_{jk} \omega^{jk}$$

(anti) self-dual $\nearrow$

$S[\epsilon, \omega]$

$\in \mathfrak{su}(2)_{\mathbb{C}}$

3i - parameter
 $IJ \leftarrow \begin{matrix} 0 & 1 & 2 & 3 \\ & \underline{1} & & \\ & i & & \end{matrix}$

$$S[e, \omega] = \int * e \wedge e^i F[\omega]$$

$$\omega^i = \frac{1}{2} \varepsilon^i_{jk} \omega^{jk} \pm i \omega^{0i} \in \mathfrak{m}(2)_{\mathbb{C}}$$

Barbero-Immirzi parameter

i) Starting $\text{Lie}(\text{SO}) \ni \omega^{\overline{IJ} \leftarrow \frac{0,1,2,3}{i}}$

$$S[e, \omega] = \int * e \wedge e \wedge F[\omega]$$

Problem: $\cdot \mathbb{C}$

$$\overset{\text{dual}}{\omega^i} = \frac{1}{2} \epsilon^i_{jk} \omega^{jk} \pm i \omega^{0i} \in \mathfrak{su}(2)_{\mathbb{C}} = \mathfrak{sl}(2, \mathbb{C})$$

Barbero-Immirzi parameter

i) Starting $\text{Lie}(\text{SO}(1,3)) \ni \omega^{\underline{IJ} \leftarrow \frac{0,1,2,3}{i}}$

$$\pm \omega^i = \frac{1}{2} \epsilon^{ijk} \pm i \omega^{0i} \in \mathfrak{su}(2)_{\mathbb{C}} = \mathfrak{sl}(2, \mathbb{C})$$

(anti) self-dual

$$S[e, \omega] = \int * e \wedge e \wedge F[\omega]$$

Problem:

- $\mathbb{C}$
- $\{e, \text{metric}\} \in \mathbb{R}$

$\mathbb{R}$ -Condition : $\omega^+ + \overline{\omega^+} = \mathbb{P}(e)$

i - parameter

$$\overline{IJ} \leftarrow \frac{\sigma_{1,1}^1 \sigma_{1,2}^2 \sigma_{1,3}^3}{i}$$

$$\omega^i = \frac{1}{2} \varepsilon^i_{jk} \omega^{jk}$$

$$\pm i \omega^{0i} \in \mathfrak{su}(2)_{\mathbb{C}} = \mathfrak{sl}(2, \mathbb{C})$$

$$S[e, \omega] = \int * e \wedge e \wedge F[\omega]$$

Problem: • $\mathbb{C}$

• $\{g, \text{metric}\} \in \mathbb{R} \longrightarrow$

R-Condition : ${}^+\omega + {}^+\overline{\omega} = \Gamma(e)$

Instead of ${}^+\omega^i$, use $A^i \equiv \underbrace{\Gamma^i(e)} + \gamma \underline{k}^i$

Immirzi parameter
 $(SO(1,3)) \ni \omega^{\underline{IJ}} \leftarrow \omega^{\underline{0,1,2,3}}_i$

$\pm \omega^i = \frac{1}{2} \varepsilon^i_{jk} \omega^{jk} \pm i \omega^{0i} \in \mathfrak{u}(2)_{\mathbb{C}} = \mathfrak{sl}(2, \mathbb{C})$

(anti) self-dual $\nearrow$

$$S[e, \omega] = \int * e \wedge e \wedge F$$

Problem: $\bullet \mathbb{C}$
 $\bullet \{g, metric\} \in$

IR-Condition : ${}^+\omega + {}^+\overline{\omega} = \Gamma(e)$

Instead of ${}^+\omega^i$, use $A^i \equiv \underbrace{\Gamma^i(e)} + \gamma \underline{\kappa}^i \in \mathfrak{su}(2)$

$$S[e, w] = \int * e \wedge e \wedge F[w] + \frac{1}{8} e \wedge e \wedge F[w]$$

$$S[e, \omega] = \int * e \wedge e \wedge F[\omega] + \frac{1}{8} e \wedge e \wedge F[\omega]$$

EOM: $T := D e = 0$

MC-Condition : $w + w = 1'(e)$

Instead of $+$ use $A^i \equiv \underbrace{1'(e)} + \gamma \underline{K^i} \in su(2)$

$\rightarrow$ First class constraints : $su(2)$

Immirzi parameter

$$(3) \Rightarrow \omega_{IJ} \leftarrow \omega_{IJ}^{1,2,3}$$

$$\pm \omega^i = \frac{1}{2} \varepsilon^i_{jk} \omega^{jk} \pm i \omega^{0i} \in \mathfrak{su}(2)_{\mathbb{C}} = \mathfrak{sl}(2, \mathbb{C})$$

