

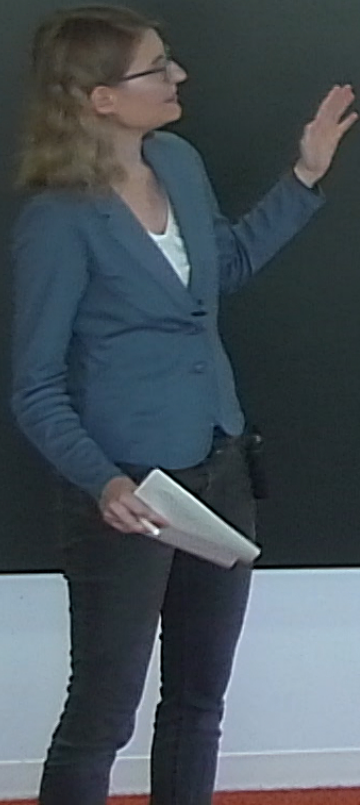
Title: Discussion Session 2

Date: Jun 26, 2017 04:00 PM

URL: <http://pirsa.org/17060101>

Abstract:

Converting entropy to curvature perturbation $\delta\zeta$ after a cosmic bounce
based on 1607.05663 w/ J. Lehners, E. Wilson-Ewing & E. Maltby
→ 2 scalar field bouncing model



Converting entropy to curvature pert ζ after a cosmic bounce
based on 1607.05663 w/ J. Lehners, E. Wilson-Ewing & E. Malmgren

→ 2-scalar field bouncing model

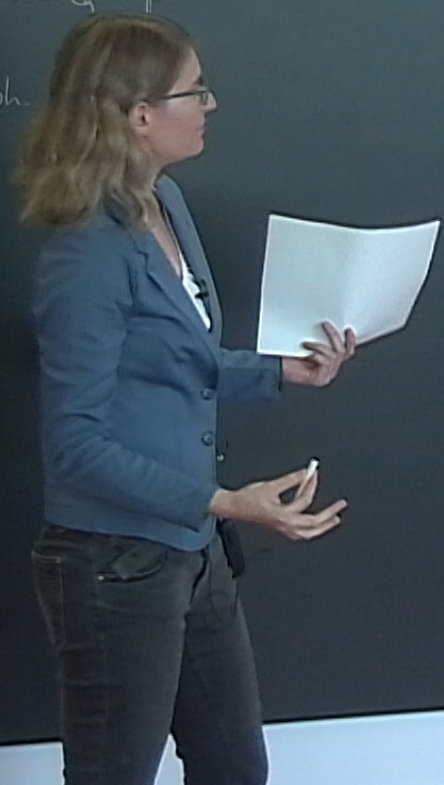
contracting ph. → bounce → expanding ph.
{ ekp ph → kin → non-sing Σ kinetic ph.
MD ghost cond.

a cosmic bounce
by E. Marder

$$S = \int d^4x \sqrt{g} \left[\frac{R}{2} + P(\chi, \phi) - \frac{1}{2}(\partial\chi)^2 - V(t, \chi) \right]$$
$$\chi = -\frac{1}{2}(\partial t)^2$$

→ expanding ph.

kinetic ph.



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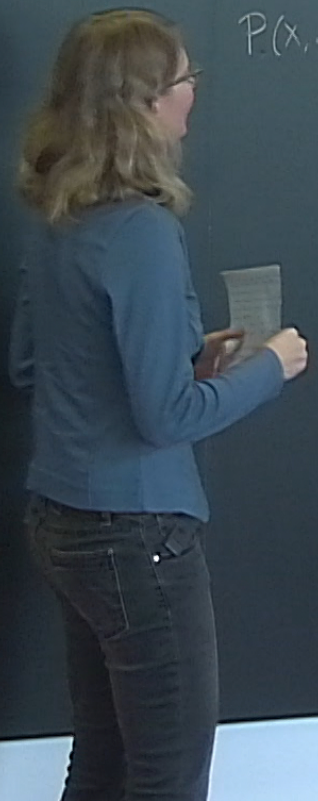
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$$P(\chi, \phi) = K(\phi)\chi + Q(\phi)\chi^2$$



a cosmic bounce

by E. M. M. M. M.

ice $\rightarrow$ expanding ph.

Σ kinetic ph.

gates.

$$S = \int d^4x \sqrt{-g} \left[\frac{R}{2} + P(\chi, \phi) - \frac{1}{2}(\partial\chi)^2 - V(\phi, \chi) \right]$$

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$$P(\chi, \phi) = K(\phi)\chi + Q(\phi)\chi^2$$

$\Rightarrow$ NEC $\Rightarrow$ no ghosts

$$P(\chi, \phi=0) = -\chi + q\chi^2$$

$$\dot{H} = -\frac{1}{2}(\rho + p) > 0$$

$\delta\phi \Rightarrow \text{curv pert} \Rightarrow R$

$\delta\chi \Rightarrow \text{entropy pert} \Rightarrow \delta s$

Converting entropy to curvature pert $\Rightarrow$ after a C
based on 1607.05663 w/ J-L Lehners, E. Wilson-Ewing & E

$\rightarrow$ 2 scalar field bouncing model

contracting ph. $\rightarrow$ bounce

$\left\{ \begin{array}{l} \text{exp ph} \\ \text{MD} \end{array} \right. \rightarrow \text{kin} \rightarrow \text{non-sing} \begin{array}{l} \text{ghost} \\ \text{rodns.} \end{array}$

$\delta\phi \Rightarrow$ curv pert $\equiv \mathcal{R}$

$\delta\chi \Rightarrow$ entropy pert $\equiv s_s$

$$\delta\dot{s} + 3H\delta s + V_{ss}\delta s + \frac{1}{2}V_{sss}(\delta s)^2 = 0$$
$$\delta s = \delta s^{(n)} + \delta s^{(n)}$$

Converting entropy to curvature pert $\equiv s$
based on 1607.05663 w/ J. Lehar, E. Wilson

$\rightarrow$ 2 scalar field bouncing model

contracting ph $\rightarrow$ be

$\left\{ \begin{array}{l} \text{ekp ph} \\ \text{MD} \end{array} \right. \rightarrow \text{kin} \rightarrow \text{non-s ghost}$

$\delta\phi \Rightarrow$ curv pert $\rightarrow \mathcal{R}$

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Converting entropy to curvature pert $\rightarrow$ based on 1607.05663 w/ J. Lehar, E. Wilson

$\rightarrow$ 2 scalar field bouncing model

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$\left\{ \begin{array}{l} \text{ekp ph} \\ \text{MD} \end{array} \right. \rightarrow \text{kin} \rightarrow \text{non-s ghost}$

$\delta\chi \Rightarrow$ entropy pert. δs

$\rightarrow$ 2-scalar field bou

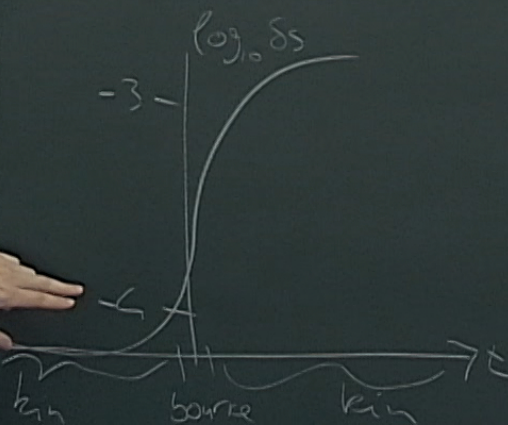
$$\delta\ddot{s} + 3H\delta\dot{s} + \underbrace{V_{ss}}_{=0}\delta s + \frac{1}{2}V_{sss}(\delta s)^2 = 0$$

$$\delta s = \delta s^{(1)} + \delta s^{(2)}$$

$$V_{ss} = V_{sss} = 0$$

contracting

{ exp. ph
MD

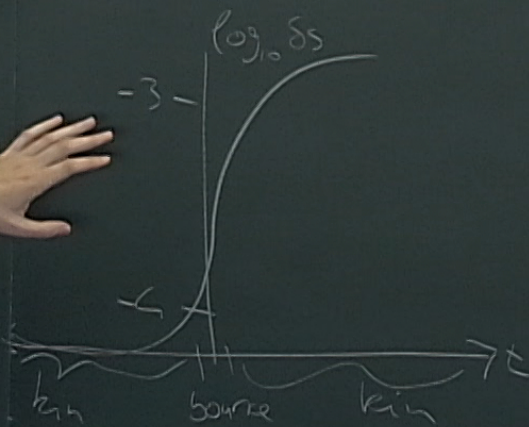


$\delta\chi \Rightarrow$ entropy pert. $\rightarrow \delta s$

$$\delta\ddot{s} + 3H\delta\dot{s} + \underbrace{V_{ss}}_{=0}\delta s + \frac{1}{2}V_{sss}(\delta s)^2 = 0$$

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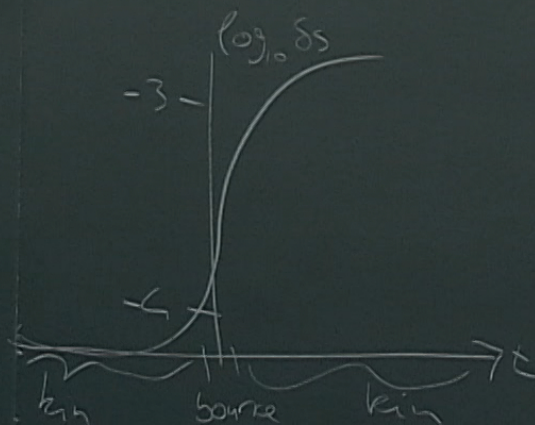
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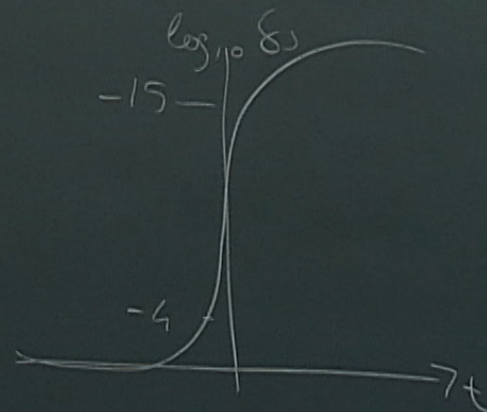
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$$\delta s = \delta s^{(1)} + \delta s^{(2)}$$

$$V_{ss} = V_{sss} = 0$$



$$V_{ss} \neq 0$$



contracting

{ exp. ph
MD

$s s$

→ 2-scalar field bouncing model

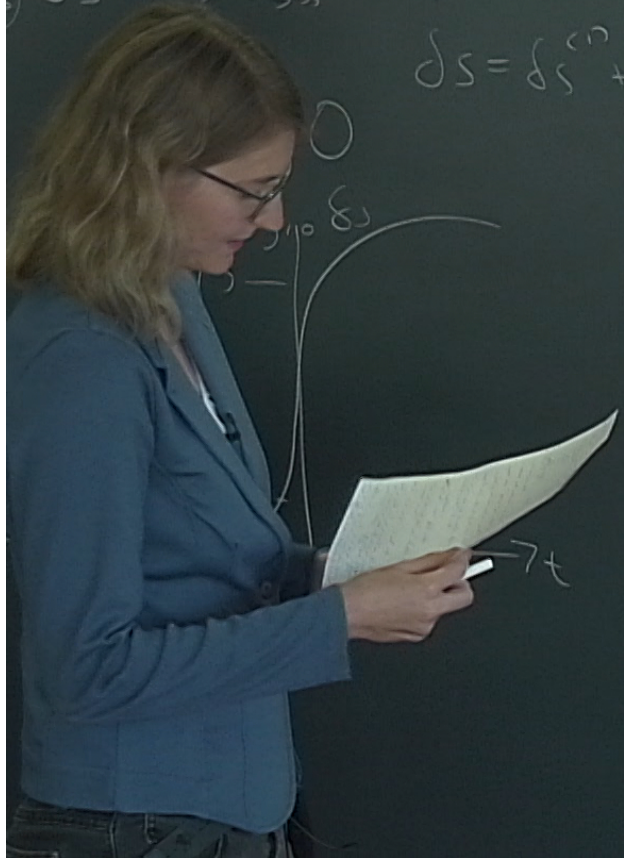
$$\delta s + \frac{1}{2} V_{ss} (\delta s)^2 = 0$$

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contracting ph. → bounce →

{ exp. ph → kin → non-sing Σ
MD ghost condens.

Important need V_{rep} & efficient conversion.



→ 2-scalar field bouncing model

contracting ph. → bounce → expanding ph.

{ ekp. ph → kin → non-sing^E kinetic ph.
MD ghost condens.

Important need V_{rep} & efficient conversion.

$$-5 \leq f_{NL} \leq +5$$

→ 2-scalar field bouncing model

contracting ph. → bounce → expanding ph.

$\left\{ \begin{array}{l} \text{ekp. ph} \rightarrow \text{kin} \rightarrow \\ \text{MD (ekp)} \end{array} \right.$
 non-sing^E ghost condens. kinetic ph.

Important need U_{rep} & efficient conversion.

$$-5 \leq f_{NL} \leq +5$$

$$r = \frac{\Delta_h(k)^2}{\Delta_R(k)^2} = \mathcal{O}(1)$$

→ 2-scalar field bouncing model

contracting ph. → bounce → expanding ph.

$\left\{ \begin{array}{l} \text{ekp. ph} \rightarrow \text{kin} \rightarrow \\ \text{MD (ekp)} \end{array} \right.$
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Important need V_{rep} & efficient conversion.

$$-5 \leq f_{NL} \leq +5$$

$$r = \frac{\Delta_h(k)^2}{\Delta_R(k)^2} = \mathcal{O}(1) \rightarrow r \lesssim 0(10^{-2})$$

t^{ns} after a cosmic bounce

E. Witten-Ewing & E. Malmgren

bounce $\rightarrow$ expanding $\rightarrow$ ph.

non-sin
ghost

kinetic ph.

conversio. $-5 \leq f_M \leq +5$

$$S = \int d^4x \sqrt{g} \left[\frac{M^2}{2} + P(X, \phi) - \frac{1}{2} (\partial_\mu \phi)^2 - U(\phi, X) \right]$$

$$X = -\frac{1}{2} (\partial_\mu \phi)^2$$

$$P(X, \phi) = K(\phi) X + Q(\phi) X^2$$

$\Rightarrow$ NEC $\Rightarrow$ no ghosts

$$P(X, \phi=0) = -X + q X^2$$

$$\dot{H} - \frac{1}{2} (\dot{\phi} \cdot p) > 0$$

rest^{ns} after a cosmic bounce

ness, E. Wilson-Ewing & E. Malmgren

odel

→ bounce → expanding ph.

