

Title: Generation of Perturbations During Inflation

Date: Apr 20, 2010 12:00 PM

URL: <http://pirsa.org/10040078>

Abstract: <span>Lecture 4</span>

$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B db dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_{0i}}{k^2(\rho+p)}$$

$$\mathcal{L} \equiv$$

$$\Phi_H \equiv -\psi + aH(B - \dots)$$

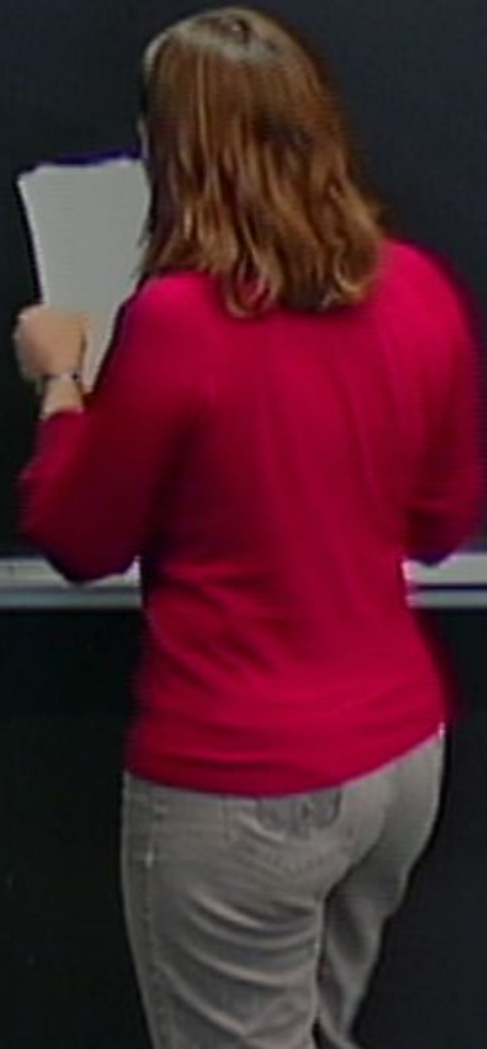


$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_{0i}}{ka(\rho+p)}$$

$$\Phi_H \equiv -\psi + aH(B - \frac{\partial \xi}{\partial t})$$

$$\mathcal{L} \equiv$$



$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2 \left[ \delta_{ij} (1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E \right] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_{0i}}{k a (\rho + p)}$$

$$\mathcal{J} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

$$\Phi_H \equiv -\psi + aH \left( B - \frac{\partial E}{\partial t} \right)$$

Outside the horizon ( $v \ll aH$ )  $\mathcal{J} = 0$

$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B db dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E] dx^i dx^j$$

$$v_B = ikB + \frac{k_i T^0_i}{ka(\rho+p)}$$

$$\Phi_H \equiv -\psi + aH(B - \frac{\partial \xi}{\partial t})$$

$$\mathcal{J} \equiv -\Phi_H - \frac{iaH}{k}$$

Outside the horizon ( $k \ll aH$ )  $\dot{\mathcal{J}} = 0$   
 $\rho = w$

$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2)E] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_{0i}}{ka(\rho+p)}$$

$$\mathcal{J} \equiv -\Phi - v_B$$

$$\Phi_H \equiv -\Psi + aH(B - \frac{\partial \mathcal{E}}{2c})$$

Outside the horizon ( $k \ll aH$ )  $\dot{\mathcal{J}} = 0$   
 $-p = w\rho \Rightarrow \delta p = w\delta\rho$

$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_{0i}}{ka(\rho+p)}$$

$$\mathcal{J} = -\frac{iaH}{k} v_B$$

$$\Phi_H = -\psi + aH(B - \frac{\partial \mathcal{E}}{2\epsilon})$$

Outside the horizon ( $k \ll aH$ )

$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$$\dot{\mathcal{J}} = 0$$

$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E] dx^i dx^j$$

$$v_B = ikB + \frac{k_i T^0_i}{ka(\rho+p)}$$

$$\Phi_H \equiv -\psi + aH(B - \frac{\partial \xi}{\partial t})$$

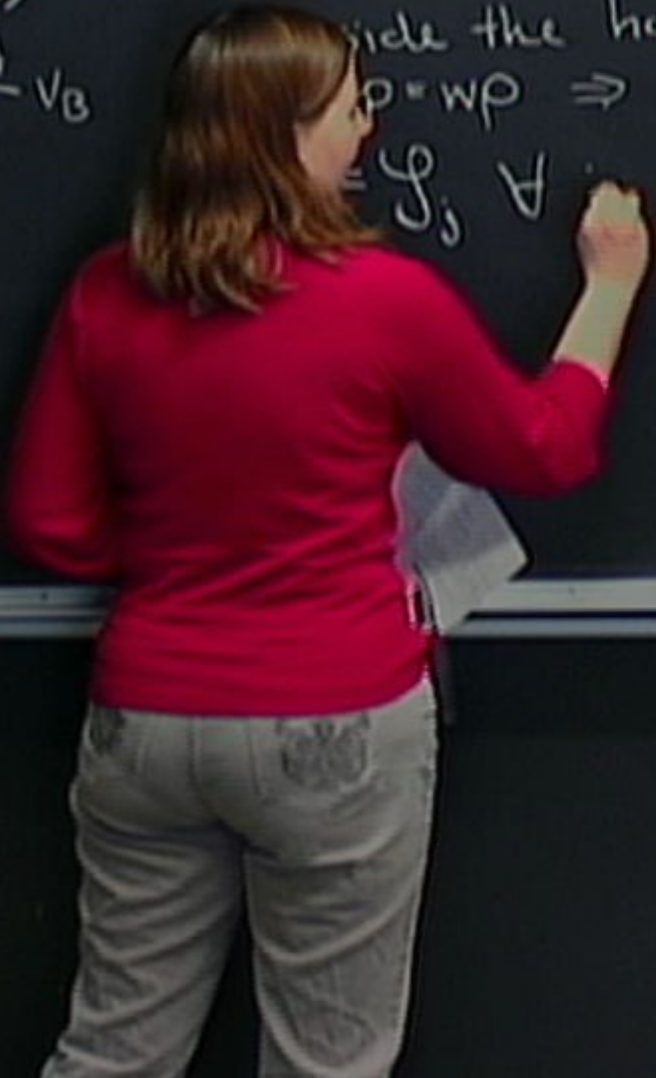
$$\mathcal{J} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

inside the horizon ( $k \ll aH$ )