self dual

$$S[e, \omega] = \int * e \wedge e \wedge F[\omega]$$

Problem: • $\mathbb{C}$

• $\{g, metric\} \in \mathbb{R} \longrightarrow$

If A is an $su(2)$ connection

- $\{G(u), A\} = Du$

- $\{H_{\text{diff}}(\vec{N}), A\} = \mathcal{L}_{\vec{N}} A$

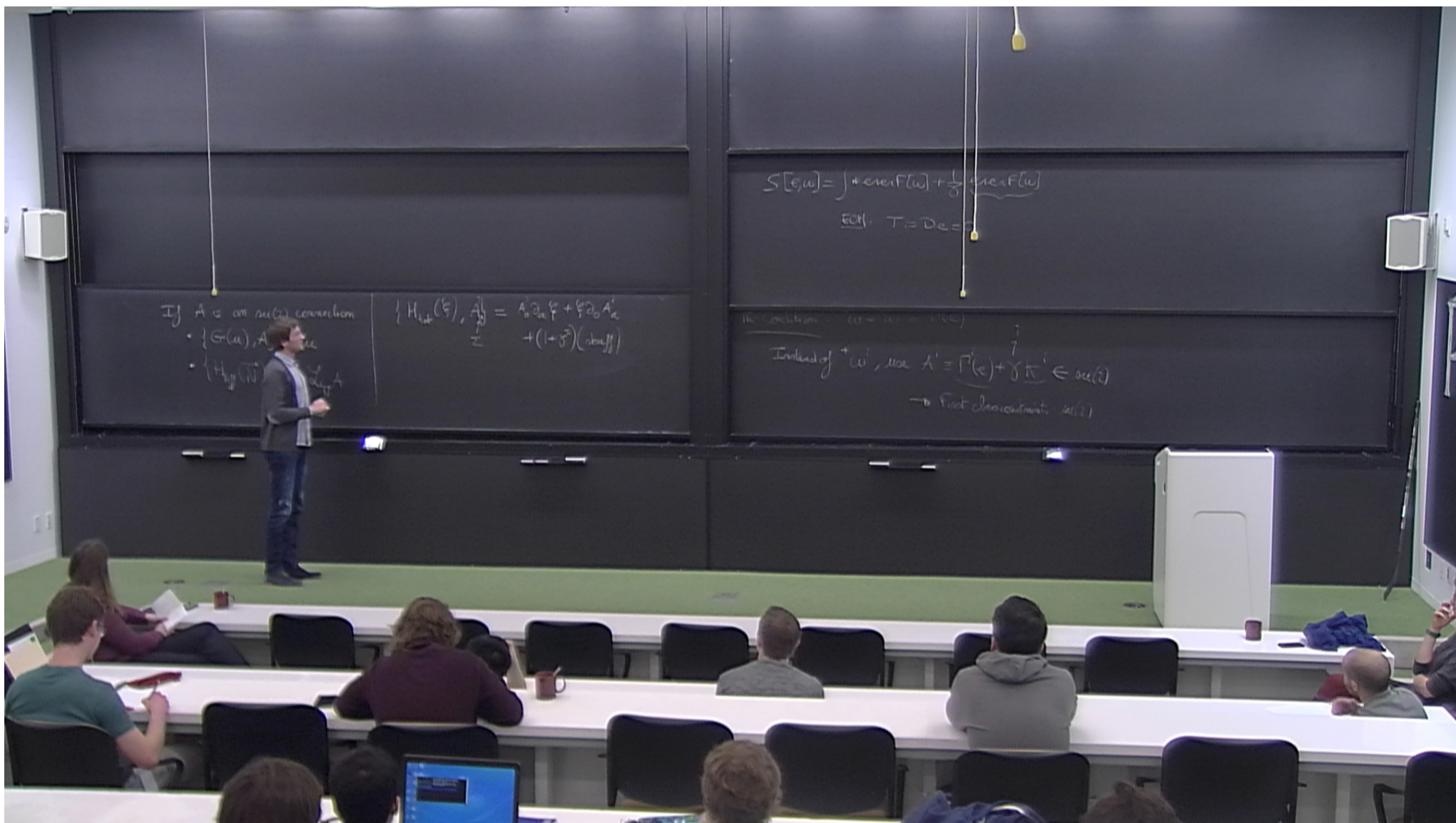
$$\{ H_{\text{tot}}(\xi), \underbrace{A_a^i}_{\Sigma} \} = A_0^i \partial_a \xi + \xi \partial_0 A_a^i$$

$$\{ H_{\text{tot}}(\xi), \underbrace{A_a^i}_{\uparrow} \} = A_0^i \partial_a \xi + \xi \partial_0 A_a^i + (1 + \gamma^2)(\text{stuff})$$

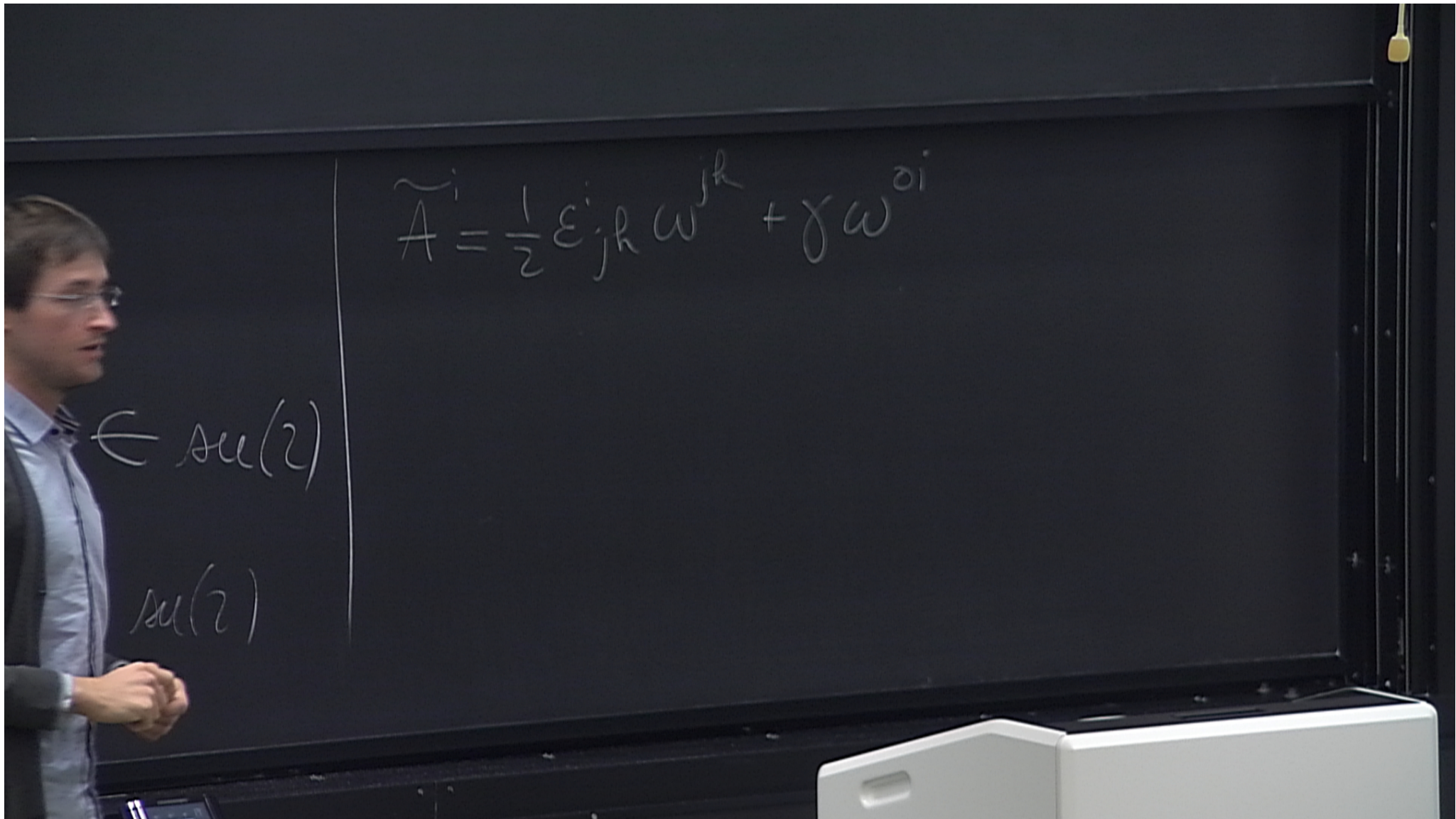
condition: $\omega + \omega = \Gamma(e)$