Σ
kinds.

kinetic ph.

$$-5 \leq f_{NL} \leq +5$$

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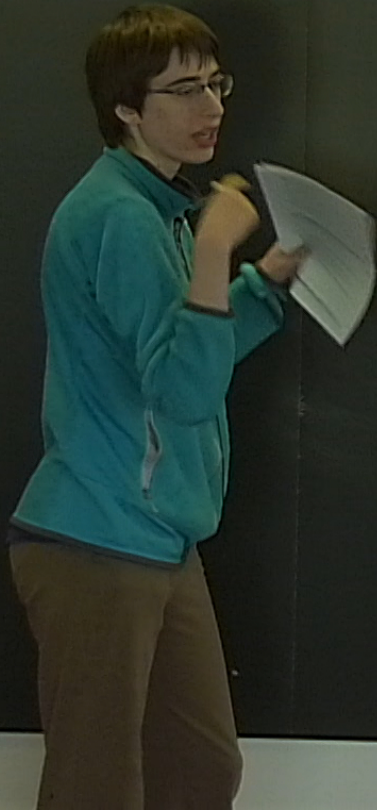
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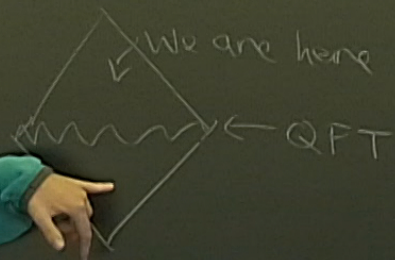
Holographic Cosmology

Periodic Time Cosmology



Holographic Cosmology

- Planck



1703.05385

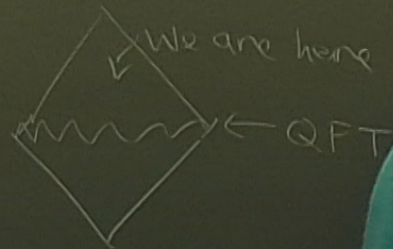
PRL 118:041301 Jan 2017

Holographic Cosmology

- Planck

1703.05385

PRL 118:041301 Jan 2017



$$A = A_0 \frac{1}{1 + \left(\frac{g g_x}{\ell}\right) \ln\left(\frac{\ell}{g g_x}\right)}$$

Holographic Cosmology

- Planck

→ We are here
→ QFT

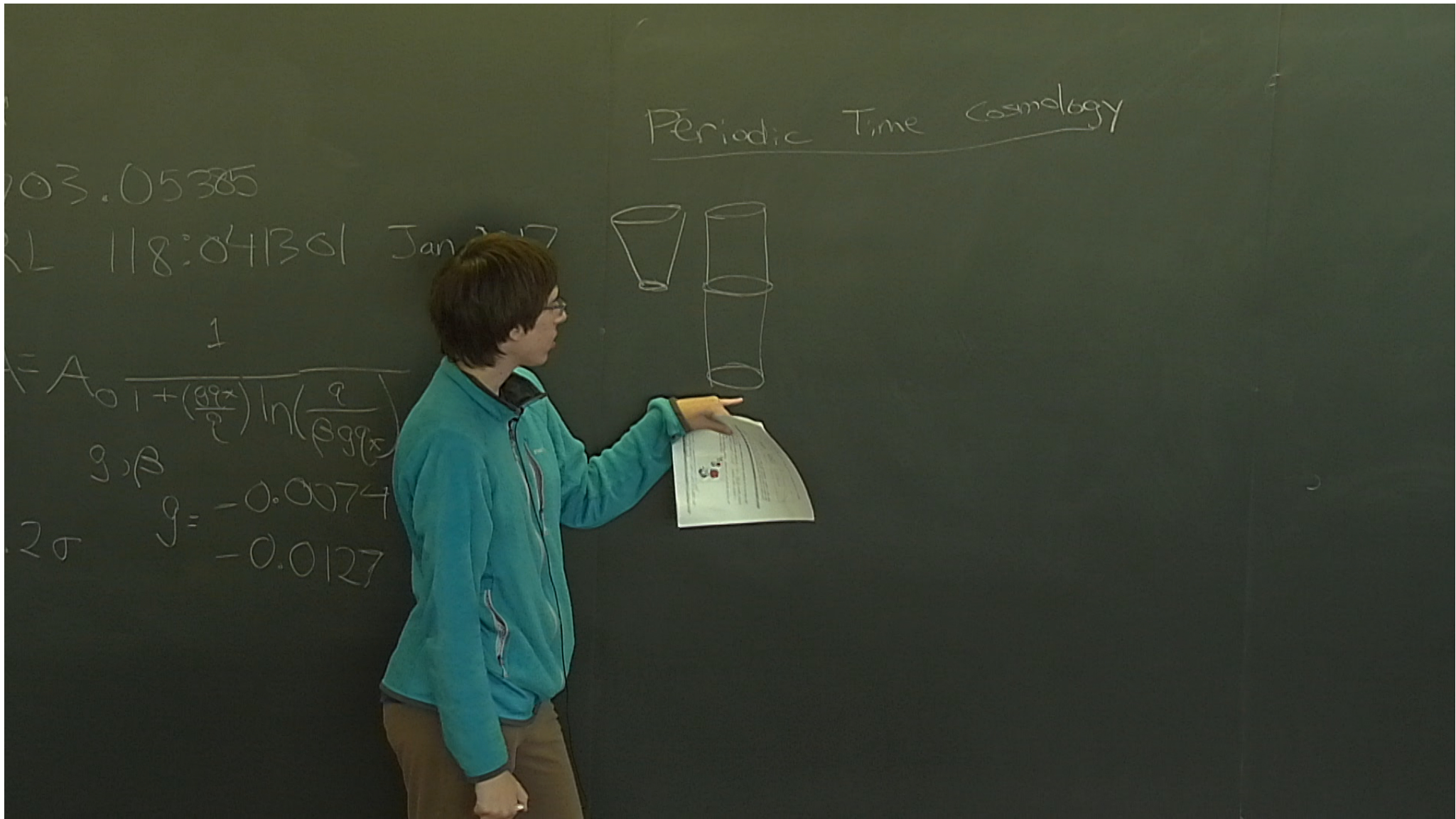
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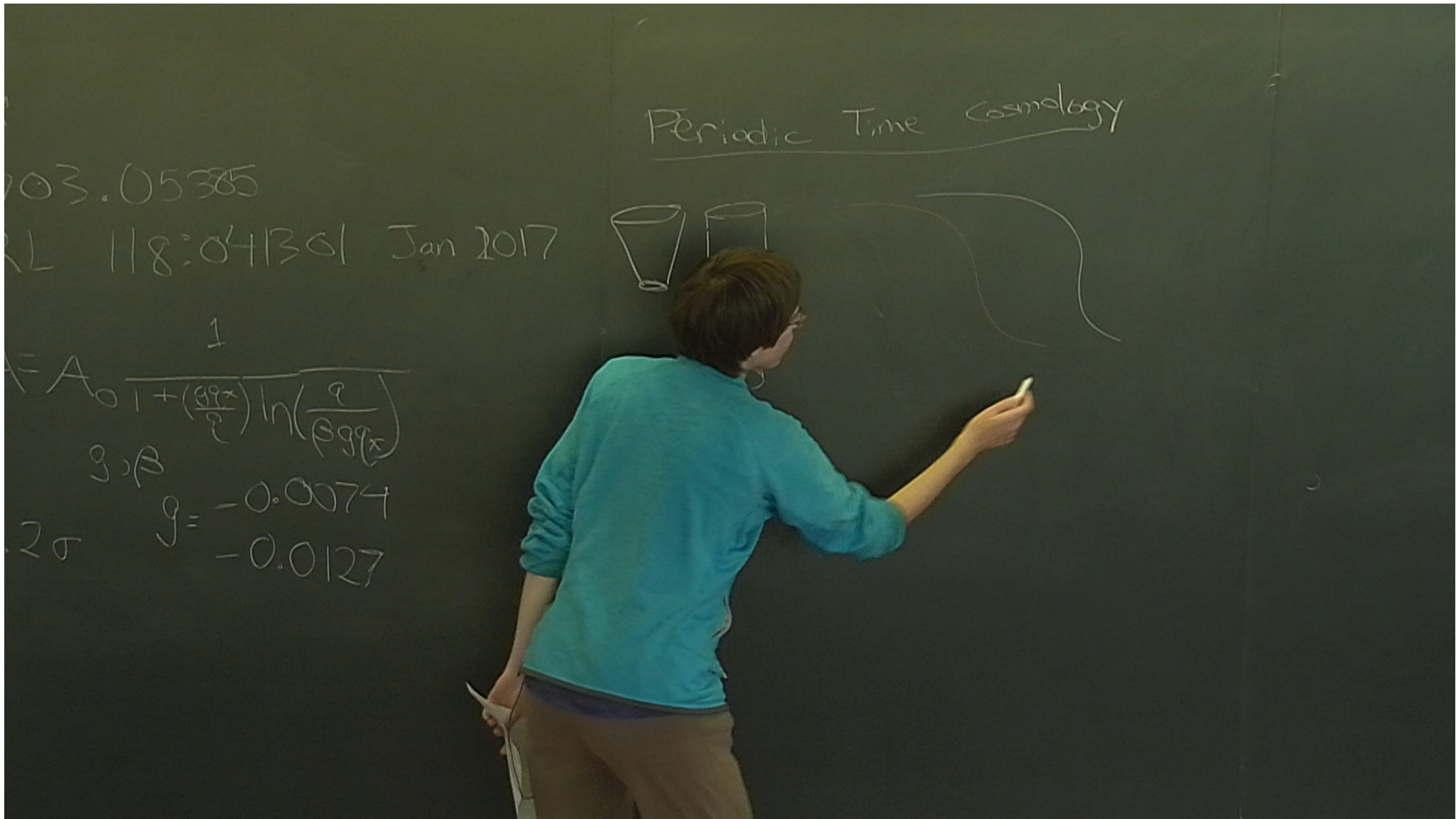
PRL 118:041301 Jan 2017

$$A = A_0 \frac{1}{1 + \left(\frac{g\beta}{\epsilon}\right) \ln\left(\frac{\epsilon}{\beta g\beta_*}\right)}$$

g, β

$2.2\sigma \quad g = -0.0074$
 -0.0127





Periodic Time Cosmology

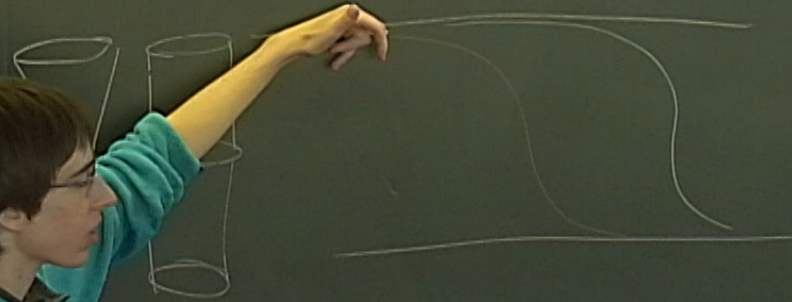
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RL 118:041301 Jan 2017

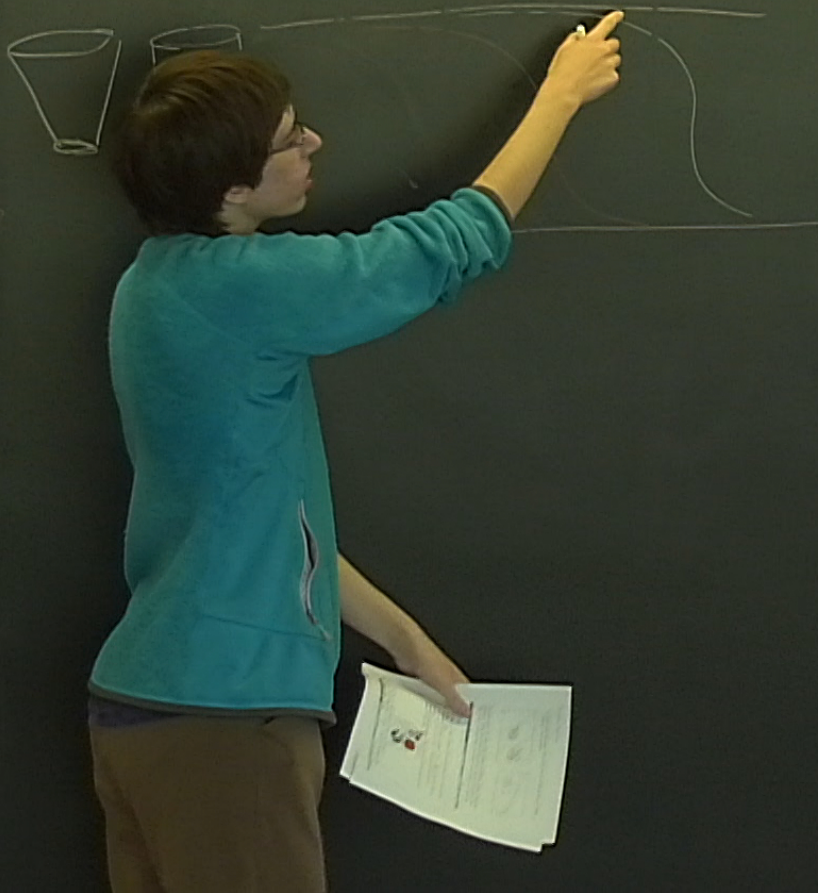
$$A = A_0 \frac{1}{1 + \left(\frac{\beta q_x}{q}\right) \ln\left(\frac{q}{\beta q_x}\right)}$$

g, β

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Periodic Time Cosmology

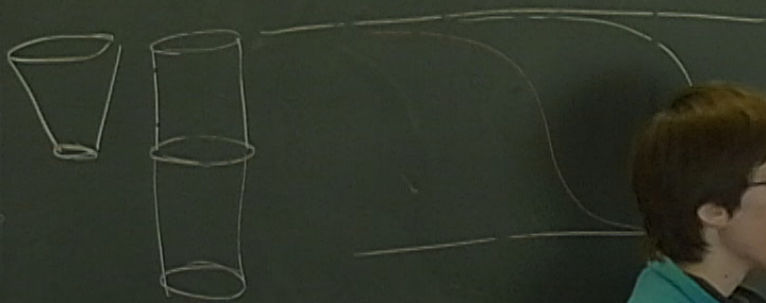


$$P = P_{\text{old}}(\alpha k) |T(\alpha k)|^2$$

$$\alpha \ll 1$$

$$A_0 \prod_{n=1}^{\infty} |T(\alpha^n k)|^2$$

Periodic Time Cosmology



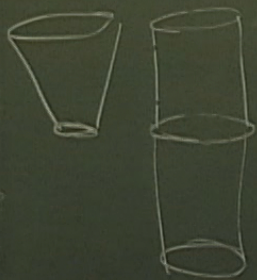
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$$A_0 \prod_{n=1}^{\infty} |T(\alpha^n k)|^2$$

$$\Delta\chi^2 = 258 \quad 5.1\sigma$$

Periodic Time Cosmology



$$P = P_{\text{old}}(a_k) |T(a_k)|^2$$

$$a \ll 1$$

$$A_0 \prod_{n=1}^{\infty} |T(a^n k)|^2$$

$$\Delta\chi^2 = 258 \quad 5.1\sigma$$

$$w \neq -1 \quad w < -1$$

$$w = -1.0238$$

$$\tau = 0.0483$$

Cosmology

$$P = P_{\text{old}}(a_k) |T(a_k)|^2$$

$a \ll 1$

$$A_0 \prod_{n=1}^{\infty} |T(a^n k)|^2$$

$$\Delta\chi^2 = 25.8 \quad 5.1\sigma$$

$$w \neq -1 \quad w < -1$$

$$w = -1.0238$$

$$\tau = 0.0483$$

$$\Delta\chi^2 = 3.4 \quad 1.8\sigma$$

$$= P_{\text{old}}(\alpha k) |T(\alpha k)|^2$$

$$\alpha \ll 1$$

$$A_0 \prod_{n=1}^{\infty} |T(\alpha^n k)|^2$$

$$\Delta \chi^2 = 258 \quad \Rightarrow$$

$$w \neq -1 \quad w < -1$$

$$\Delta \chi^2$$



Questions

- What is the new physics responsible for the bounce?
- Might this new physics resolve the singularity for the perturbations as well as the background?
- Does this new physics have any observational signature?
- What general principles underlie the theory, beyond wanting to resolve the singularity?
- Does a consistent picture for cosmology require that both the background and perturbations are quantised?
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- What are the common features of different cosmological bounce scenarios?
- Can they be classified in a useful way?