$$\boxed{\dot{\mathcal{J}} = 0}$$

$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$$A = \mathcal{J}_i v^i$$





$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_{0i}}{ka(\rho+p)}$$

$$\mathcal{F} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

$\mathcal{F}$

$$\Phi_H \equiv -\psi + aH(B - \frac{\partial \mathcal{E}}{2\mathcal{L}})$$

Outside the horizon ( $k \ll aH$ )  
 $p = w\rho \Rightarrow \delta p = w \delta \rho$

$$\boxed{\dot{\mathcal{F}} = 0}$$

$\mathcal{F}_i = \mathcal{F}_j \quad \forall i, j \Rightarrow$  adiabatic

$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2)E] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_i}{ka(\rho+p)}$$

$$\mathcal{L} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

$$\mathcal{L}_i = -\Phi_{H,i} - H \frac{\delta p_i}{\rho_i}$$

$$\Phi_H \equiv -\Psi + aH(B - \frac{\partial \mathcal{E}}{2c})$$

Outside the horizon ( $k \ll aH$ )  
 $p = w\rho \Rightarrow \delta p = w\delta\rho$

$$\boxed{\dot{\mathcal{L}} = 0}$$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

$$ds^2 = -(1-2A)dt^2 - 2a\partial_i B dt dx^i + a^2 [\delta_{ij} (1+2\Phi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E] dx^i dx^j$$

$$v_B = \kappa B + \frac{k^i T^0_i}{\kappa a(\rho+p)}$$

$$\mathcal{L} = -\Phi_H - \frac{iaH}{\kappa} v_B$$

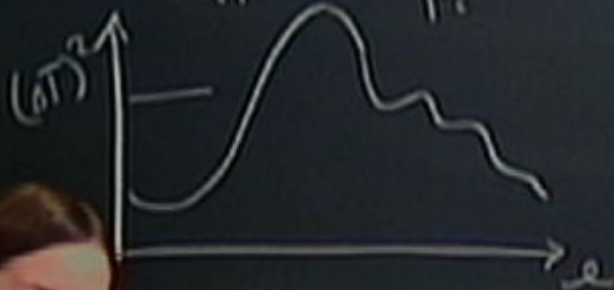
$$\mathcal{L}_i = -\Phi_{,i} - H \frac{\delta p_i}{\delta p}$$