Instead of ω^i , use $A^i \equiv \underbrace{\Gamma^i(e)} + \gamma \underbrace{k^i} \in \mathfrak{su}(2)$

→ First class constraints: $\mathfrak{su}(2)$



$$\{ H_{\text{tot}}(\xi), \underbrace{A_a^i}_{\Sigma} = A_0^i \partial_a \xi + \xi \partial_0 A_a^i + (1 + \delta^2)(\text{stuff})$$



$\in \mathfrak{su}(2)$

$\mathfrak{su}(2)$

$$\tilde{A}_i = \frac{1}{2} \epsilon_{ijk} \omega^{jk} + \gamma \omega^{0i}$$

$$E = \det(e) e$$

Get QG over all scales

Scale is dynamical.

Example:

$$\begin{aligned} S_{\text{eff}} &= \dots a(k) L_{\text{matter}} \\ &= \dots a(k(g)) \end{aligned}$$

Get QG over all scales

Scale is dynamical

Example:

$$\begin{aligned} S_{\text{eff}} &= \dots a(k) L_{\text{matter}} \\ &= \dots a(k(g)) L_{\text{matter}} \end{aligned}$$

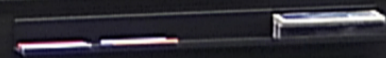
Scales

Usual picture of lattice models

"Small"

"Large"

matter
L matter



Scales

Usual picture of lattice models

discretize and
define your
model

"small"

extract physics
at large scales

"large"

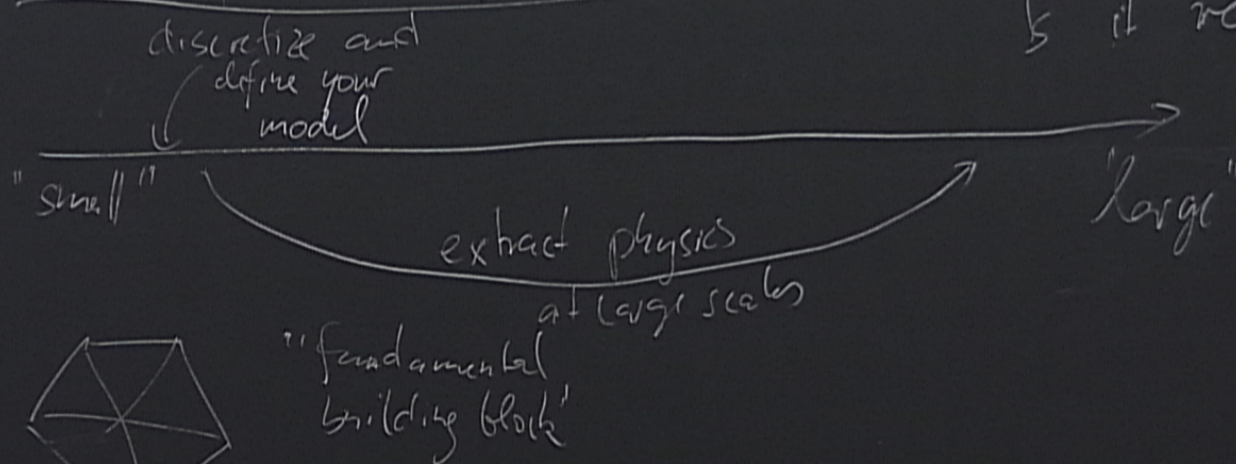
↳ it reasonable?

matter
L matter

Scales

matter
L matter

Usual picture of lattice models

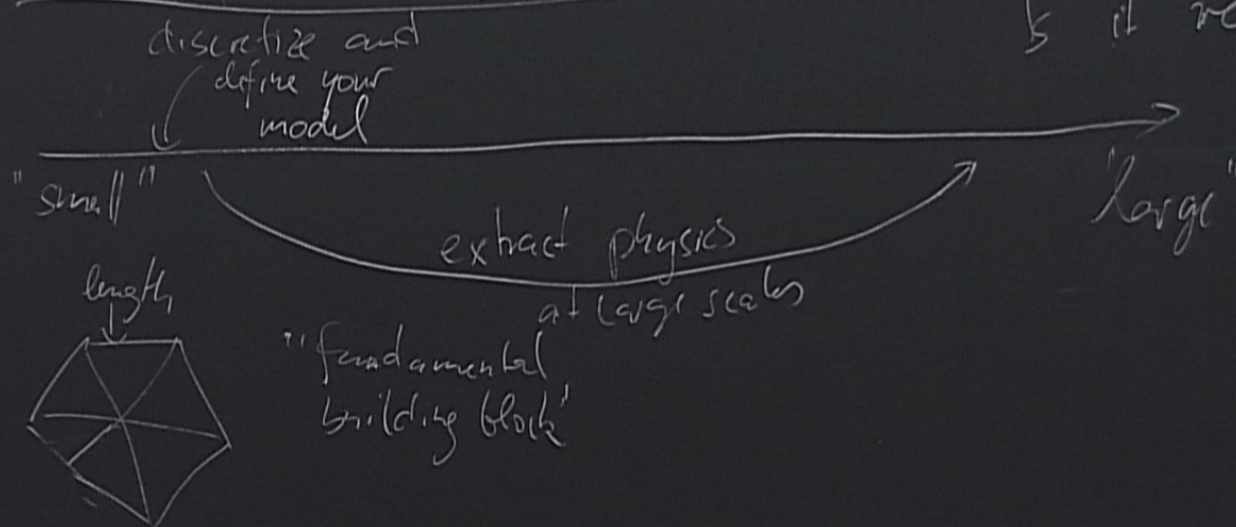


↳ it reasonable?