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Perfect Bounce (w/ N. Turok)

$a(\eta)$
conformal

- extend a to negative values
Complex
quantum

classical PRL & PRL

Perfect Bounce (w/ N. Turok)

$a(\eta)$
conformal

- extend a to $\left\{ \begin{array}{l} \text{negative values} \\ \text{complex} \end{array} \right.$ classical PRL & PRL
- boundary conditions at $a \rightarrow \pm\infty$ quantum
- avoid $a=0$ in complex plane

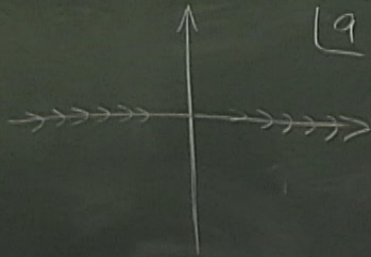
Perfect Bounce (w/ N. Turok)

$a(\eta)$
conformal

- extend a to ^{classical PRL & PRL} negative values
Complex
- boundary conditions at $a \rightarrow \pm \infty$
quantum
- avoid $a=0$ in complex plane
- conformal symmetry (matter + GR)

Ex.

radiation-dominated ^{flat FRW} universe $a(\eta) \propto \eta$
[9]



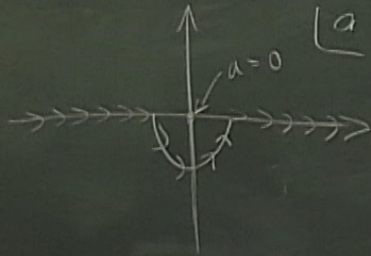
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classical PRL & PRL

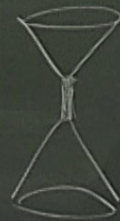
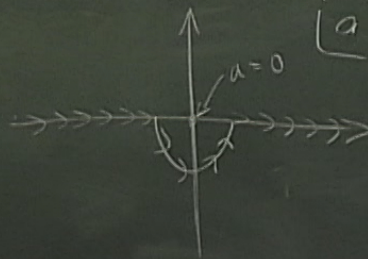
Complex

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flat FRW



Perfect Bounce (w/ N. Turok)

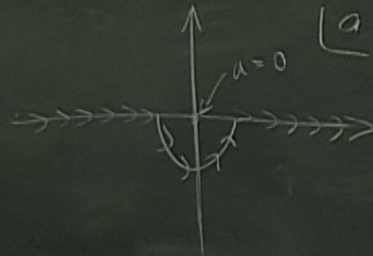
$a(\eta)$
conformal

- extend a to negative values

$\uparrow$ classical PRL & PRL
 $\downarrow$ complex
 $\uparrow$ quantum
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Ex.

radiation-dominated universe $a(\eta) \propto \eta$
 flat FRW



Weyl-invariant GR
 "Dirac gravity"

$$S = \frac{1}{16\pi G} \int d^4x \sqrt{-g} R$$

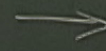
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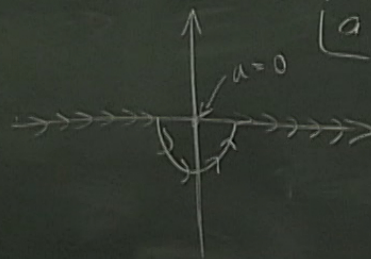
Weyl-invariant GR
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$$S = \frac{1}{16\pi G} \int d^4x \sqrt{-g} R[g]$$

$$\tilde{g}_{\mu\nu} = g_{\mu\nu} \phi^2 \dots$$



Ex. radiation-dominated universe $a(\eta) \propto \eta$



Perfect Bounce (w/ N. Turok)

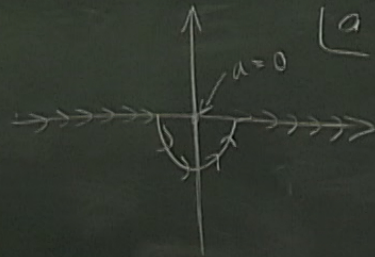
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 Complex
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Ex.

radiation-dominated flat FRW universe $a(\eta) \propto \eta$



Weyl-invariant GR
"Dirac gravity"

$$S = \frac{1}{16\pi G} \int d^4x \sqrt{-\tilde{g}} R[\tilde{g}] \quad \tilde{g}_{\mu\nu} = g_{\mu\nu} \phi^2 \dots$$

$$\rightarrow S = \int d^4x \sqrt{-g} \left(\frac{1}{2} (\partial\phi)^2 + \frac{1}{12} R[g] \right)$$

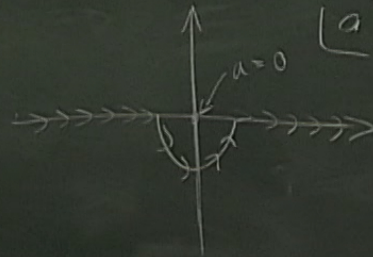
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radiation-dominated universe $a(\eta) \propto \eta$
 flat FRW



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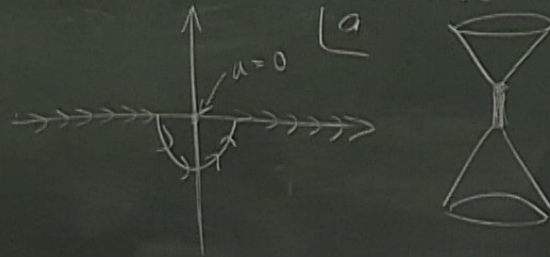
$$S = \frac{1}{16\pi G} \int d^4x \sqrt{-g} R[g] \quad \tilde{g}_{\mu\nu} = g_{\mu\nu} \phi^2 \dots$$

$$\rightarrow S = \int d^4x \sqrt{-g} \left(\frac{1}{2} (\partial\phi)^2 + \frac{\phi^2}{12} R[g] \right)$$

Perfect Bounce (w/ N. Turok)

- $a(\eta)$
 conformal
- extend a to negative values
 (classical PRL & PRL)
 (Complex)
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 - boundary conditions at $a \rightarrow \pm\infty$
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Ex. radiation-dominated universe $a(\eta) \propto \eta$
 flat FRW



Weyl-invariant GR
 "Dirac gravity"

$$S = \frac{1}{16\pi G} \int d^4x \sqrt{-\tilde{g}} \tilde{R}[\tilde{g}] \quad \tilde{g}_{\mu\nu} = g_{\mu\nu} \phi^2 \dots$$

$$\rightarrow S = \int d^4x \sqrt{-g} \left(\frac{1}{2} (\partial\phi)^2 + \frac{\phi^2}{12} R[g] \right) \quad \begin{matrix} g \rightarrow \Omega^2 g \\ \phi \rightarrow \Omega^{-1} \phi \end{matrix}$$

N. Turok)
RL & PRI
values

Weyl-invariant GR
"Dirac gravity"

$$S = \frac{1}{16\pi G} \int d^4x \sqrt{-g} R[g]$$

$$\tilde{g}_{\mu\nu} = g_{\mu\nu} \phi^2 \dots$$

$$\rightarrow S = \int d^4x \sqrt{-g} \left(\frac{1}{2} (\partial\phi)^2 + \frac{\phi^2}{12} R[g] \right)$$

$$g \rightarrow \Omega^2 g$$

$$\phi \rightarrow \Omega^{-1} \phi$$

$$ds^2 = a^2(\eta) (-d\eta^2 + dx^2)$$

Questions

- What is the new physics responsible for the bounce?
- Might this new physics resolve the perturbations as well as the bounce?
- Does this new physics have any general principles underlying the bounce?
- Wanting to resolve the singularity, is there a consistent picture for cosmology where the background and perturbations are well-defined across the bounce or pre-bounce phase?
- Setting initial conditions?
- What are the common features of different cosmological bounce scenarios?
- How can they be classified in a useful way?

N. Turok)
RL & PRI
values

Weyl-invariant GR
"Dirac gravity"

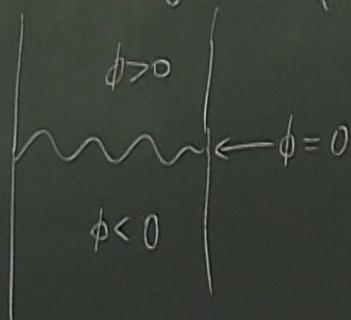
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$$\tilde{g}_{\mu\nu} = g_{\mu\nu} \phi^2 \dots$$

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$$g \rightarrow \Omega^2 g$$

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$$ds^2 = a^2(\eta) (-d\eta^2 + dx^2)$$

Questions

- What is the new physics responsible for the bounce?
- Might this new physics resolve the perturbations at the bounce?
- Does this new physics resolve the initial conditions problem?
- What general principle is beyond wanting to resolve the initial conditions problem?
- Does a consistent picture exist for both the background and the perturbations?
- Does the bounce require setting initial conditions?
- What are the different cosmological models?
- Can they be deconstructed?

N. Turok)
RL & PRI
values

Weyl-invariant GR
"Dirac gravity"

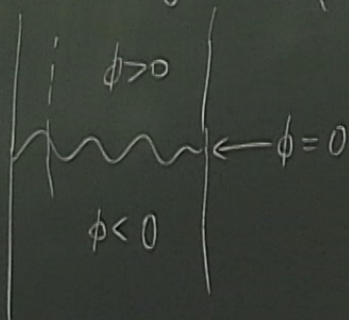
$$S = \frac{1}{16\pi G} \int d^4x \sqrt{-g} R[g]$$

$$\tilde{g}_{\mu\nu} = g_{\mu\nu} \phi^2 \dots$$

$$\rightarrow S = \int d^4x \sqrt{-g} \left(\frac{1}{2} (\partial\phi)^2 + \frac{\phi^2}{12} R[g] \right)$$

$$g \rightarrow \Omega^2 g$$

$$\phi \rightarrow \Omega^{-1} \phi$$



$$a \sim \int^{-1/2} (-g)^{-1/8} \phi$$

↑
energy density in radiation

$$ds^2 = a^2(\eta) (-d\eta^2 + dx^2)$$

Questions

- What is the new physics responsible for the bounce?
- Might this new physics resolve the perturbations as well as the bounce?
- Does this new physics have any general principles underlying it beyond wanting to resolve the singularity?
- Does a consistent picture for cosmology exist where both the background and perturbations are well-defined?
- Does the bounce or pre-bounce phase allow for setting initial conditions?
- What are the common features of different cosmological bounce scenarios?
- Can they be classified in a useful way?

Wdh



$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi = 0$$

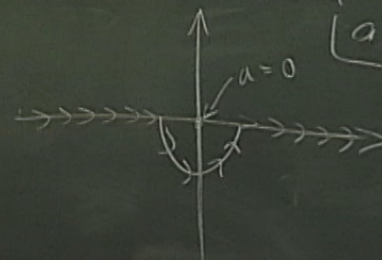
Perfect Bounce (w.)

$a(\eta)$
conformal

- extend a to ^{classical} negative ^{quant} complex
- boundary conditions at
- avoid $a=0$ in complex
- conformal symmetry

Ex.

radiation-dominated flat FR universe



Wdh

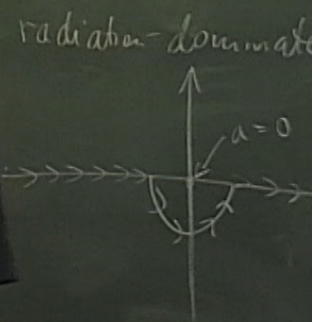
$$\left(-\frac{d^2}{da^2} + \frac{\textcircled{C}}{a^2} + m^2 \right) \chi = 0$$

conf. coupled scalars

Perfect Bound

$a(\eta)$
conformal

- extend a
- boundary con
- avoid $a=0$
- conformal



Wdh

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi = 0$$

{
 Conf. coupled
 Scalars
 minimally c.s
 anisotropies

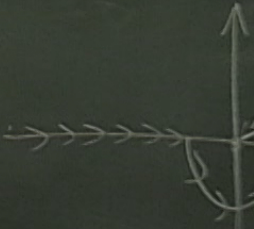
Perfect B

$a(\eta)$
 conformal

- exten
- bound
- avoid
- confo

Ex.

radiation-d



Wdh

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi = 0$$

Conf. coupled
Scalars
minimally c.s
anisotropies

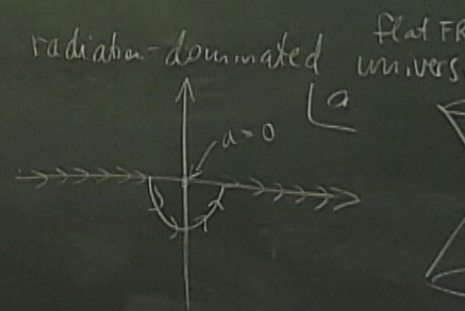
$m \sim$ total energy
in radiation fluid

$a(\eta)$
conformal

Perfect Bounce

- extend a to negative
- boundary conditions at
- avoid $a=0$ in complex
- conformal symmetry

Ex.



Wdh

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi = 0$$

$$\begin{aligned} a &\rightarrow \lambda a \\ m &\rightarrow \frac{1}{\lambda} m \end{aligned}$$

Conf. coupled
Scalars
minimally c.s
anisotropies

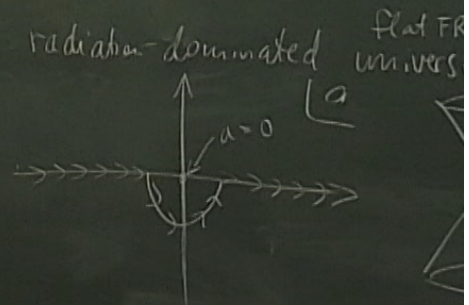
$m \sim$ total energy
in radiation fluid

$a(\eta)$
conformal

Perfect Bounce

- extend a to negative ^{classical} complex
- boundary conditions at $a=0$ ^{quantum}
- avoid $a=0$ in complex
- conformal symmetry

Ex.