$$\Phi_H = -\Psi + aH \left( B - \frac{\partial E}{\partial \tau} \right)$$

Outside the horizon ( $k \ll aH$ )  $\mathcal{L} = 0$

$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic



$$S_i = -k_B \ln \Omega_i$$

$$= -k_B \ln \Omega_i$$

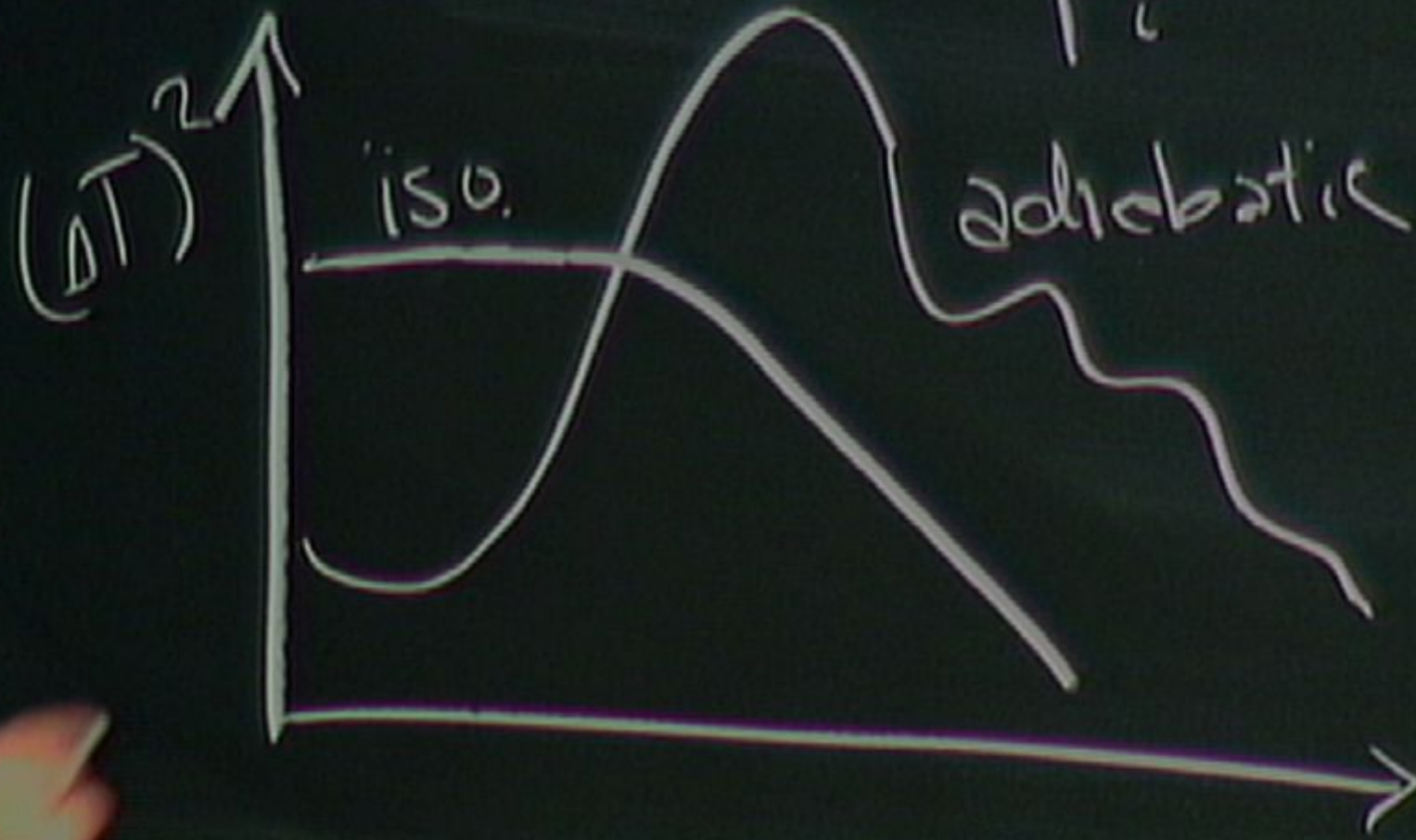
$$= -k_B \ln \Omega_i$$

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$$S_i$$

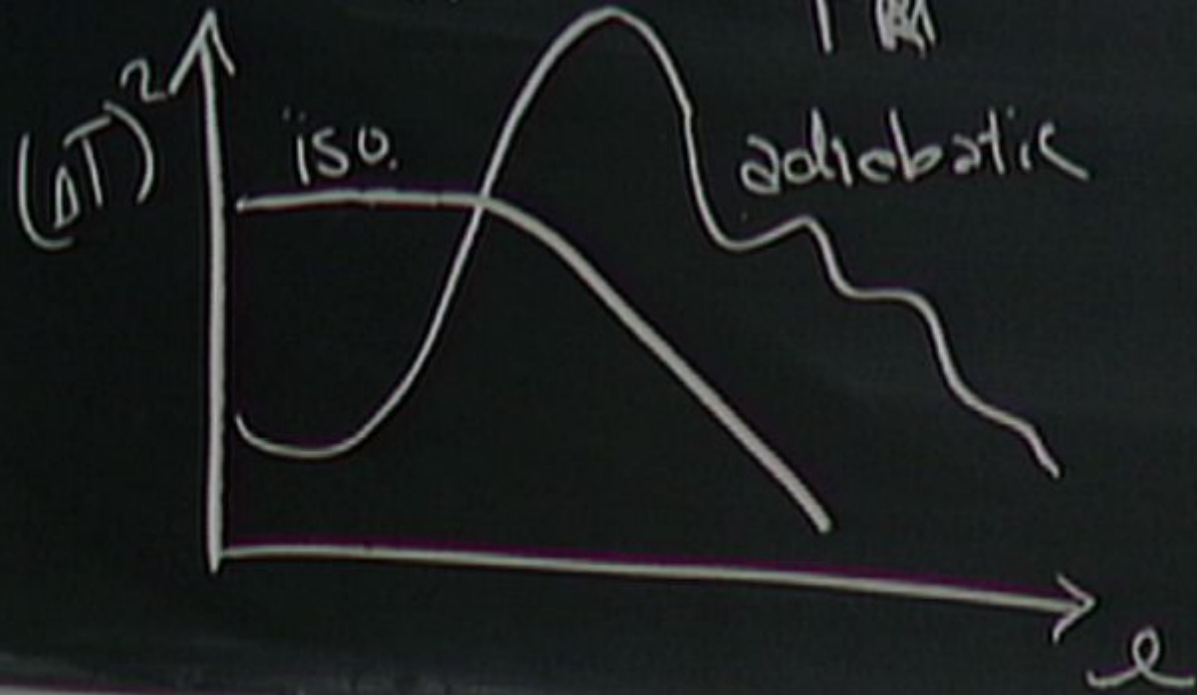


$$\mathcal{S} = - \Phi_H - \frac{1}{2} \frac{v_B}{k} \frac{1}{H}$$

$$\mathcal{S}_M = - \Phi_H - \frac{1}{2} \frac{\delta p_M}{\rho_M} \frac{1}{H}$$

Outside

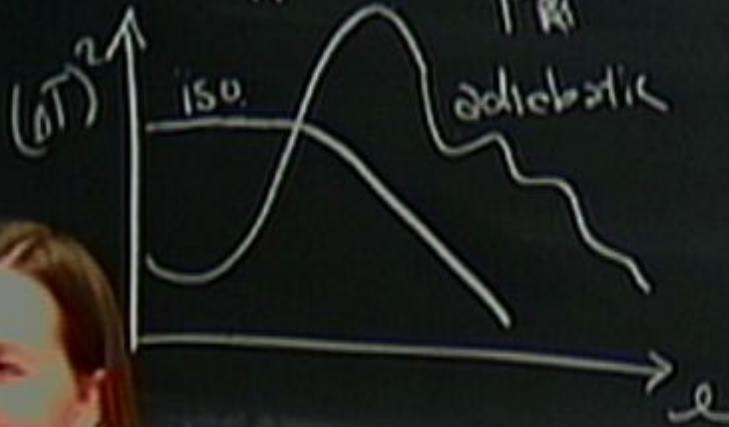
$$\mathcal{S}_i = \dots$$



$$v_B = ikB + \frac{k^i T^o_i}{ka(\rho + p)}$$

$$\mathcal{L} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

$$\mathcal{L}_M = -\Phi_H - H \frac{\delta p_M}{\dot{p}_M}$$



$$\Phi_H \equiv -\Psi + aH \left( B - \frac{\partial t}{\partial \tau} \right)$$

Outside the horizon  
 $p = w\rho \Rightarrow \delta p =$

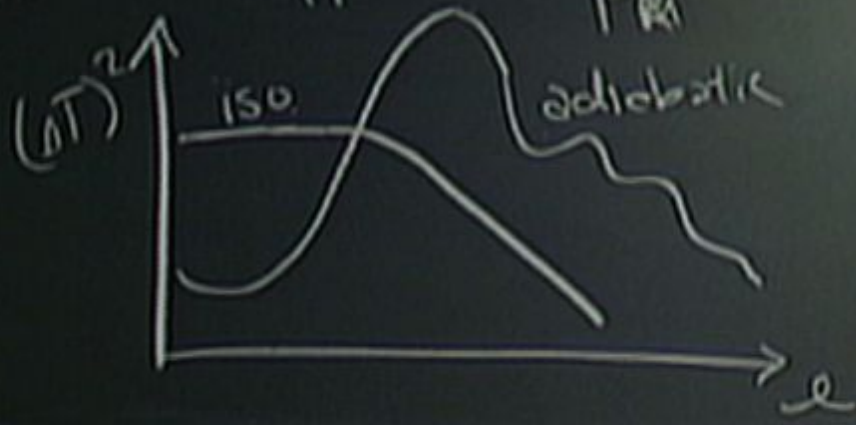
$$\mathcal{L}_i = \mathcal{L}_j \quad \forall i, j \Rightarrow \text{adiabatic}$$

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$$U = -\frac{\Phi_H}{k} v_B$$

$$\mathcal{L}_M = -\Phi_H - H \frac{\delta p_{RI}}{\rho_{RI}}$$

$$\mathcal{L}_i = \mathcal{L}_s \quad \forall i \Rightarrow \text{adiabatic}$$



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$$\delta\phi = 0$$

$$E = 0$$

$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2)]$$

$$v_B = ikB + \frac{k^i T^0_i}{ka(\rho+p)}$$

$$\Phi_H \equiv -\psi + aH\left(B - \frac{\partial \mathcal{E}}{\partial \tau}\right)$$

$$\mathcal{S} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

Outside the horizon ( $k \ll aH$ )  
 $p = w\rho \Rightarrow \delta p = w_i \delta \rho$

$$\mathcal{S}_M = -\Phi_H - H \frac{\delta p_M}{\dot{\rho}_M}$$

$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Rightarrow$  adiabatic

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$$\delta\phi = 0$$

$$E = 0$$





$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2 \psi)]$$

$$v_B = ikB + \frac{k^i T^0_i}{ka(\rho+p)}$$

$$\Phi_H \equiv -\psi + aH\left(B - \frac{\partial \mathcal{E}}{\partial \tau}\right)$$