Scales

matter
L matter

Usual picture of lattice models



Scales

Usual picture of lattice models

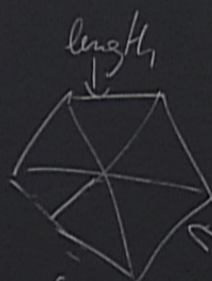
discretize and
define your
model

↳ it reasonable?

"small"

extract physics
at large scales

"large"

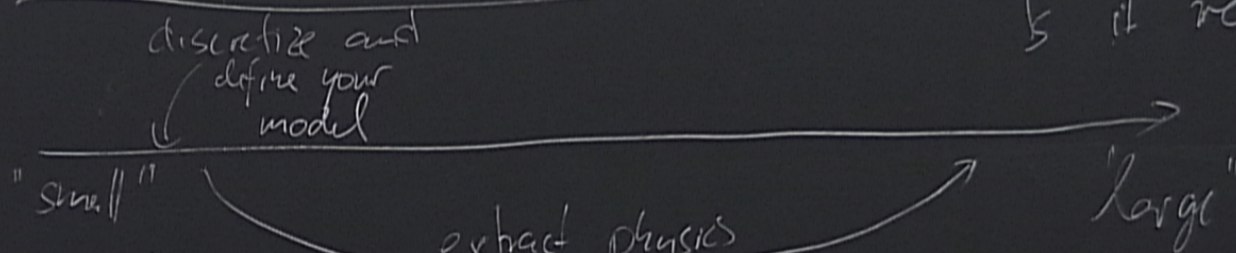


"fundamental
building block"

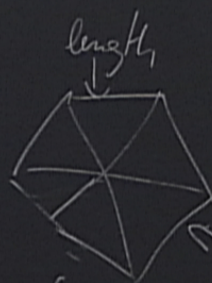
of any size U (metric: bdy)
 Z (metric: bdy)

Scales

Usual picture of lattice models



↳ it reasonable?



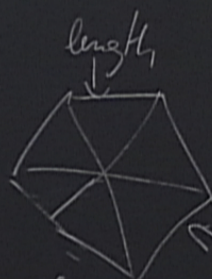
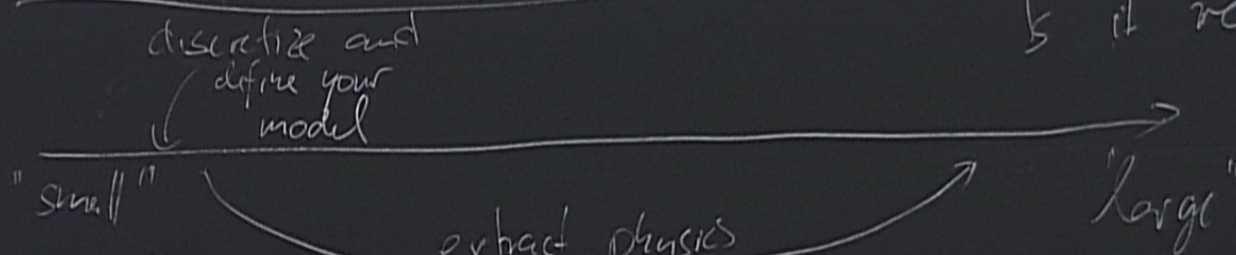
"fundamental
building block"

of any size $U(\text{metric: body})$
 $Z(\text{metric: body})$

Gauss $Z(\text{body data})$ for all scales.

Scales

Usual picture of lattice models



"fundamental
building block"

of any size $U(\text{metric: body})$
 $Z(\text{metric: body})$

↳ it reasonable?

⇒ guess $Z(\text{body data})$ for all scales.

⇒ Solve the theory!

reasonable guess

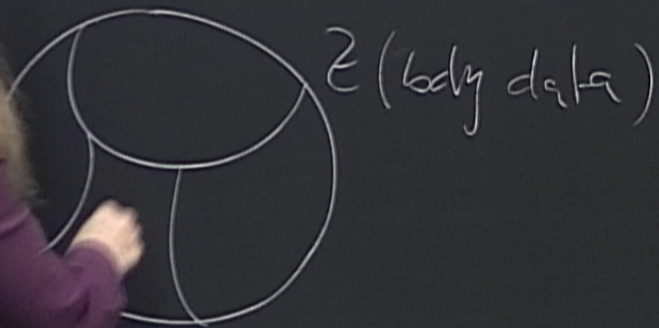
Z (bdry data)

informed by
large scales

→ "scales"



reasonable guess $z(\text{bdry data})$
small scales
informed by large scales
"scales"