Wdh

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi(a, m, \pi, \phi) = 0$$

$$\begin{aligned} a &\rightarrow \lambda a \\ m &\rightarrow \frac{1}{\lambda} m \end{aligned}$$

$m \sim$ total energy in radiation fluid

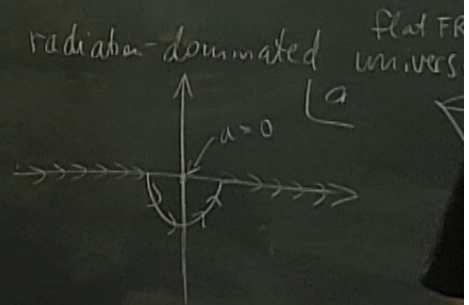
Conf. coupled
Scalars
minimally c.s.
anisotropies

$a(\eta)$
conformal

Perfect Bounce

- extend a to negative ^{classical} complex
- boundary conditions at $a=0$ ^{quantum}
- avoid $a=0$ in complex
- conformal symmetry

Ex.



Wdh

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi(a, m, \pi_c) = 0$$

$$\begin{aligned} a &\rightarrow \lambda a \\ m &\rightarrow \frac{1}{\lambda} m \end{aligned}$$

Conf. coupled
Scalars
minimally c.s
anisotropies

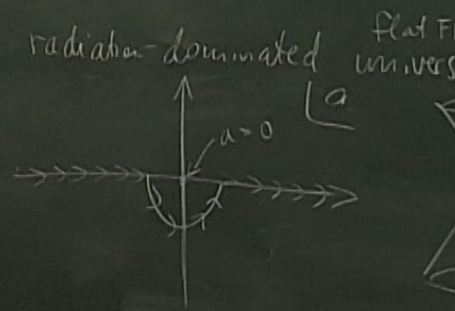
$a(\eta)$
conformal

$m \sim$ total energy
in radiation fluid

Perfect Bounce

- extend a to negative ^{classical} complex
- boundary conditions at $a=0$
- avoid $a=0$ in complex
- conformal symmetry

Ex.



Wdh

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi(a, m, \pi_c \rightarrow 0)$$

$$\begin{aligned} a &\rightarrow \lambda q \\ m &\rightarrow \frac{1}{\lambda} m \end{aligned}$$

conf. coupled scalars
minimally c.s.
anisotropies

$a(\eta)$
conformal

$m \sim \text{total energy in radiation fluid}$

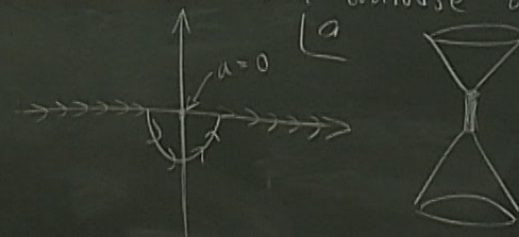
$$\chi^{(\pm)}(q, m, -) \sim e^{\mp i m a}$$

both at $\begin{cases} a \rightarrow +\infty \\ a \rightarrow -\infty \end{cases}$

Perfect Bounce (w/ N. Turok)

- extend a to negative values (classical PRL & PRL)
- boundary conditions at $a \rightarrow \pm\infty$ (quantum)
- avoid $a=0$ in complex plane
- conformal symmetry (matter + GR)

radiation-dominated flat FRW universe $a(\eta) \propto \eta$



Wdh

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi(a, m, \pi_c) = 0$$

$$\begin{aligned} a &\rightarrow \lambda q \\ m &\rightarrow \frac{1}{\lambda} m \end{aligned}$$

conf. coupled scalars
minimally c.s
anisotropies

$a(\eta)$
conformal

$m \sim \text{total energy in radiation fluid}$

$$\chi^{(\pm)}(a, m, -) \sim e^{\mp i m a}$$

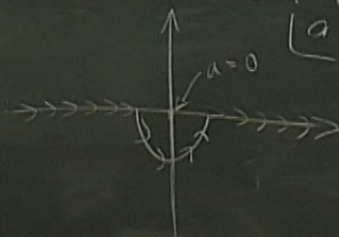
both at $\begin{cases} a \rightarrow +\infty \\ a \rightarrow -\infty \end{cases}$

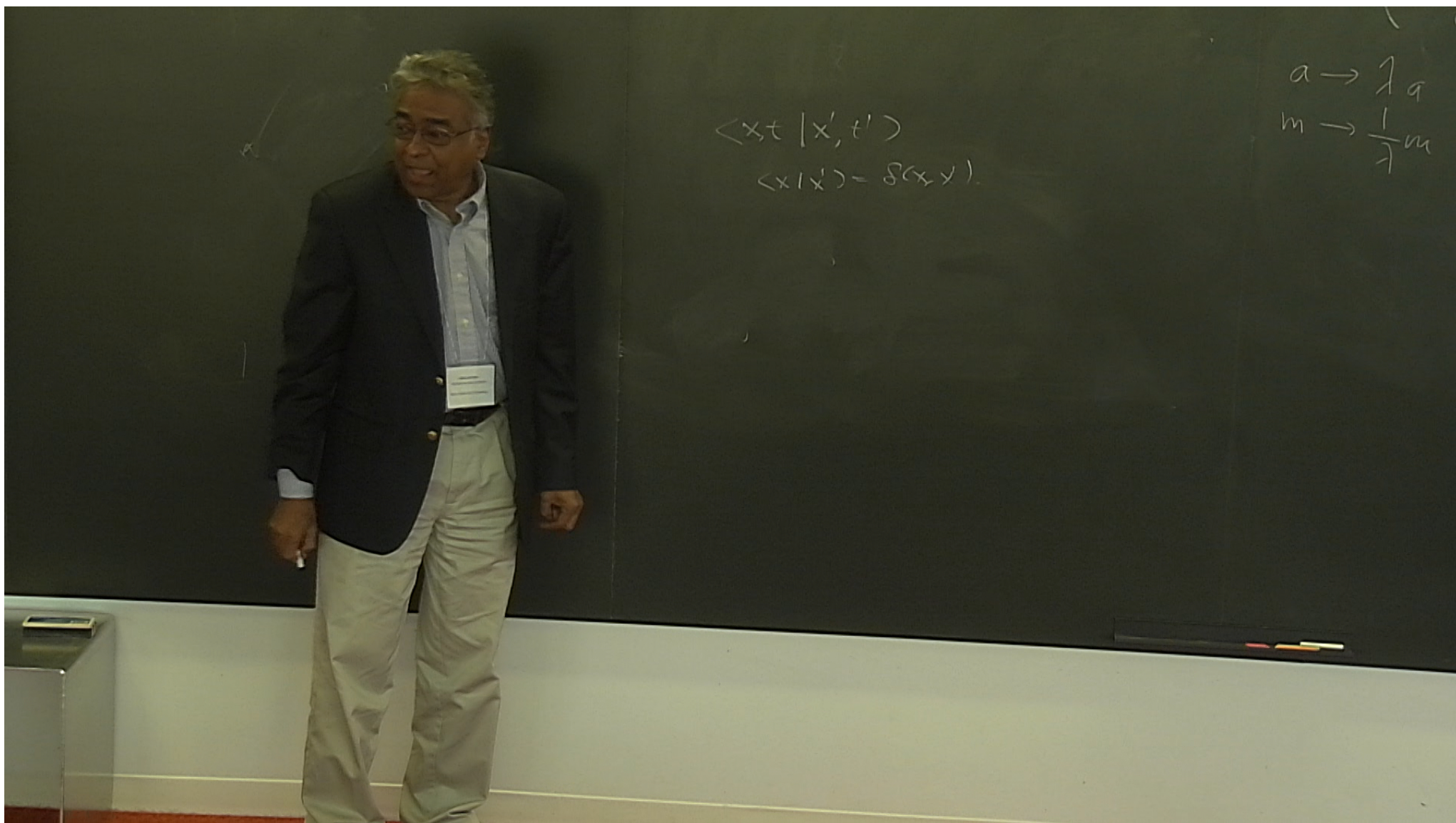
Perfect Bounce (w/ N. Turok)

- extend a to negative values
- boundary conditions at $a \rightarrow \pm\infty$
- avoid $a=0$ in complex plane
- conformal symmetry (matter + GR)

Ex.

radiation-dominated universe $a(\eta) \propto \eta$





$$\int dx dx' \psi_1(x) \langle x, t | x', t' \rangle \psi_2(x') = \langle \psi_1(t) | \psi_2(t) \rangle$$

$$\langle x | x' \rangle = \delta(x - x')$$

$$a \rightarrow \lambda a$$

$$m \rightarrow \frac{1}{\lambda} m$$

$$i\oint_{\partial D} \omega$$

$$\mathcal{H} \Delta_F$$

$$\langle x | \langle x, t | x', t' \rangle \psi_2(x) = \langle \psi_1(t) | \psi(t) \rangle$$

$$\langle x | \psi \rangle = \delta(x, y)$$

Wdh

$$\left(-\frac{d^2}{da^2} + \frac{c}{a^2} + m^2 \right)$$

$$a \rightarrow \lambda q$$

$$m \rightarrow \frac{1}{\lambda} m$$

$$\chi^{(\pm)}(q, m, \dots)$$

$$i \oint_{\gamma} dN$$

$$\mathcal{H} \Delta_F = -i\delta$$

$$S \langle x, t | x', t' \rangle \psi_2(x) = \langle \psi_1(t) | \psi_2(t) \rangle$$

$$\langle x | x' \rangle = \delta(x - x')$$

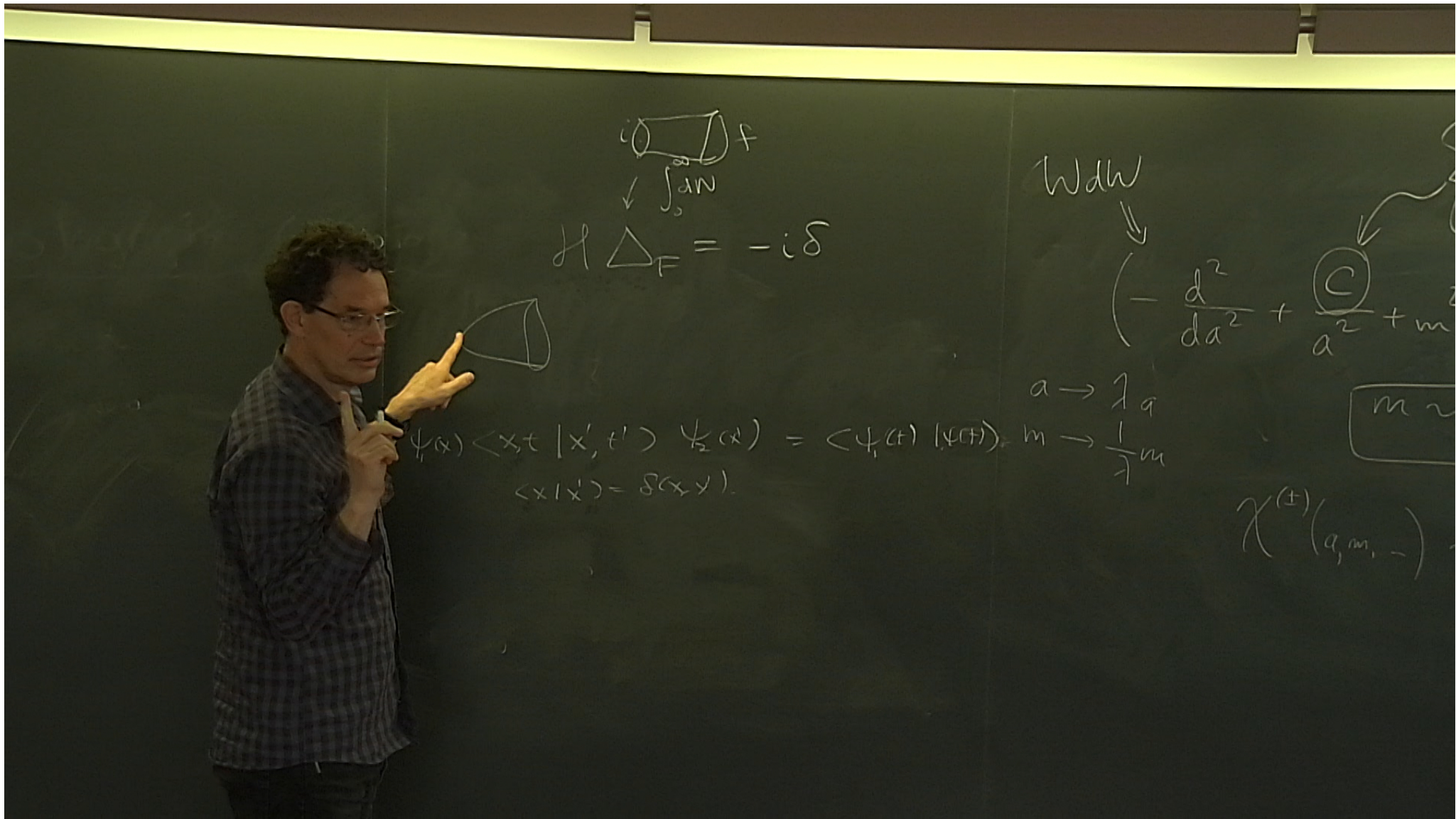
Wdw

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right)$$

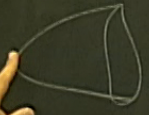
$$a \rightarrow \lambda q$$

$$m \rightarrow \frac{1}{\lambda} m$$

$$\chi^{(\pm)}(q, m, -)$$



$$\begin{array}{c}
 \text{Diagram: a rectangle with a vertical line on the left, a horizontal line on the top, and a diagonal line on the right. A small circle is on the top horizontal line. An arrow points from the top horizontal line to the text } \int dN. \\
 \mathcal{H} \Delta_F = -i\delta
 \end{array}$$