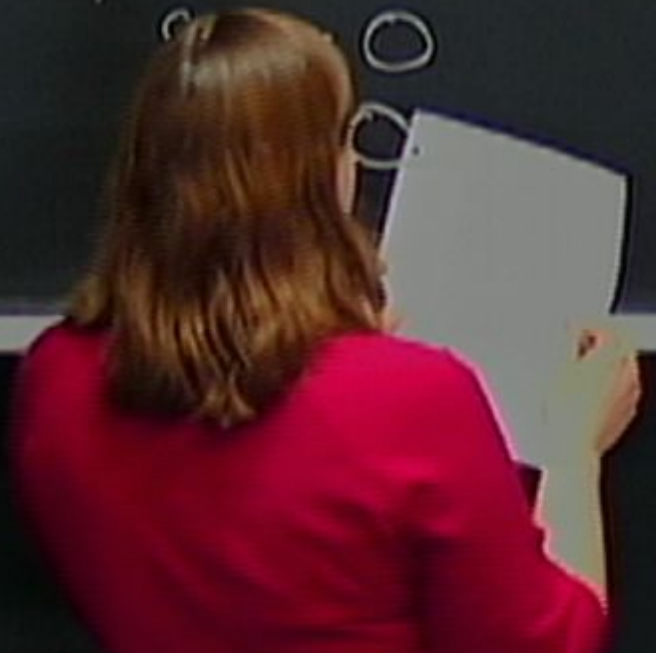
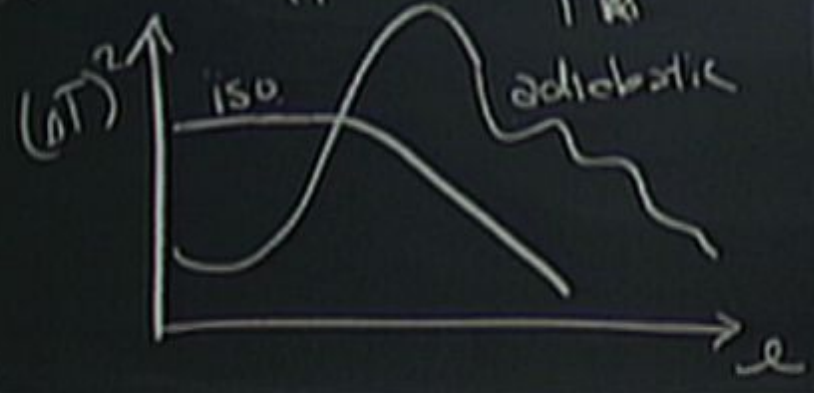
$$\mathcal{S} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

Outside the horizon ( $k \ll aH$ )  
 $p = w\rho \Rightarrow \delta p = w \delta \rho$

$$\mathcal{S}_M = -\Phi_H - H \frac{\delta p_M}{\dot{\rho}_M}$$

$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Rightarrow$  adiabatic

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$$ds^2 = -(1+2A)dt^2 - 2a\partial_i B dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2 \psi)]$$

$$v_B = ikB + \frac{k^i T^0_i}{ka(\rho+p)}$$

$$\Phi_H \equiv -\psi + aH\left(B - \frac{\partial \mathcal{E}}{\partial \tau}\right)$$

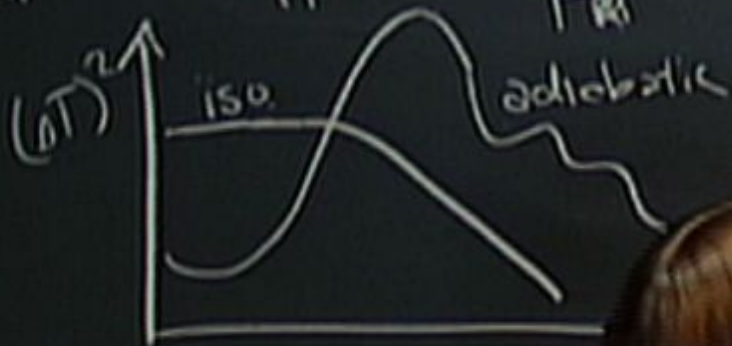
$$\mathcal{S} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

Outside the horizon ( $k \ll aH$ )  
 $p = w\rho \Rightarrow \delta p = w_i \delta \rho$

$$\mathcal{S}_M = -\Phi_H - H \frac{\delta p_M}{\dot{\rho}_M}$$

$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Rightarrow$  adiabatic

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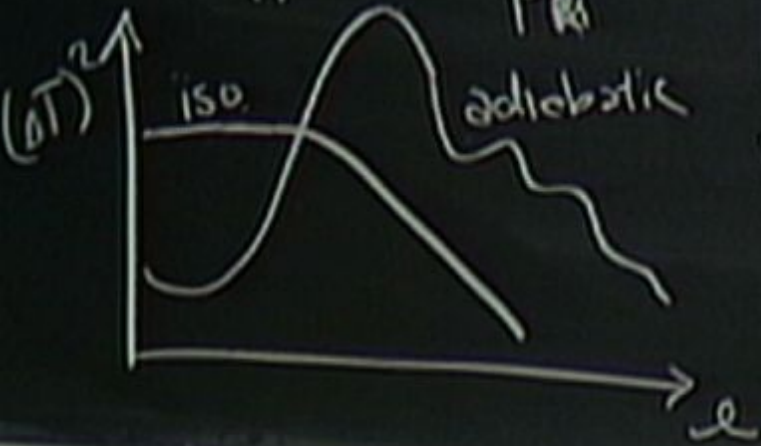
$$\delta\phi = 0 \Rightarrow \mathcal{S} = \psi$$

$$E = 0$$

$$ikB + \frac{k \cdot T_0}{ka(\rho+p)}$$

$$= -\Phi_H - \frac{iaH}{k} v_B$$

$$= -\Phi_H - H \frac{\delta p_M}{\rho_M}$$



$$\Phi_H \equiv -\Psi + aH \left( B - \frac{\alpha}{2\epsilon} \right)$$

Outside the horizon ( $k \ll aH$ )  $\left[ \mathcal{S} = \right.$   
 $p = w\rho \Rightarrow \delta p = w \delta \rho$

$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Rightarrow$  adiabatic

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inflation  $\rightarrow \delta\phi = 0$   
 $E = 0 \Rightarrow \mathcal{S} = \Psi$

$$(1+2A)dt^2 - 2a\partial(B)dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2)E] dx^i dx^j$$

$$k^i T_i$$

$$k^2 B + \frac{k^i T_i}{k^2(\rho+p)}$$

$$\bar{\Phi}_H \equiv -\psi + aH\left(B - \frac{\partial \mathcal{E}}{\partial \tau}\right)$$