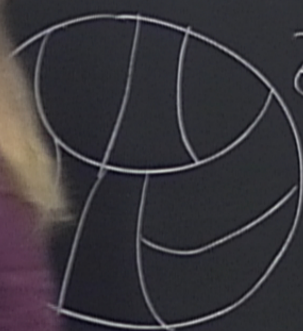


reasonable guess $z(\text{bdry data})$

small scales

informed by large scales

"scales"



$$z(\text{bdry data}) = \int \prod z(\text{bdry})$$

reasonable guess $z(\text{bdry data})$

small scales

informed by large scales

"scales"



$$z'(\text{bdry data}) = \int \prod_{\text{building blocks}} z(\text{bdry})$$

reasonable guess z (bdry data)

small scales

informed by large scales

"scales"



$$z'(\text{bdry data}) = \int \prod_{\text{building blocks}} z(\text{bdry})$$

$$z' = z_{\text{initial}}$$

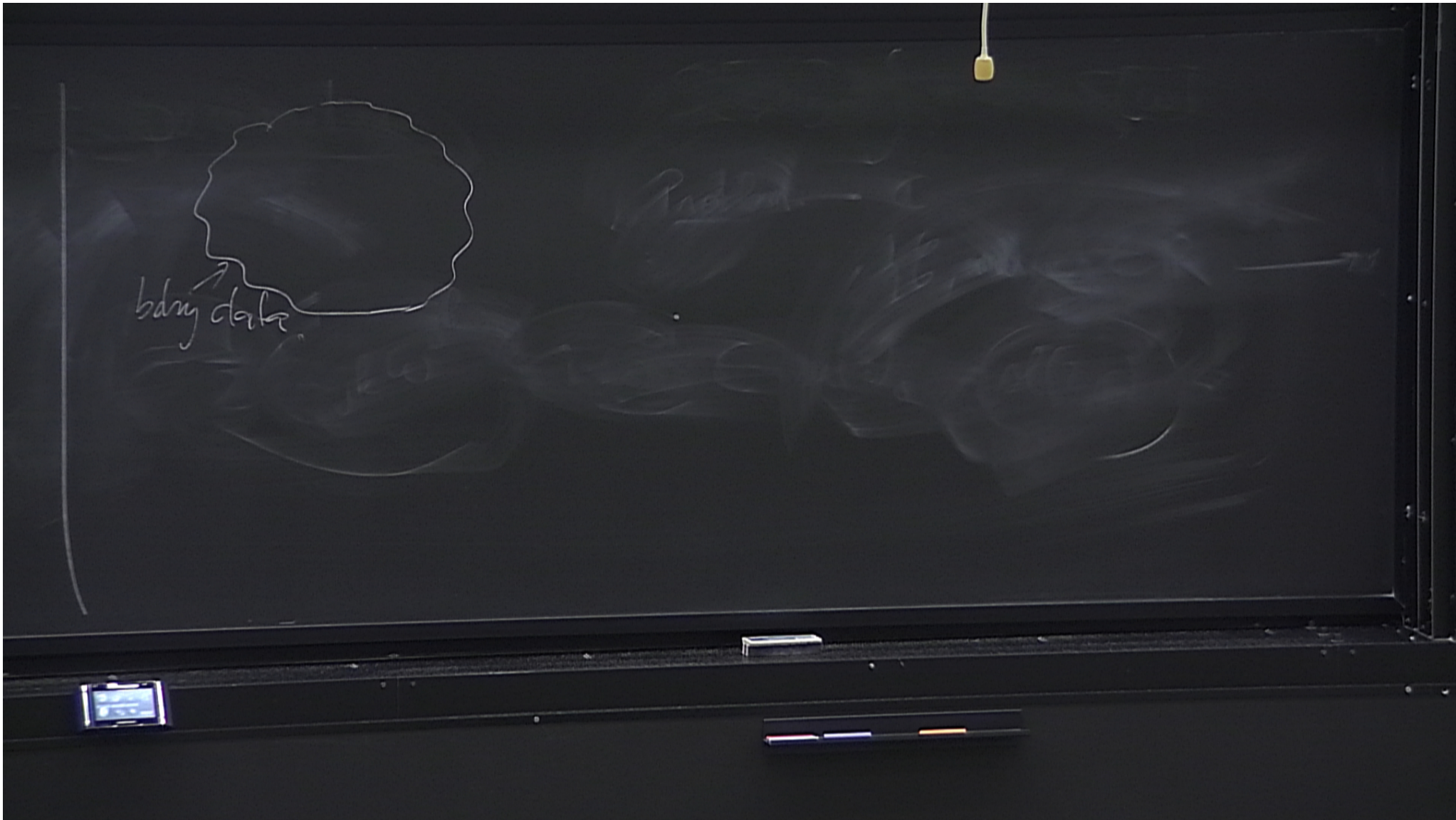
reasonable guess z (bdry data)

small scales

informed by large scales

"scales"

$z'(bdry\ data)$
 $= \int \prod_{\text{building blocks}} z(bdry)$
 $z' = z_{\text{initial}}$
 z_{perfect}



reasonable guess z (bdry data)

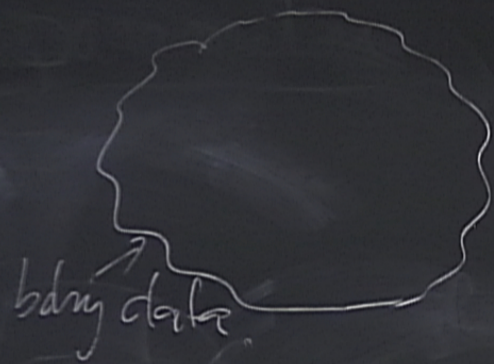
small scales

informed by large scales

"scales"

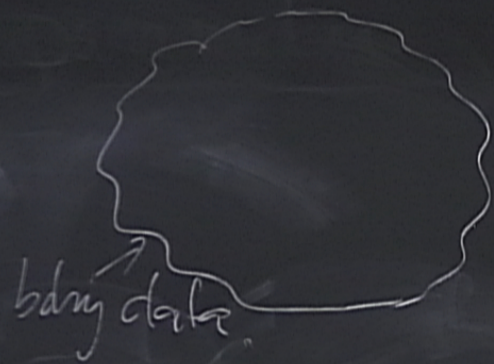

 $z'(\text{bdry data}) = \int \prod_{\text{building blocks}} z(\text{bdry})$

$z' = z_{\text{initial}}$
 $z'_{\text{perfect}} = z_{\text{perfect}}$



- Holographic formulation

- Z_{perfect} (approx) is "easy" to get for "simple" bdy data



• Holographic formulation

• Z_{perfect} (approx) is "easy"
to get for "simple" bdy data



QM

$$\langle \psi_f | e^{-iHt} | \psi_i \rangle$$

QFT

W-coupling

QM

QFT

$$\langle \psi_f | e^{-iHt} | \psi_i \rangle$$

W-coupling

S-matrix

$t \rightarrow \pm\infty$, asympt. states
[free particles]