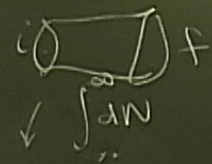
$$\begin{aligned}
 \psi_1(x) \langle x, t | x', t' \rangle \psi_2(x) &= \langle \psi_1(t) | \psi_2(t) \rangle \\
 \langle x | x' \rangle &= \delta(x - x')
 \end{aligned}$$

$$\begin{aligned}
 &WdW \\
 &\Downarrow \\
 &\left(-\frac{d^2}{da^2} + \frac{\textcircled{C}}{a^2} + m^2 \right)
 \end{aligned}$$

$$\begin{aligned}
 a &\rightarrow \lambda q \\
 m &\rightarrow \frac{1}{\lambda} m
 \end{aligned}$$

$$\boxed{m \sim}$$

$$\chi^{(\pm)}(q, m, -)$$



$$\mathcal{H} \Delta_F = -i\delta$$



$$\langle x, t | x \rangle \psi_2(x) = \langle \psi_1(t) | \psi(t) \rangle$$

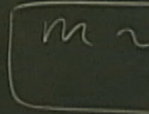
$$\langle x | = \delta(x, y)$$

Wdw

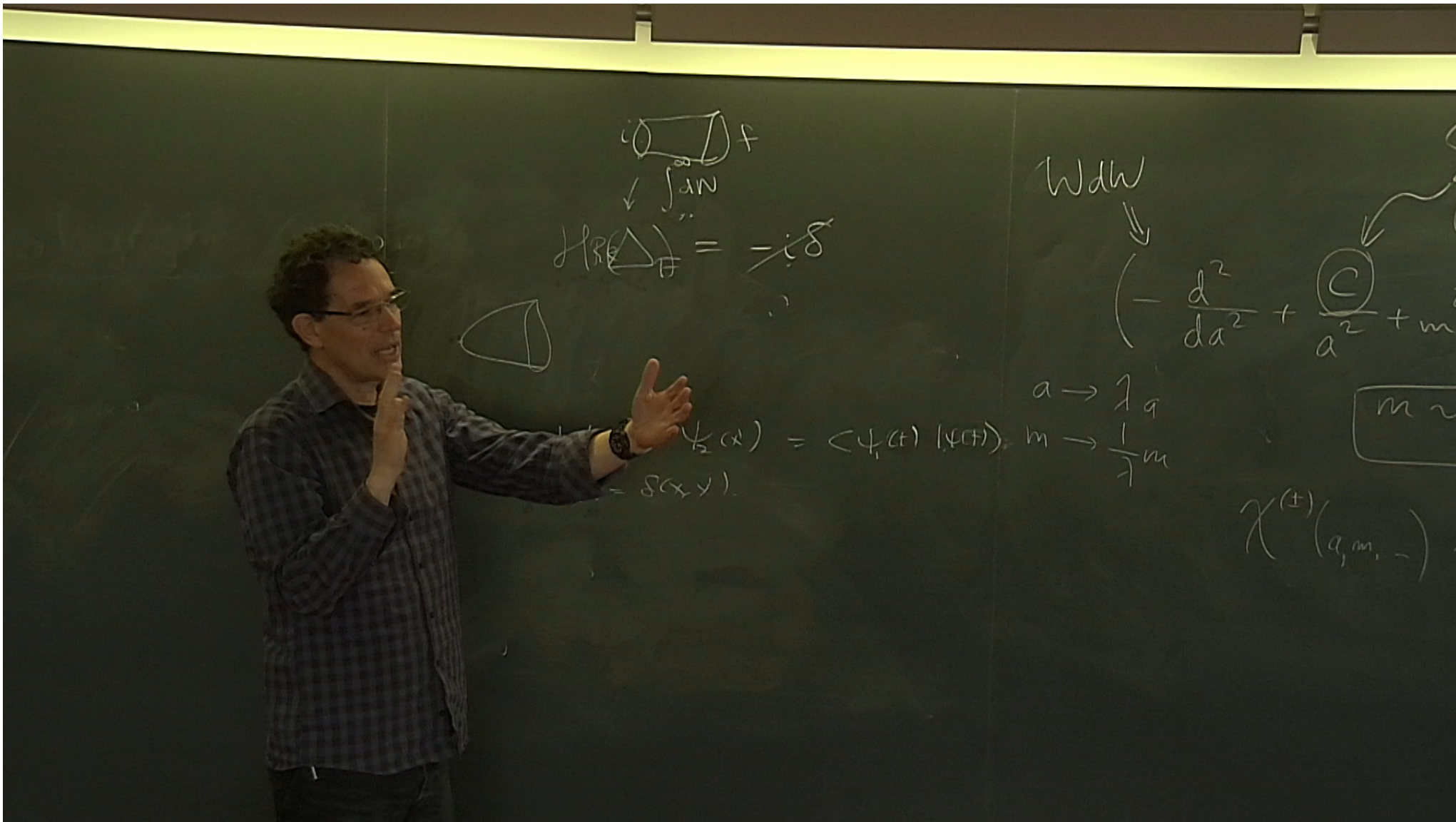
$$\left(-\frac{d^2}{da^2} + \frac{c}{a^2} + m^2 \right)$$

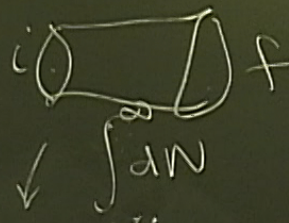
$$a \rightarrow \lambda q$$

$$m \rightarrow \frac{1}{\lambda} m$$

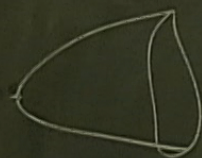


$$\chi^{(\pm)}(q, m, -)$$





$$\text{Res}(\Delta) = -i\delta$$



Wdh



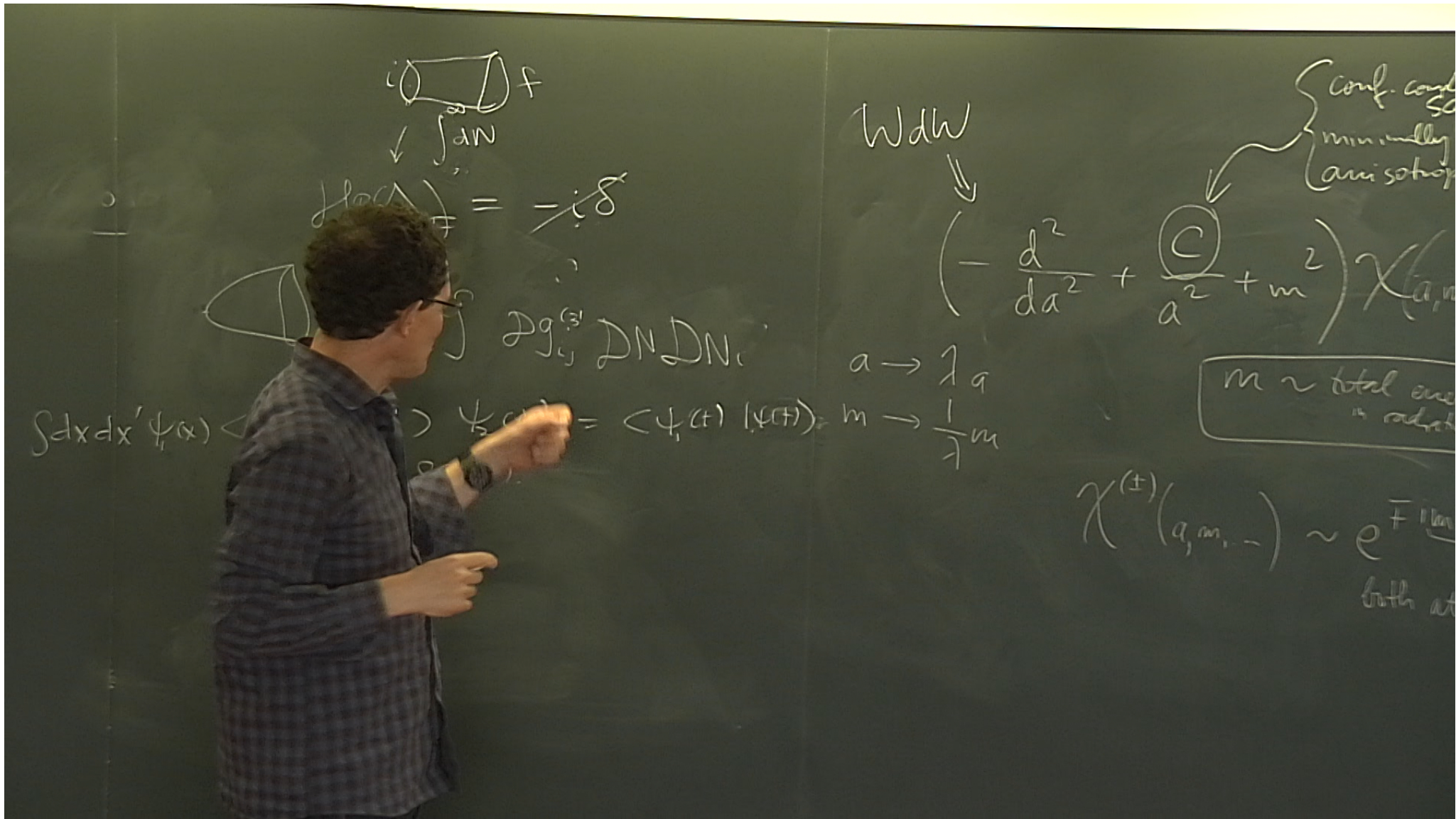
$$\left(- \frac{d^2}{da^2} \right)$$

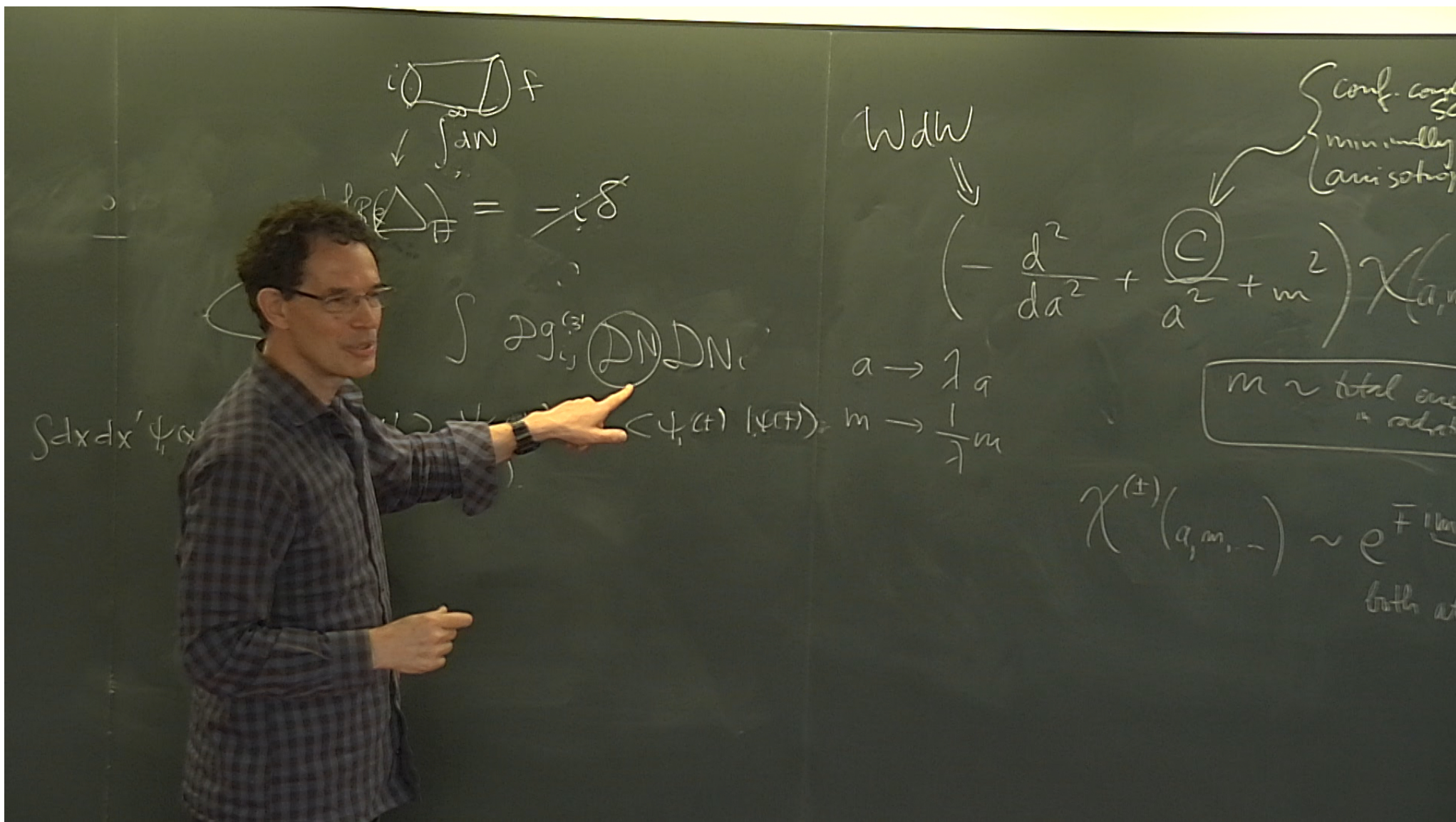
$$a \rightarrow \lambda a$$

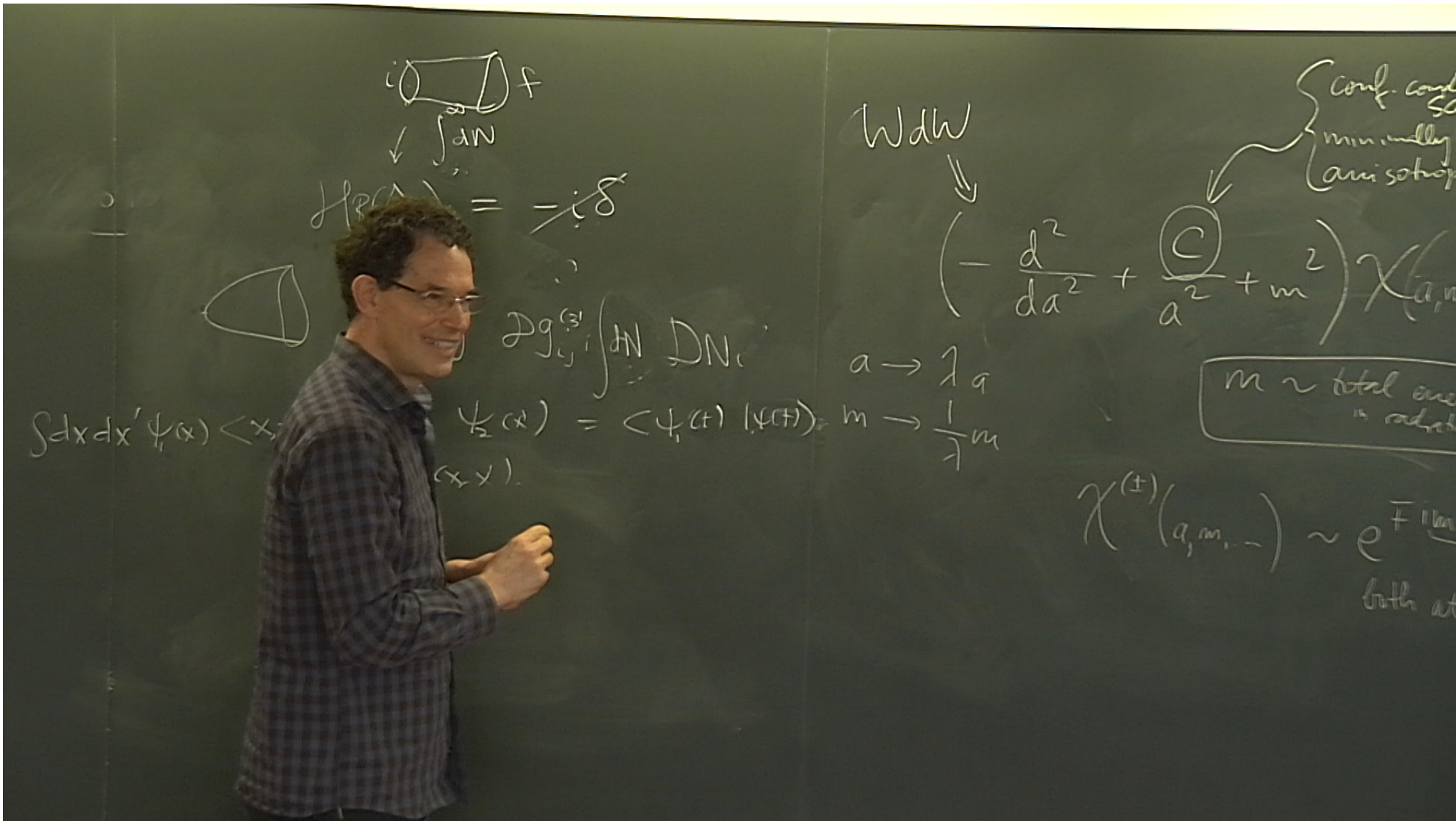
$$m \rightarrow \frac{1}{\lambda} m$$

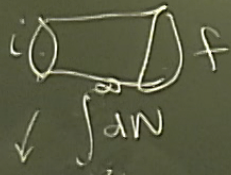
$$\int dx dx' \psi(x) \langle x, t | x', t' \rangle \psi_2(x) = \langle \psi_1(t) | \psi_2(t) \rangle$$