Outside the horizon ( $k \ll aH$ )  $\mathcal{J} = 0$

$$-\bar{\Phi}_H - \frac{i a H}{k} v_B$$

$$p = w\rho \Rightarrow \delta p = w_i \delta \rho$$

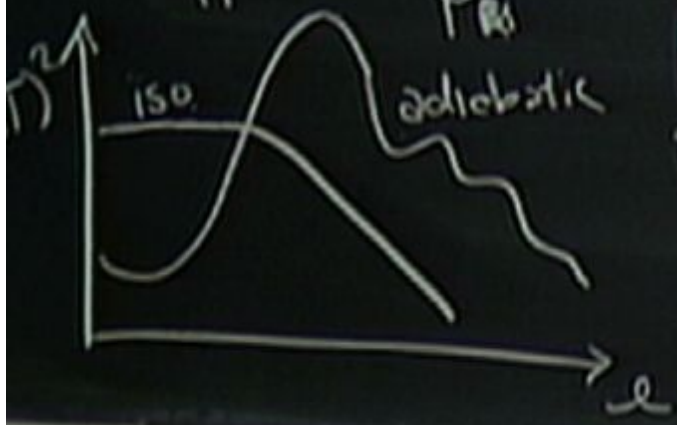
$$-\bar{\Phi}_H - H \frac{\delta p_i}{\rho_i}$$

$\mathcal{J}_i = \mathcal{J}_j \forall i, j \Rightarrow$  adiabatic

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inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$$\Rightarrow \mathcal{J} = \psi$$

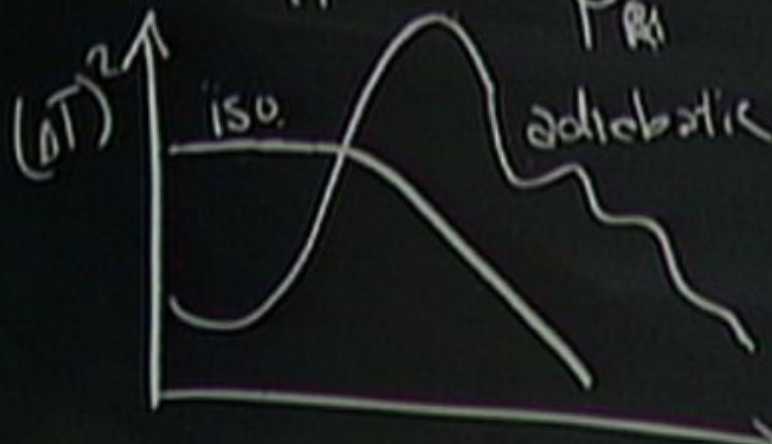


$$ds^2 = -(1+2A)dt^2 - 2a\partial(\beta)dt dx^i + a^2 \gamma_{ij} (1+2\psi)$$

$$V_B \equiv ik\beta + \frac{k^i T_i^0}{ka(\rho+p)} \rightarrow 0$$

$$\psi = -\Phi_H - \frac{iaH}{k} V_B$$

$$\delta \rho = -\Phi_H - H \frac{\delta p}{\dot{\rho}}$$



$$\Phi_H \equiv -\psi + aH \left( \beta - \frac{\partial \beta}{\partial \tau} \right)$$

Outside the horizon  
 $p = w\rho \Rightarrow \delta p$

$$\delta_i = \delta_j \quad \forall i, j \Rightarrow$$

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$$\text{inflaton} \rightarrow \delta\phi = 0$$

$$E = 0$$



$$ds^2 = -(1+2A)dt^2 - 2a\partial(\beta)dt dx^i + a^2 \gamma_{ij} (1+2\psi)$$

$$v_B = ikB + \frac{k^i T_i^0}{ka(\rho+p)} \rightarrow 0$$

$$\mathcal{L} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

$$\mathcal{L}_M \equiv -\Phi_H - H \frac{\delta p_M}{\rho_M}$$

$$\Phi_H \equiv -\psi + aH \left( \beta - \frac{\partial \beta}{\partial \tau} \right)$$

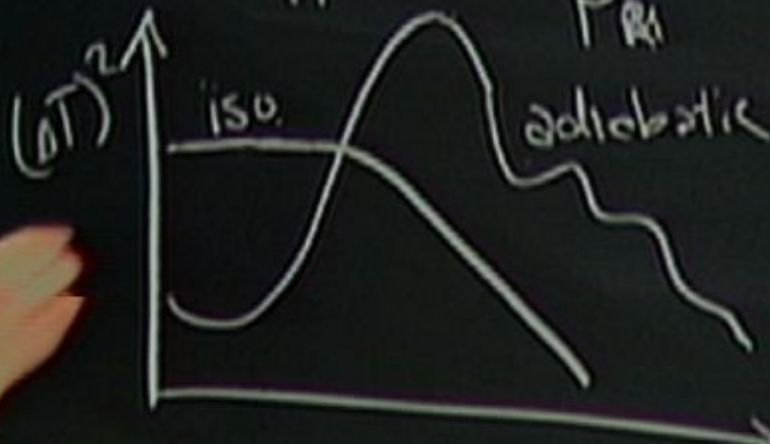
Outside the horizon  
 $p = w\rho \Rightarrow \delta p$

$$\mathcal{L}_i = \mathcal{L}_j \quad \forall i, j \Rightarrow$$

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$$\text{inflaton} \rightarrow \delta\phi = 0$$

$$E = 0$$



$$ds^2 = -(\dots) + \dots$$

$$v_B = ikB + \frac{k \cdot T}{\omega(\rho+p)}$$

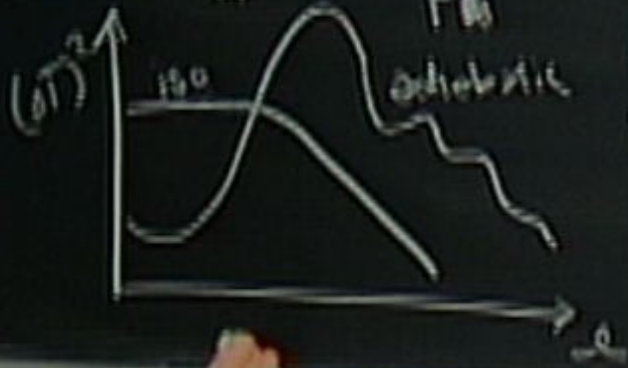
$$\Phi_H \equiv -\psi + \text{th}(\beta - \frac{E}{T})$$

$$\mathcal{F} \equiv -\Phi_H = \frac{i\rho H}{k} \quad (v_B)$$

Outside the horizon ( $k \ll \omega H$ )  $\boxed{\dot{\mathcal{F}} = 0}$   
 $p = w\rho \Rightarrow \delta p = w \delta \rho$