S-coupled

lattice, cutoff

$$\longrightarrow \langle \psi_f | \psi_i \rangle$$

$$\longrightarrow \langle \psi_f | \psi_i \rangle_{\text{phys}} = \langle P \psi_f | \psi_i \rangle_{\text{kin}}$$

matrix
 $\rightarrow \pm\infty$, asympt. states
 [free particles]

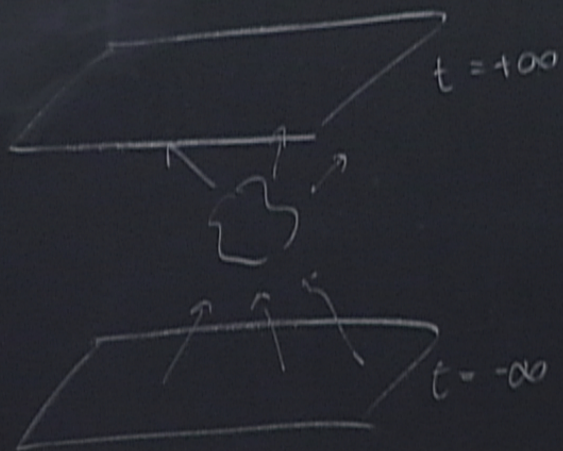
time, cutoff

$$E \in \text{supp}(\hat{T}) \in \text{supp}(\hat{H})$$

But classical limit

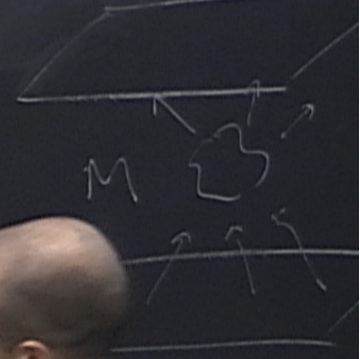
TQFT $d\text{-dim } \mathcal{B} \rightarrow \mathcal{H}$
 $M : \partial M = \mathcal{B} \rightarrow Z_M[\mathcal{B}] \in \mathbb{C}$

$$Z = \int \mathcal{D}\phi \, e^{iS_M[\phi]}$$



TQFT $d\text{-dim } \mathcal{B} \leadsto \mathcal{H}$
 $M : \partial M = \mathcal{B} \rightarrow Z_M[\mathcal{B}] \in \mathbb{C}$

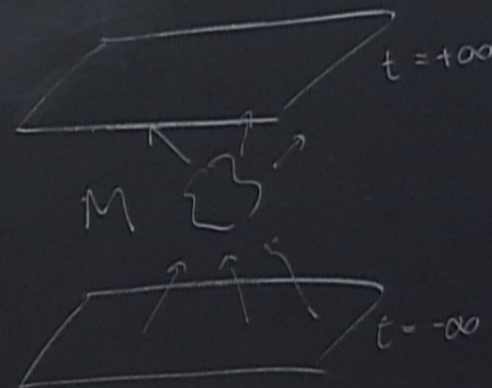
$$Z = \int \mathcal{D}\phi \, e^{iS_M[\phi]}$$



$$d\text{-dim } B \rightarrow \mathcal{H}$$

$$M : \partial M = B \rightarrow Z_M[B] \in \mathbb{C}$$

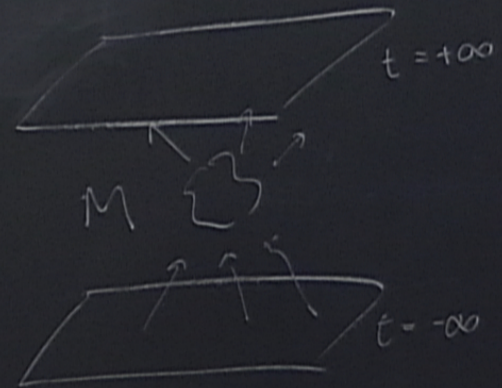
$$= \int \mathcal{D}\phi \, e^{iS_M[\phi]}$$



$$d\text{-dim } B \leadsto \mathcal{H}$$

$$M : \partial M = B \rightarrow Z_M[B] \in \mathbb{C}$$

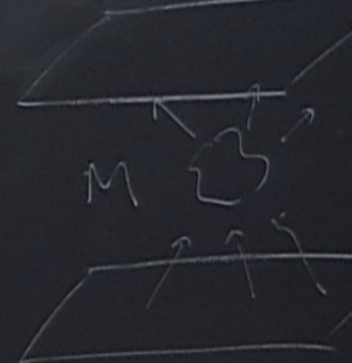
$$Z = \int \mathcal{D}\phi \, e^{\frac{i}{\hbar} S_M[\phi]} \xrightarrow{\hbar \rightarrow 0} e^{\frac{i}{\hbar} S[\phi_d]}$$



TQFT $d\text{-dim } B \leadsto \mathcal{H}$
 $M : \partial M = B \rightarrow Z_M[B] \in \mathbb{C}$

$$Z = \int \mathcal{D}\phi \, e^{\frac{i}{\hbar} S[\phi]} \xrightarrow{\hbar \rightarrow 0} e^{\frac{i}{\hbar} S[\phi_{cl}]}$$

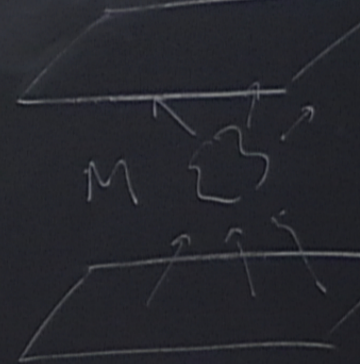
$\hbar \rightarrow 8\pi G \hbar = \ell_P^2$