$$\langle x | x' \rangle = \delta(x - x')$$









$$H(\mathbb{R}^3)_{\mathbb{H}} = -i\delta$$

$$2g_{ij}^{(3)} \int dN DN_i$$

$$\int dx dx' \psi(x)$$

$$\psi_2(x) = \langle \psi_1(t) | \psi(t) \rangle$$

Wdw

$$\left(-\frac{d^2}{da^2} + \frac{C}{a^2} + m^2 \right) \chi(a, m)$$

$$a \rightarrow \lambda a$$

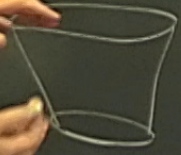
$$m \rightarrow \frac{1}{\lambda} m$$

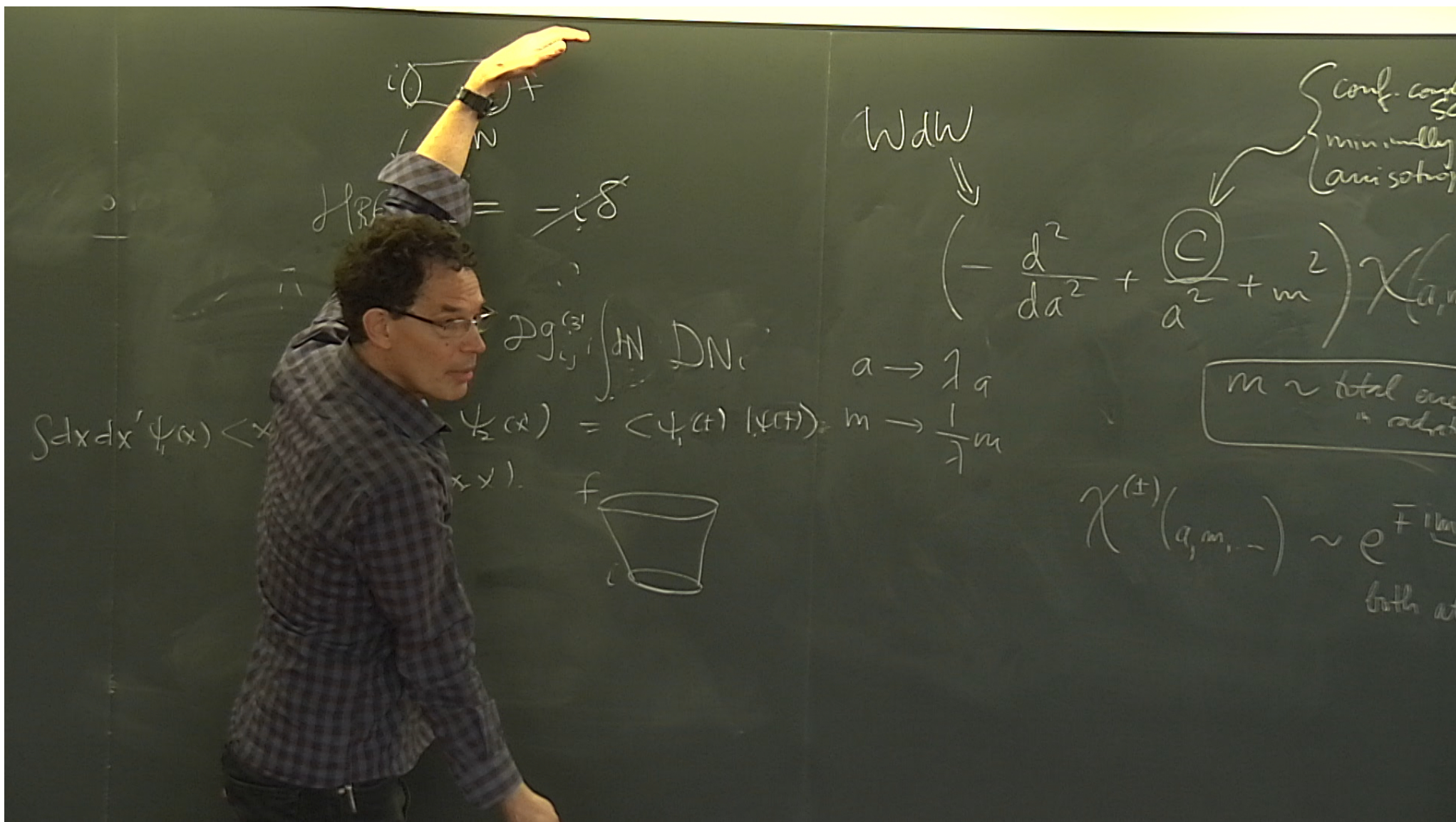
conf. cond
minimally
anisotropic

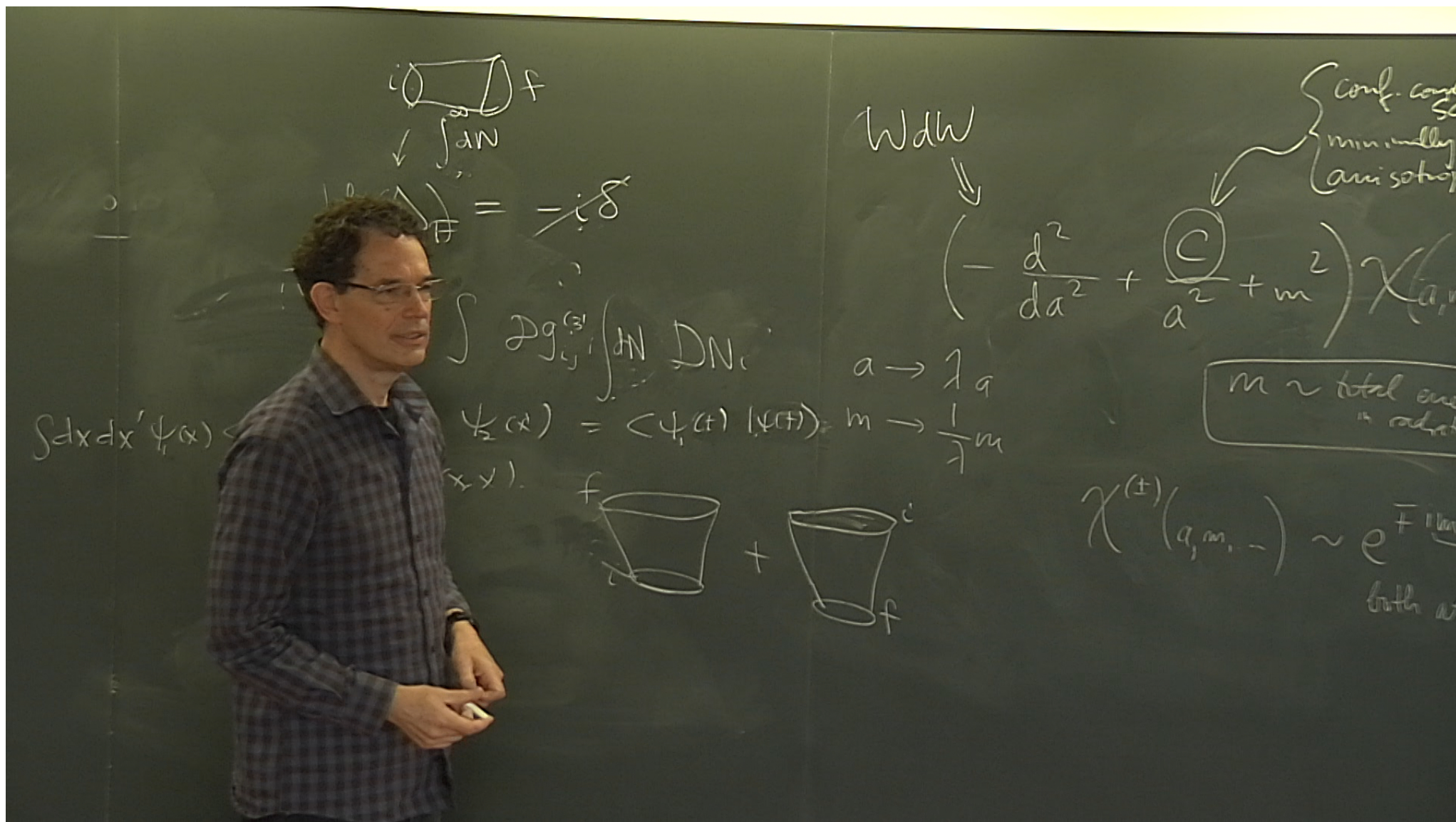
$$m \sim \text{total energy in sector}$$

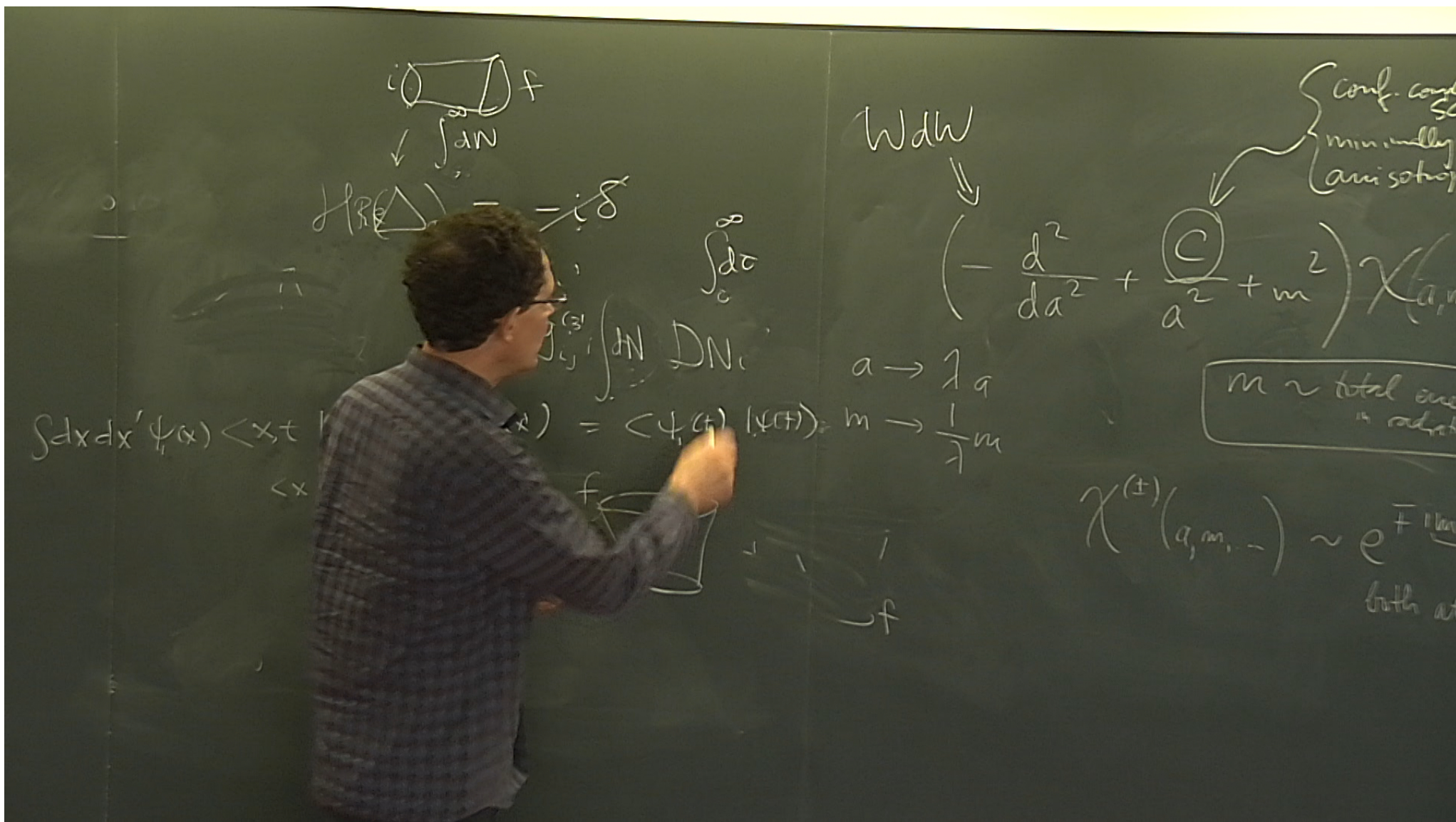
$$\chi^{(\pm)}(q, m, \dots) \sim e^{\mp i k a}$$