$$\mathcal{F}_M \equiv -\Phi_H = H \frac{\delta p_M}{\rho_M}$$

$\mathcal{F}_i = \mathcal{F}_j \quad \forall i, j \Rightarrow$  adiabatic



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$\delta\phi = 0$   
 $E = 0 \Rightarrow \boxed{\mathcal{F} = \psi}$

$$ds^2 = -(1+2A)dt^2 - 2a\partial(B)dt dx^i + a^2 \left[ \gamma_{ij} (1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E \right] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_i^0}{k a (\rho + p)}$$

$$\Phi_H \equiv -\psi + aH \left( B - \frac{\partial E}{\partial \tau} \right)$$

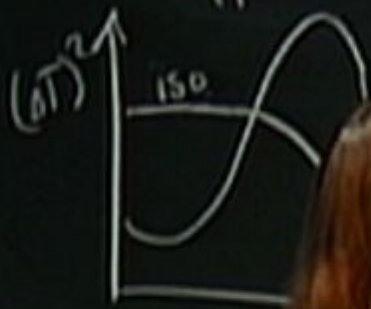
$$\mathcal{L} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

Outside the horizon ( $k \ll aH$ )  $\dot{\mathcal{L}} = 0$

$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$$\mathcal{L}_M = -\Phi_H - H \frac{\delta p}{\rho + p}$$

$\mathcal{L}_i = \mathcal{L}_j \quad \forall i, j \Rightarrow$  adiabatic



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inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$$\Rightarrow \mathcal{L} = \psi$$



$$ds^2 = -(1+2A)dt^2 - 2a\partial(B)dt dx^i + a^2 \left[ \delta_{ij} (1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E \right] dx^i dx^j$$

$$v_B = ikB + \frac{k^i T_i^0}{k a (\rho + p)}$$

$$\Phi_H \equiv -\psi + aH \left( B - \frac{\partial E}{\partial \tau} \right)$$

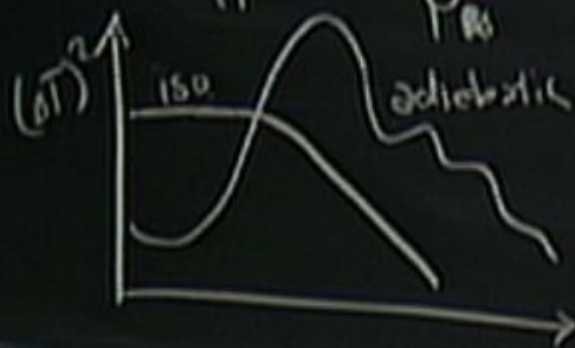
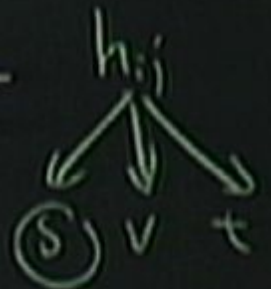
$$\mathcal{L} \equiv -\Phi_H - \frac{iaH}{k} v_B$$

Outside the horizon ( $k \ll aH$ )  $\mathcal{L} = 0$

$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$$\mathcal{L}_M = -\Phi_H - H \frac{\delta p_M}{\dot{\rho}_M}$$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic



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$$\mathcal{L} = 0 \Rightarrow \mathcal{L} = \psi$$



$$ds^2 = -(1+2A)dt^2 - 2a\partial(B)dbdx^i + a^2 \left[ \phi_0(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) E \right] dx^i dx^j$$

$$V_B = i\kappa B + \frac{k^i T^0_i}{2\rho(\rho+p)}$$

$$\Phi_H = -\psi + \frac{1}{2H} \left( B - \frac{\partial E}{\partial t} \right)$$

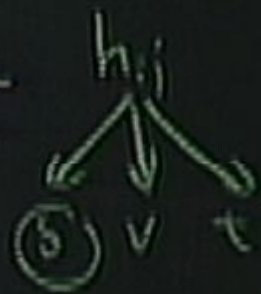
$$\mathcal{S} = -\Phi_H - \frac{i a H}{\kappa} \mathcal{V}_B$$

Outside the horizon ( $k \ll aH$ )  $\mathcal{S} = 0$

$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$$\mathcal{S}_M = -\Phi_H - H \frac{\delta p_{ij}}{\rho_{ij}}$$

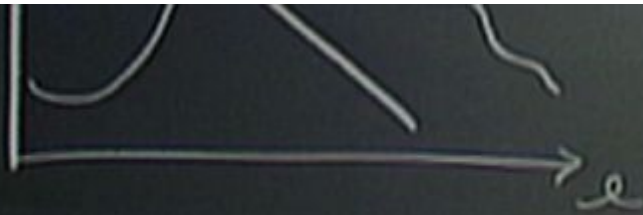
$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Leftrightarrow$  adiabatic



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inflation  $\delta\phi = 0$   
 $E = 0$