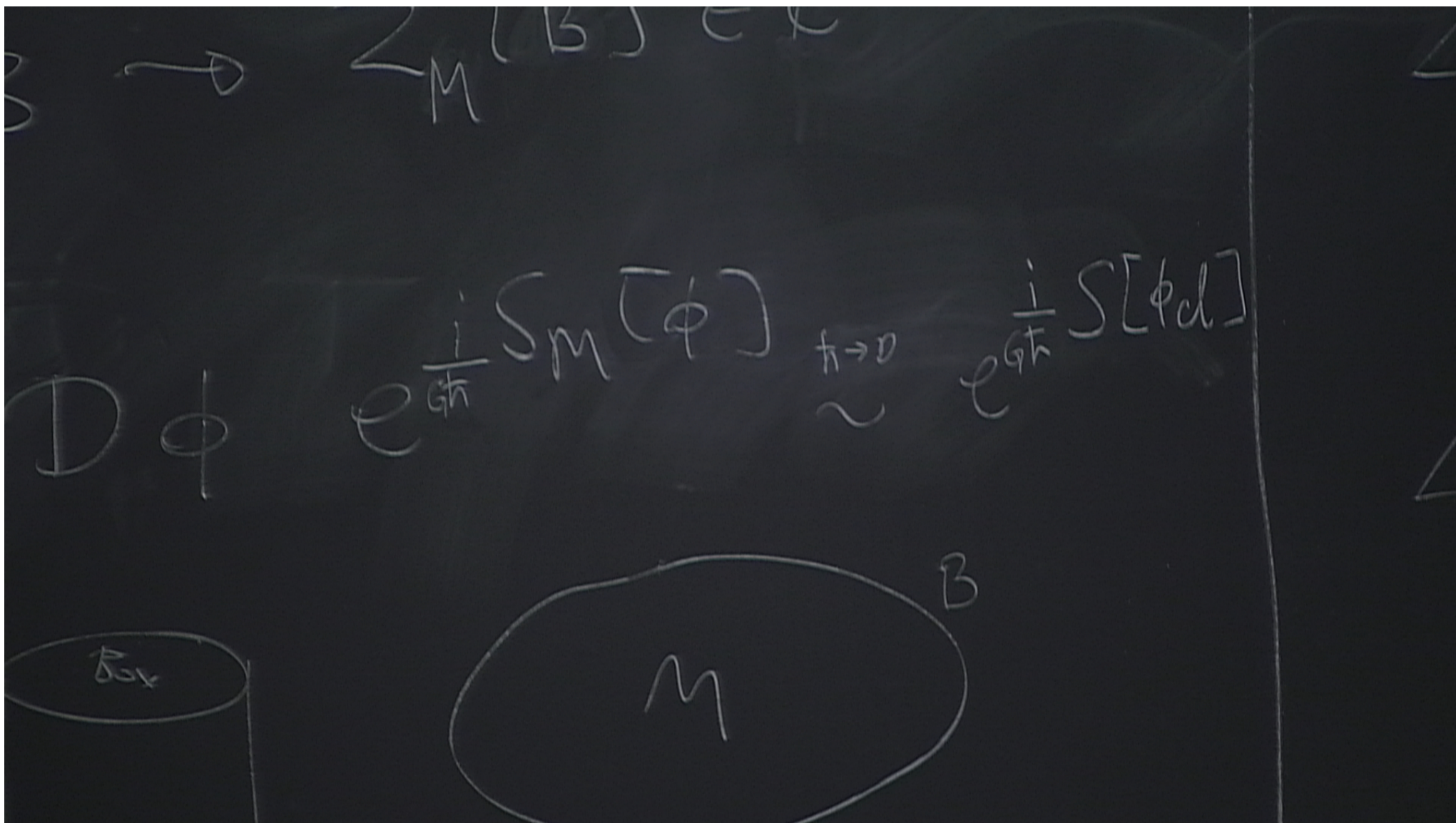


TQFT $d\text{-dim } B \leadsto \mathcal{H}$
 $M : \partial M = B \rightarrow Z_M[B] \in \mathbb{C}$

$$Z = \int \mathcal{D}\phi \, e^{\frac{i}{\hbar} S_M[\phi]} \xrightarrow{\hbar \rightarrow 0} e^{\frac{i}{\hbar} S[\phi_{cl}]}$$

$$\rightarrow 8\pi G \hbar = \ell_P^2$$

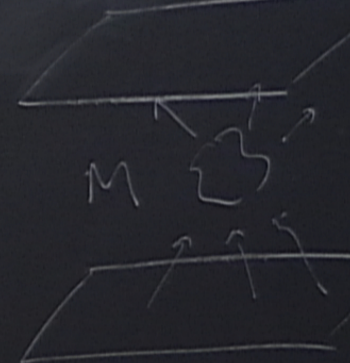




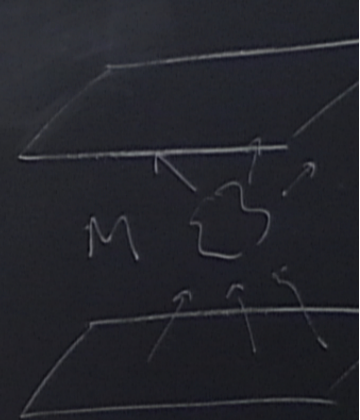
TQFT $d\text{-dim } B \leadsto \mathcal{H}$
 $M : \partial M = B \leadsto Z_M[B] \in \mathbb{C}$

$$Z = \int \mathcal{D}\phi \, e^{\frac{i}{\hbar} S_M[\phi]} \xrightarrow{\hbar \rightarrow 0} e^{\frac{i}{\hbar} S[\phi_{cl}]}$$

$\hbar \rightarrow 8\pi G \hbar = \ell_P^2$



Gravity and the Quantum?



Don't Trust your teachers!

Gravity and the Quantum?

① Rather Versus Geometry Unification:

Don't Trust your teachers!

Demerit

Newton

Einstein

Physics

Testing

LOH

Gravity and the Quantum?

① Rather Versus Geometry Unification:

Don't Trust your teachers!

Democritus

Newton

Einstein

Philosophy

Physics

Logic

Gravity and the Quantum?

- ① Matter Versus Geometry Unification:
- ② Discrete vs Continuum:

Don't Trust your teachers!

Democrite

Newton

Einstein

Philosophy

Testing

Logic

Gravity and the Quantum?

- ① Matter Versus Geometry: Unification
- ② Discrete vs Continuum: Non Locality

Don't Trust your teachers!

Democrite

Philosophy
Testing

Next
Ed

Gravity and the Quantum?