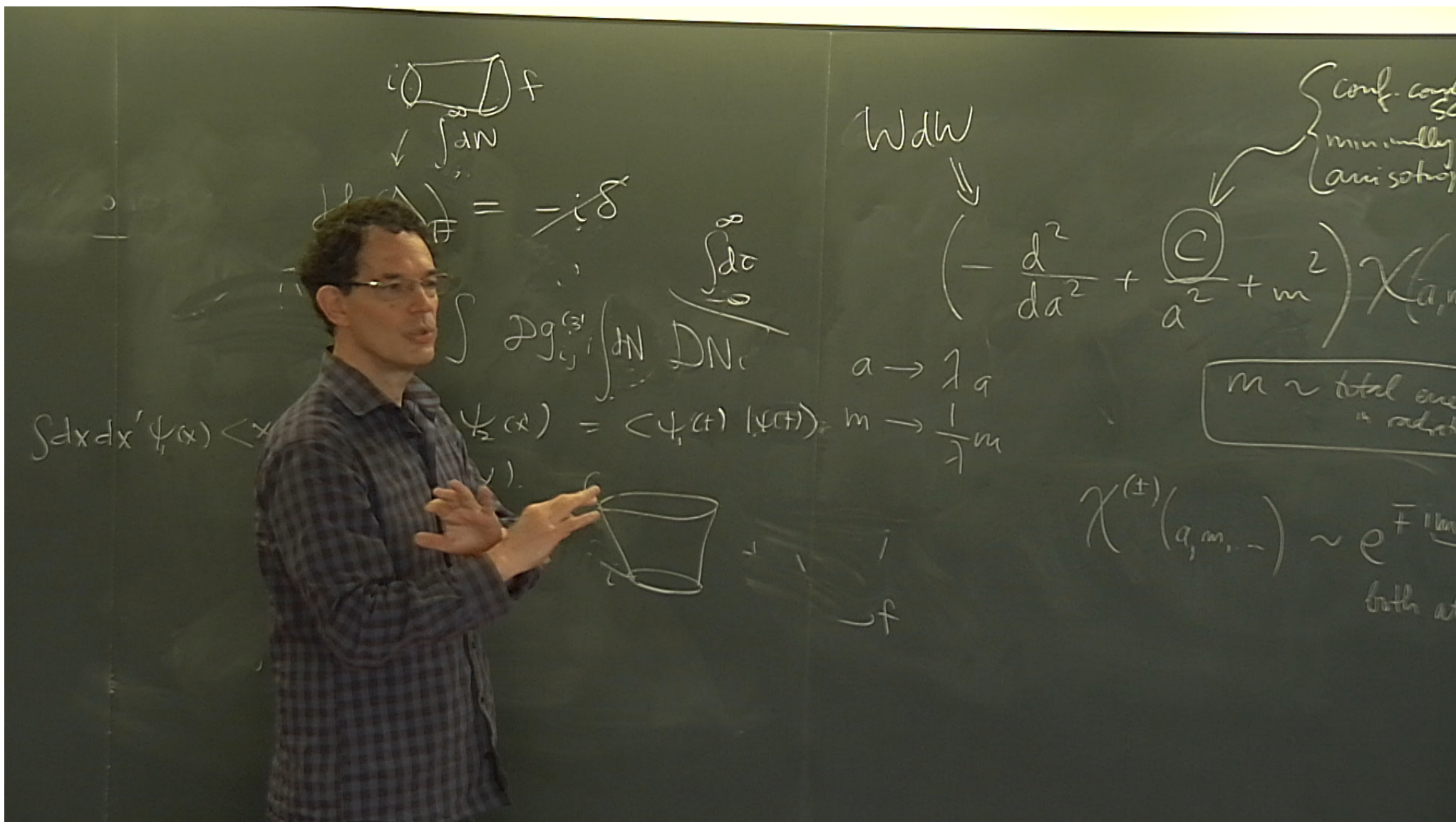
both at

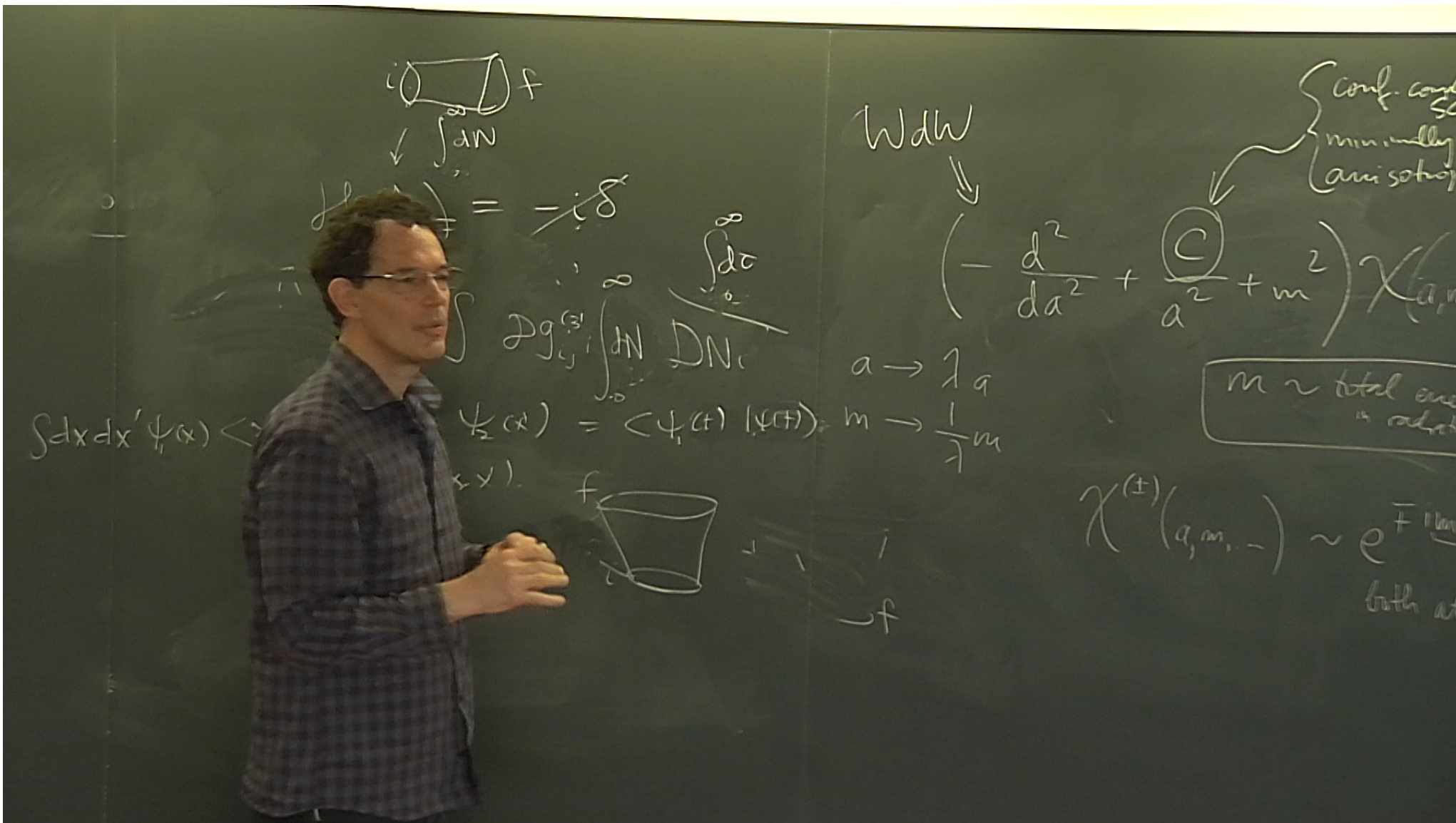


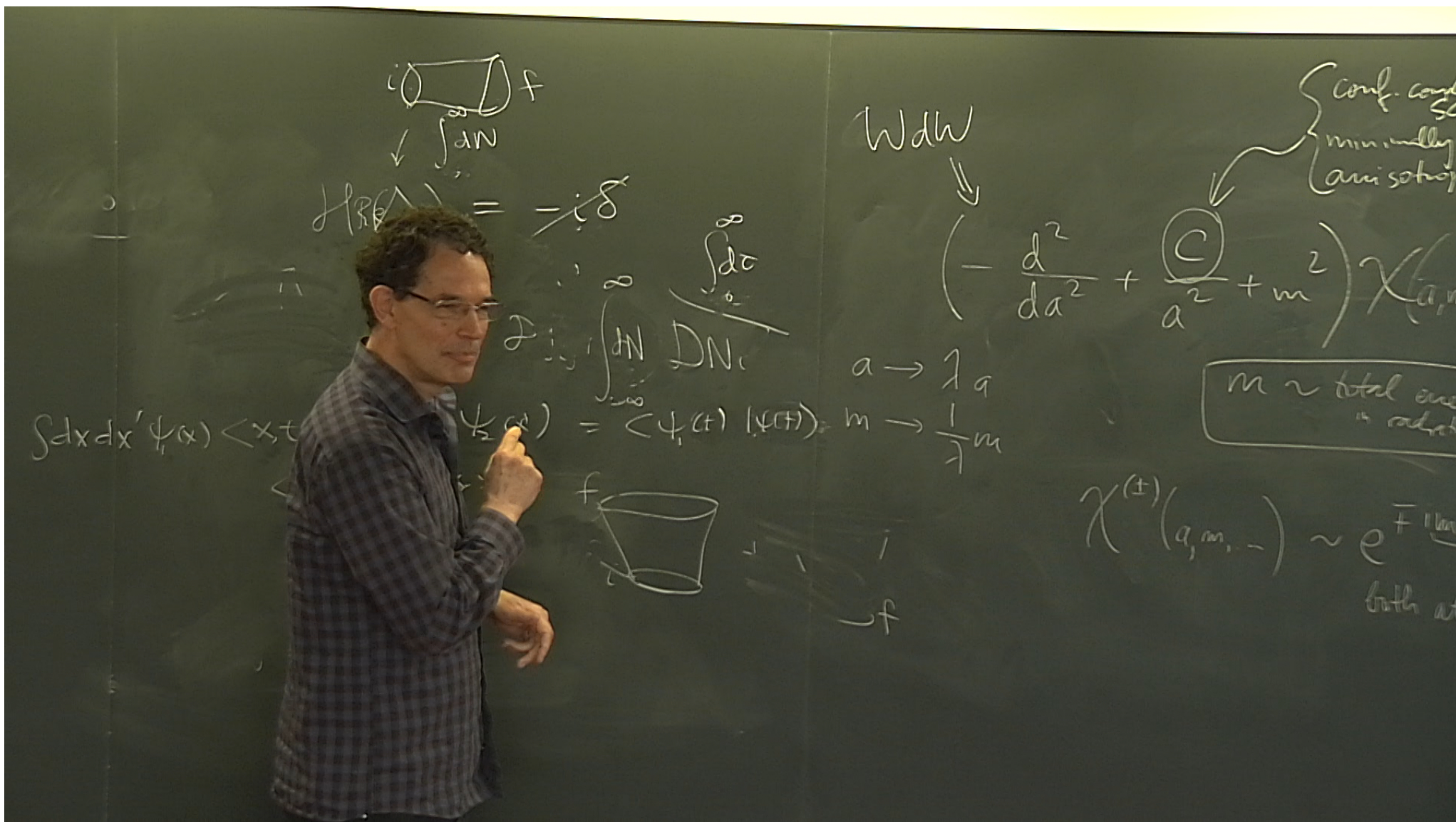


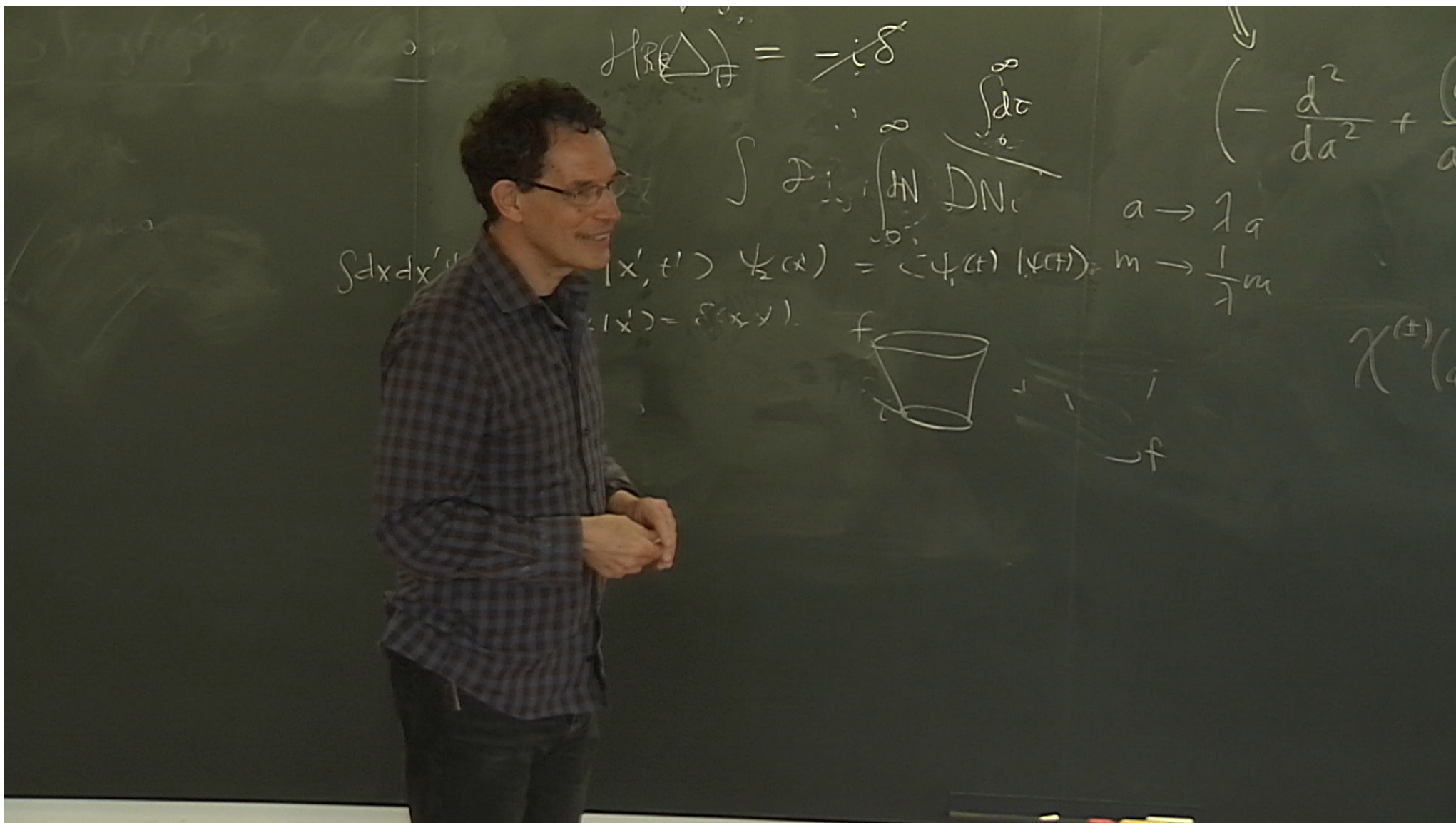


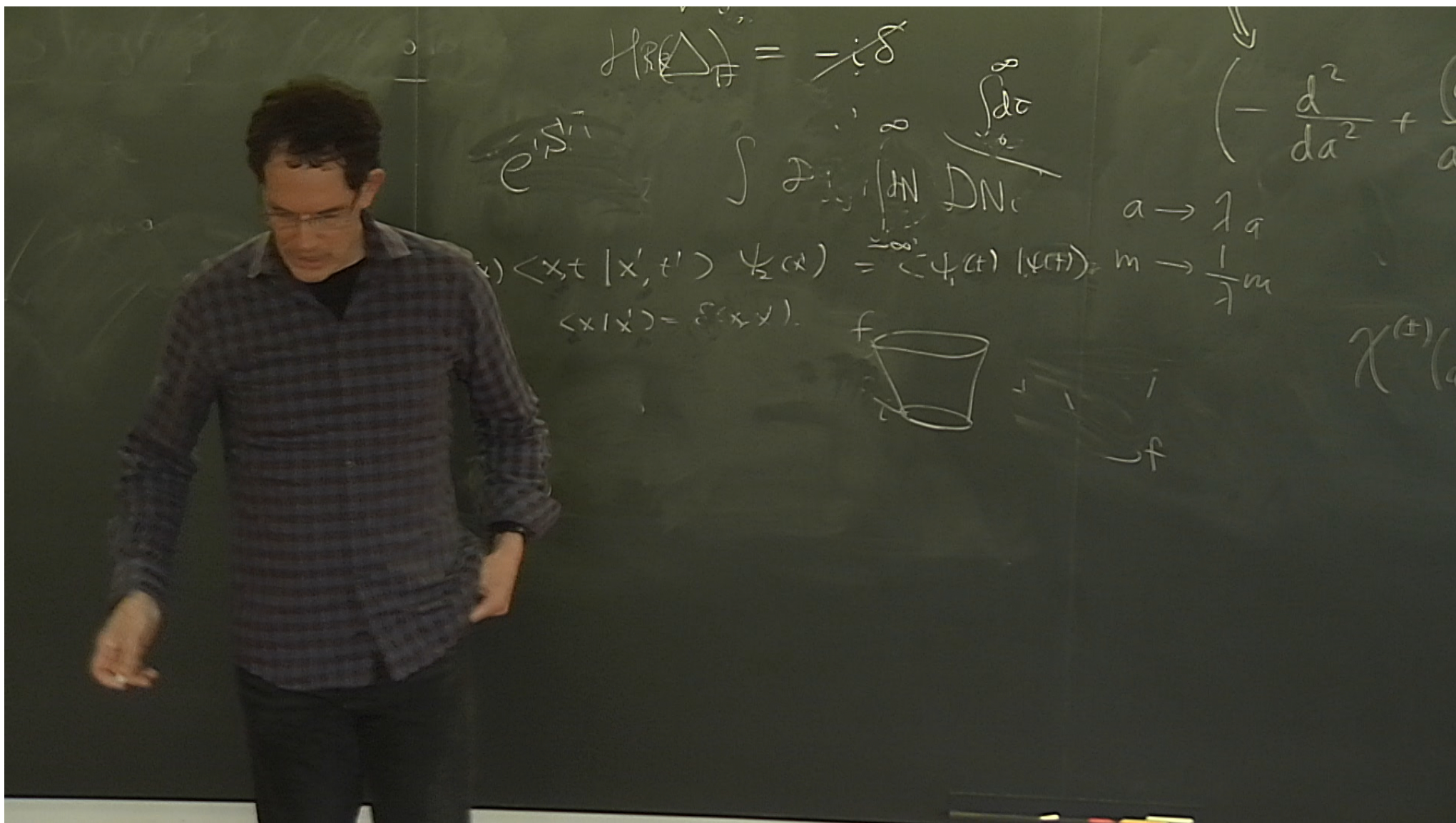


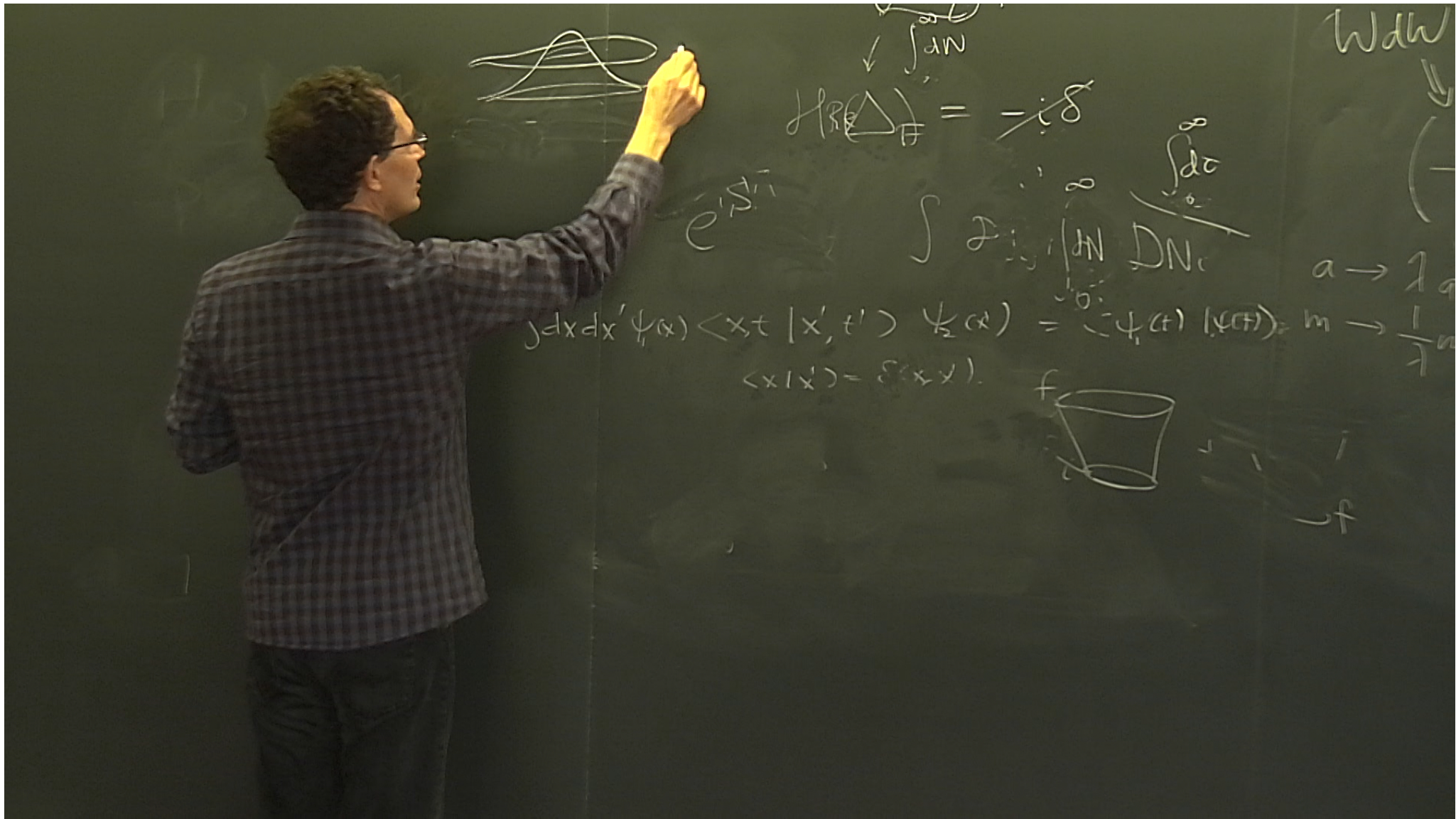


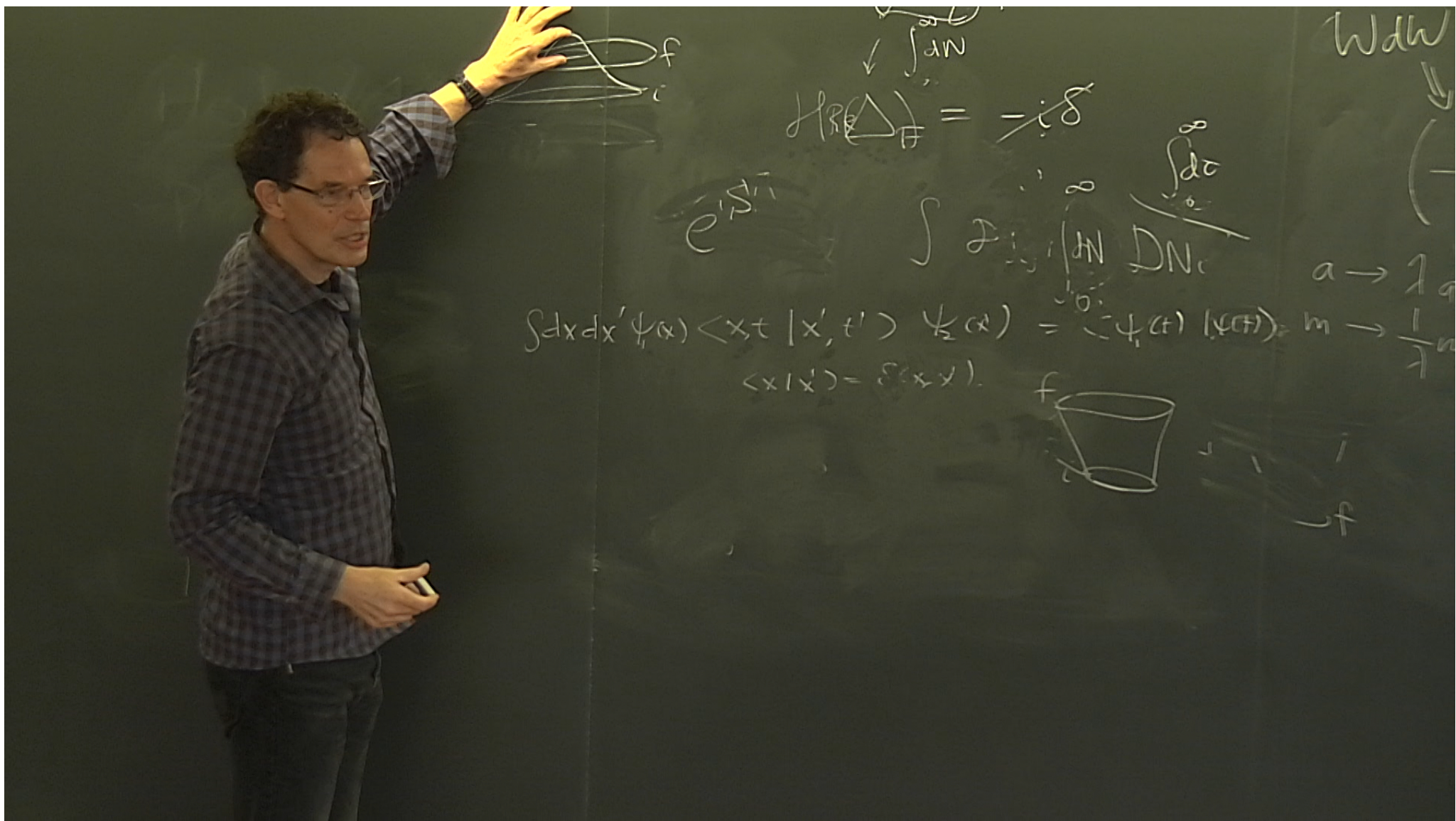


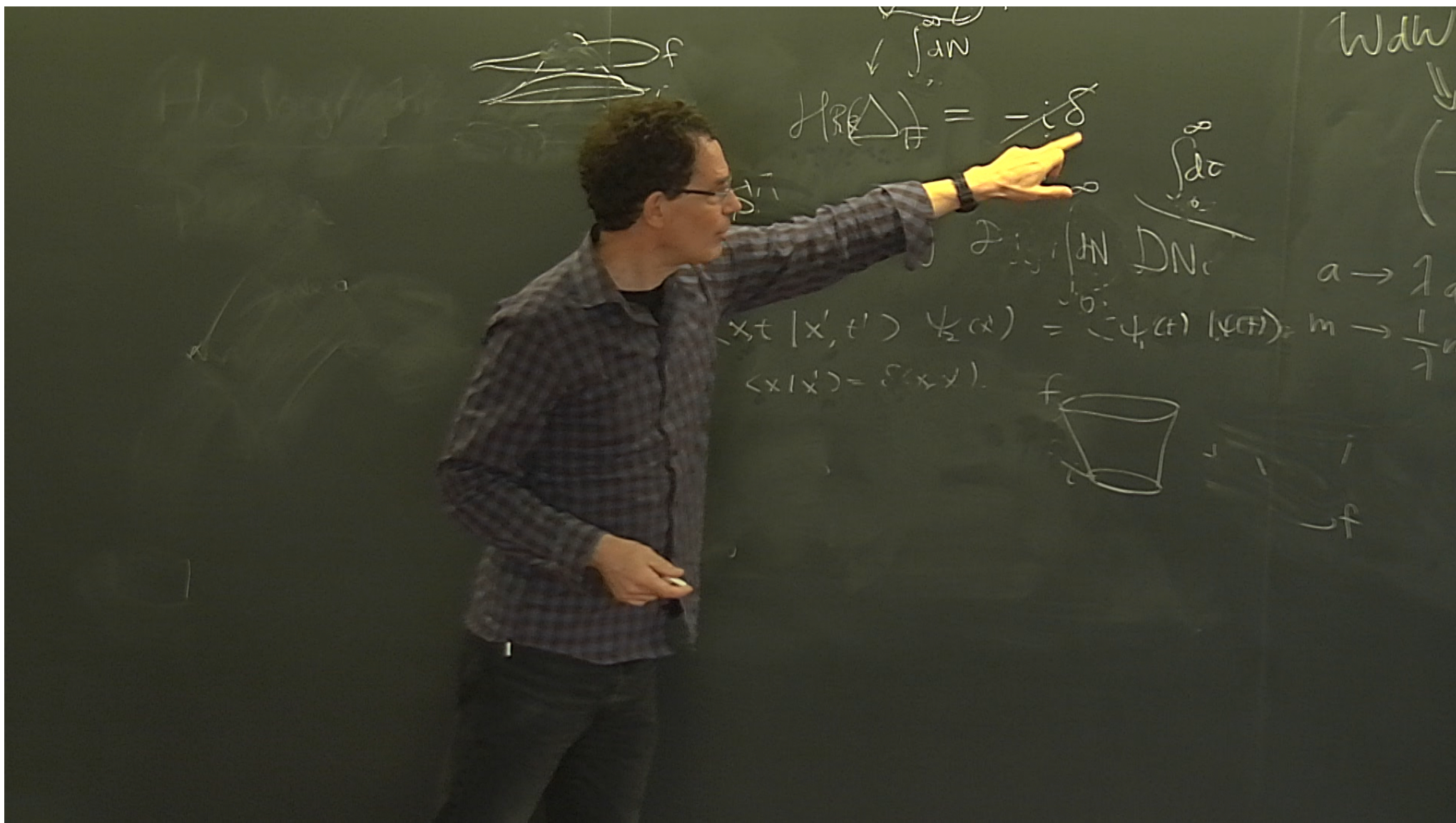












$$\langle x | e^{-iHt} | x \rangle$$

$$H(\Delta) = -i\delta$$

$$e^{iS_1}$$

$$\int \mathcal{D}N \frac{\int_0^\infty d\alpha}{DN}$$

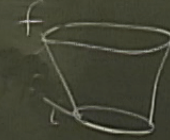
$$\left(-\frac{d^2}{da^2} + \frac{c}{a^2} + m^2 \right)$$

$$\int dx dx' \psi(x) \langle x, t | x', t' \rangle \psi(x) = \int dx \psi(x) \langle x, t | x, t' \rangle \psi(x)$$

$$a \rightarrow \lambda a$$

$$m \rightarrow \frac{1}{\lambda} m$$

$$\langle x | x' \rangle = \delta(x - x')$$



$$\chi^{(\pm)}(q, m, -) \sim$$