$$\Rightarrow \mathcal{S} = \psi$$

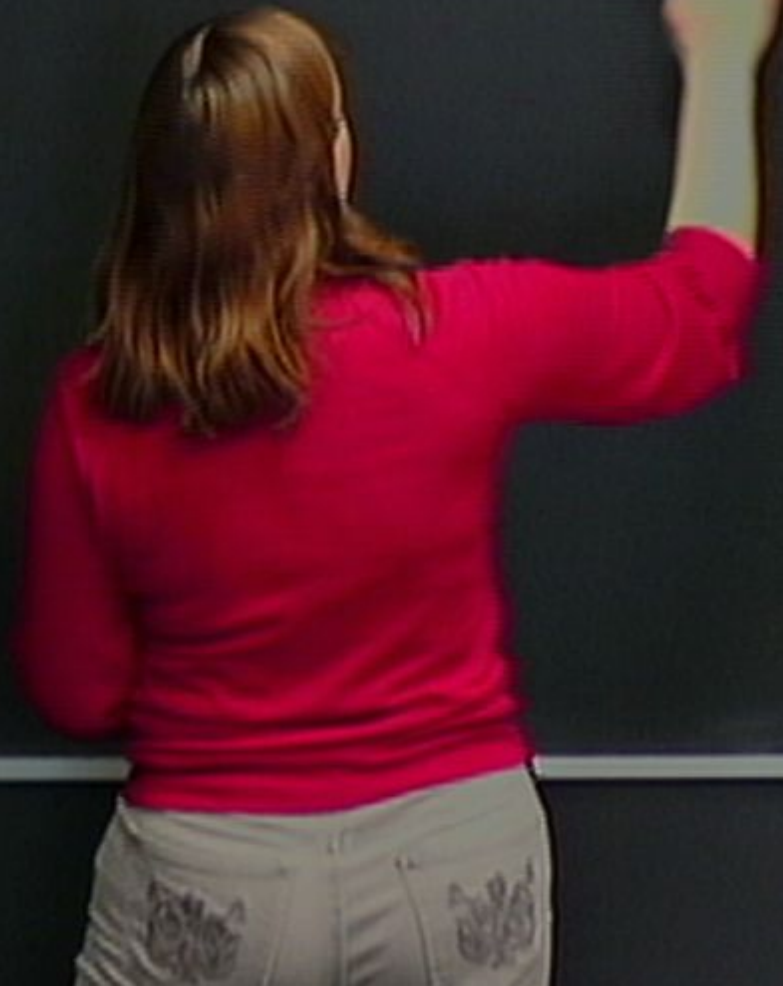


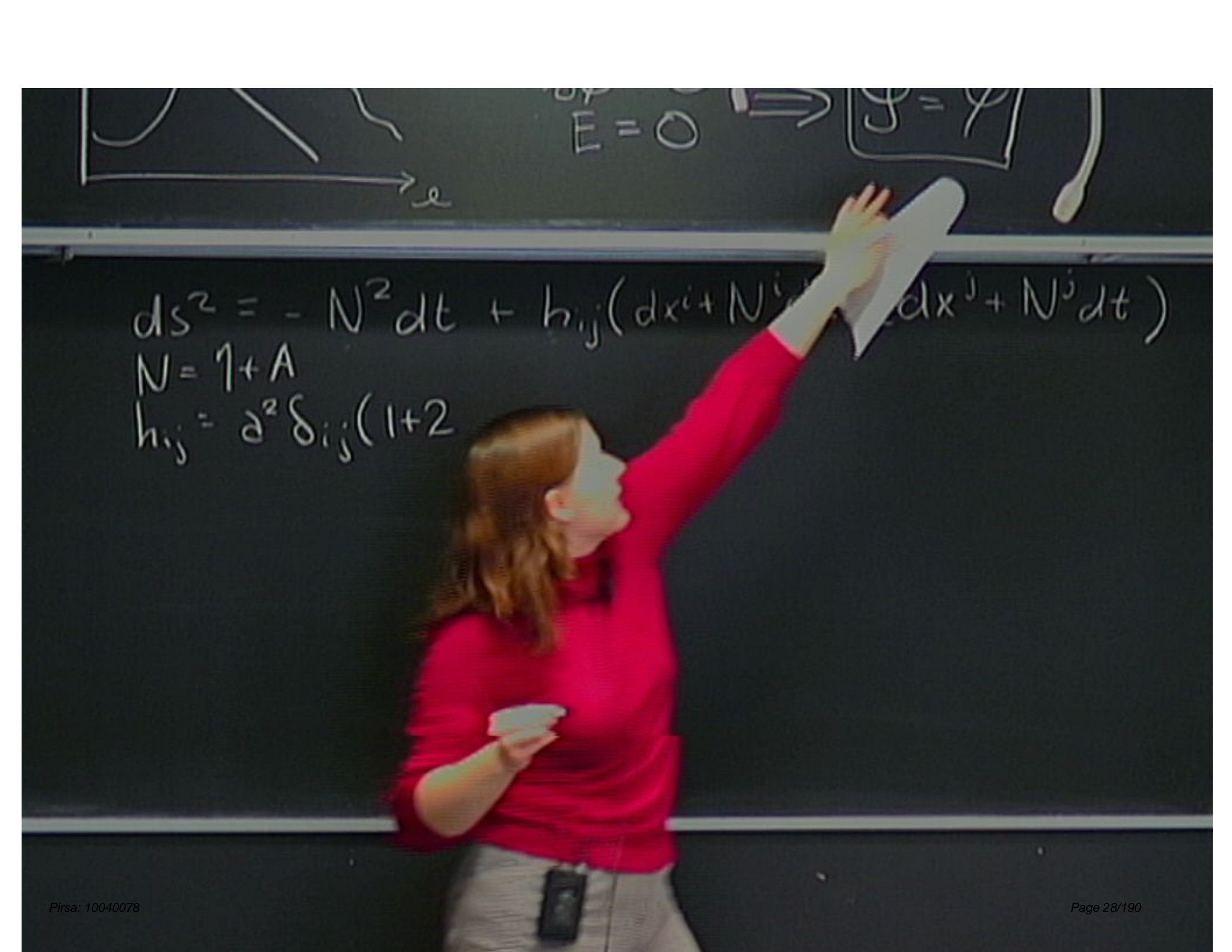
$$E=0$$



$$\boxed{\mathcal{L} = \mathcal{L}}$$

$$ds^2 = -N^2 dt^2 + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$





The image shows a woman with long brown hair, wearing a bright red sweater and light-colored pants, standing in front of a chalkboard. She is pointing her right hand towards the top right of the board. The chalkboard contains several mathematical expressions. At the top, there is a diagram of a coordinate system with an arrow labeled 'e'. To its right, the equation  $E=0$  is written, followed by an arrow pointing to a boxed equation  $\psi = \psi$ . Below these, the main equation for the metric tensor is written:  $ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$ . Underneath this, two more equations are written:  $N = 1 + A$  and  $h_{ij} = a^2 \delta_{ij} (1 + 2$ .

$$ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$
$$N = 1 + A$$
$$h_{ij} = a^2 \delta_{ij} (1 + 2$$

$$ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

$$N = 1 + A$$

$$h_{ij} = a^2 \delta_{ij} (1 + 2\mathcal{Y})$$

$$N^i = -\frac{1}{a} \partial^i B$$

inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$$\boxed{\mathcal{L} = \mathcal{L}}$$

$$t + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

29) 
$$S = \int \sqrt{-g} \left[ \frac{R}{16\pi G} - \frac{1}{2}(\nabla\phi)^2 - V(\phi) \right] d^4x$$

$m = -\frac{\Phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

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 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0 \Rightarrow \boxed{\mathcal{L} = \mathcal{Y}}$