- ① Matter Versus Geometry Unification
- ② Discrete vs Continuum: Non Locality
- ③ Diffeo invariance

Don't Trust your teachers!

Democrite

Newton

Einstein

ϕ Φ ψ

String

QG

Gravity and the Quantum?

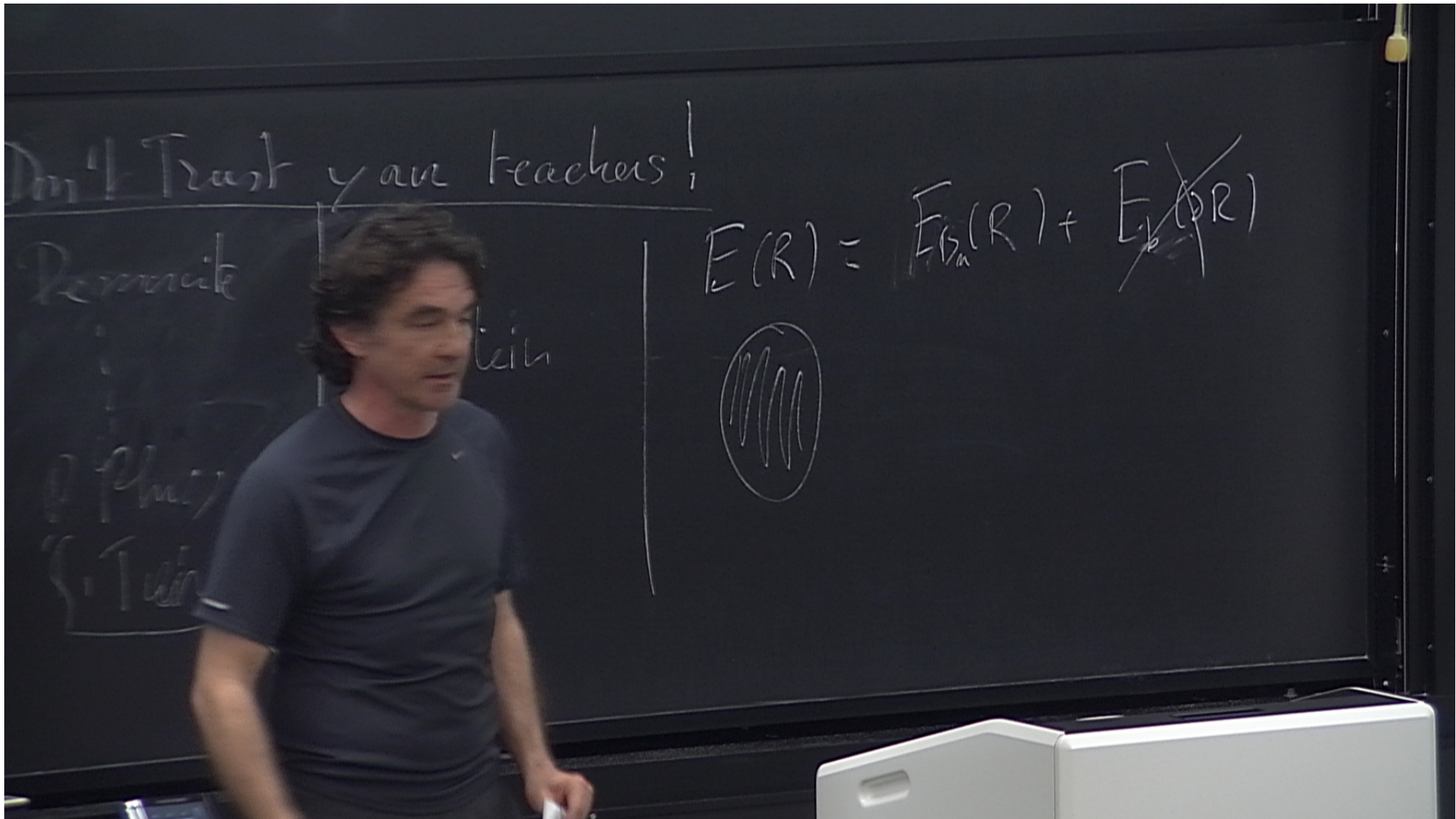
- ① Matter Versus Geometry Unification:
- ② Discrete vs Continuum: Non Locality
- ③ Diffec invariance $\leftrightarrow$ Holography

Don't Trust your teachers!

Democrite

ϕ ϕ ϕ

ϕ ϕ ϕ



Don't Trust your Teachers!

Remember Newton
Einstein

$$E(R) = E_{\text{M}}(R) + \cancel{E_{\text{b}}(R)} \quad \text{E.T.}$$



= 0

Don't Trust your Teachers!

Newton
Einstein

...

$$E(R) = E_{\text{kin}}(R) + \cancel{E_{\text{pot}}(R)} \quad \text{F.T.}$$
$$\text{[Diagram: A circle with vertical lines inside, followed by an equals sign, a circle, and a plus sign, then a circle with a horizontal line through it.]}$$

Gravity and the Quantum?

- ① Matter Versus Geometry: Unification:
- ② Discrete vs Continuum: Non locality
- ③ Diffeo invariance $\leftrightarrow$ Holography: Dynamics

Don't Trust

Remember

Philosophy

History

Gravity and the Quantum?

- ① Matter Versus Geometry: Unification:
- ② Discrete vs Continuum: Non locality
- ③ Diffeo invariance $\rightarrow$ Holography: Dynamics
- ④ DOF?

Don't Trust
Remember

P Ph
{ T

Gravity and the Quantum?

- ① Matter Versus Geometry: Unification:
- ② Discrete vs Continuum: Non locality
- ③ Diffeo invariance $\rightarrow$ Holography: Dynamics
- ④ DOF?: Bill have no classical hair?

Don't Trust
Remember

Phic
{ Theory

Gravity and the Quantum?

- ① Matter Versus Geometry: Unification:
- ② Discrete vs Continuum: Non locality
- ③ Diffeo invariance $\rightarrow$ Holography: Dynamics
- ④ DOF?: Bill have ~~no~~ classical hair?

Don't Trust
Remember