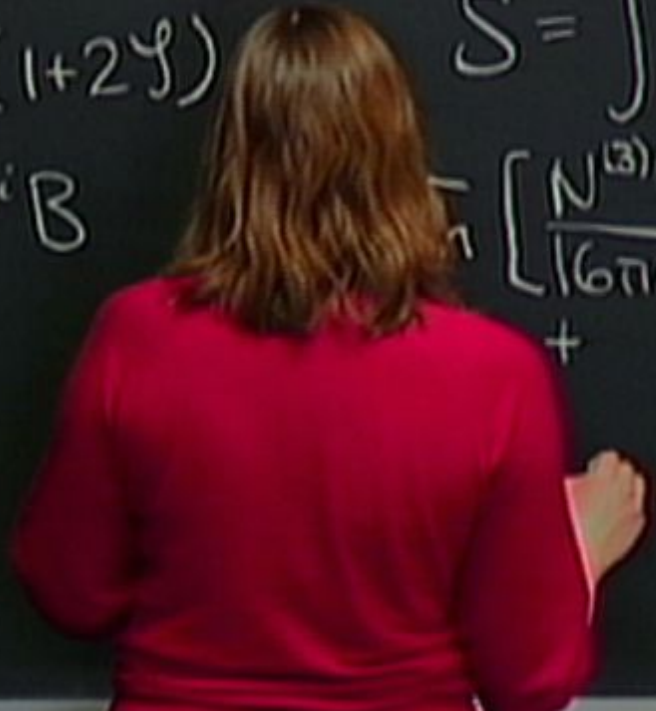
$h_{ij}$

ADM  $ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$

$N = 1 + A$   
 $h_{ij} = a^2 \delta_{ij} (1 + 2\mathcal{Y})$   
 $N^i = -\frac{1}{a} \partial^i B$

$S = \int \sqrt{-g} \left[ \frac{R}{16\pi G} - \frac{1}{2} (\nabla\phi)^2 - V(\phi) \right] d^4x$

$\mathcal{L} = \int \left[ \frac{N^{(3)} R}{16\pi G} - NV + \frac{1}{16\pi GN} (E_{ij} E^{ij} - E^2) \right]$



$m = -\frac{\Phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_i \forall i \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0 \Rightarrow \boxed{\mathcal{L} = \mathcal{L}}$

$h_{ij}$   
 $\downarrow$   
 $\downarrow$   
 $\downarrow$

ADM  $ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$

$N = 1 + A$   
 $h_{ij} = a^2 \delta_{ij} (\dots 2\mathcal{L})$   
 $N^i = -\dots$

$S = \int \sqrt{-g} \left[ \frac{R}{16\pi G} - \frac{1}{2}(\nabla\phi)^2 - V(\phi) \right] d^4x$

$S = \int \sqrt{h} \left[ \frac{N^{(3)}R}{16\pi G} - NV + \frac{1}{16\pi GN} (E_{ij}E^{ij} - E^2) + \frac{1}{2N}(\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \phi \partial_j \phi \right]$

$E_{ij}$



$m = -\frac{\Phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0 \Rightarrow \boxed{\mathcal{L} = \mathcal{Y}}$

$h_{ij}$   
 $\downarrow$   
 $\downarrow$   
 $\downarrow$   
 $t$

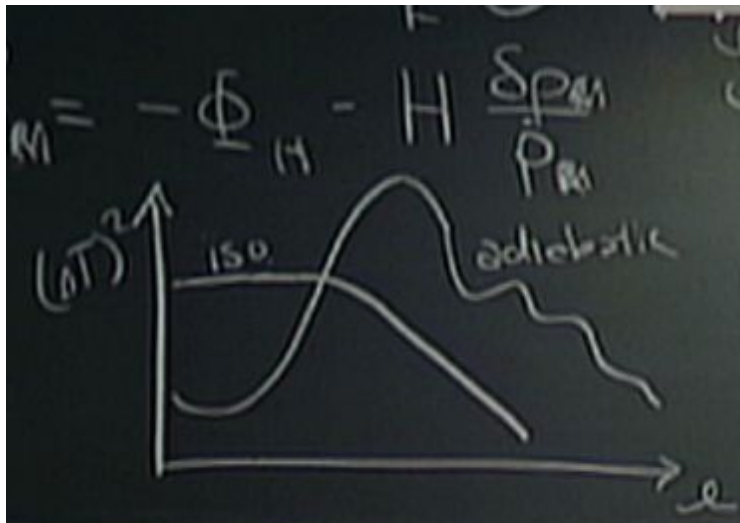
ADM  $ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$

$N = 1 + A$   
 $h_{ij} = \delta_{ij}(1 + 2\mathcal{Y})$

$S = \int \sqrt{-g} \left[ \frac{R}{16\pi G} - \frac{1}{2}(\nabla\phi)^2 - V(\phi) \right] d^4x$

$S = \int \sqrt{h} \left[ \frac{N^{(3)}R}{16\pi G} - NV + \frac{1}{16\pi GN} (E_{ij}E^{ij} - E^2) \right. \\ \left. + \frac{1}{2N} (\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \phi \partial_j \phi \right]$

$E_{ij} = \frac{1}{2} \dot{h}_{ij} - \nabla_i N_j - \nabla_j N_i$



$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002

inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $\downarrow$   
 $\otimes$   
 $\downarrow$   
 $t$

ADM  $ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$

$N = 1 + A$   
 $h_{ij} = a^2 \delta_{ij} (1 + 2\mathcal{Y})$   
 $N^i = -\frac{1}{a} \partial^i B$

$S = \int \sqrt{-g} \left[ \frac{R}{16\pi G} - \frac{1}{2} (\nabla\phi)^2 - V(\phi) \right] d^4x$

$S = \int \sqrt{h} \left[ \frac{N^{(3)}R}{16\pi G} - NV + \frac{1}{16\pi GN} (E_{ij}E^{ij} - E^2) + \frac{1}{2N} (\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \phi \partial_j \phi \right]$

$E_{ij} = \frac{1}{2} \dot{h}_{ij} - \nabla_i N_j - \nabla_j N_i$

$\mathcal{L} = -\dot{\phi}^2 - H^2 \frac{\delta p_{\text{eff}}}{\delta \dot{\phi}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
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$S = \int \sqrt{h} \left[ \frac{N^{(3)}R}{16\pi G} - NV + \frac{1}{16\pi GN} (E_{ij}E^{ij} - E^2) \right. \\ \left. + \frac{1}{2N} (\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \phi \partial_j \phi \right]$

$E_{ij} = \frac{1}{2} \dot{h}_{ij} - \nabla_i N_j - \nabla_j N_i$   
 $E = E^i_i$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$m = -\frac{\Phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
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$h_{ij}$

ADM  $ds^2 = -N^2 dt + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$

$N = 1 + A$   
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 $N^i = -\frac{1}{a} \partial^i B$

$S = \int \sqrt{-g} \left[ \frac{R}{16\pi G} - \frac{1}{2} (\nabla\phi)^2 - V(\phi) \right] d^4x$

$S = \int \sqrt{h} \left[ \frac{N^{(3)}R}{16\pi G} - NV + \frac{1}{16\pi GN} (E_{ij}E^{ij} - E^2) + \frac{1}{2N} (\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \phi \partial_j \phi \right]$

$E_{ij} = \frac{1}{2} \dot{h}_{ij} - \nabla_i N_j - \nabla_j N_i$   
 $E = E^i_i$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\phi}}{H}$$

$$B = \frac{1}{a} \frac{\dot{\phi}}{H} - a \nabla^{-2}$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\phi}}{H}$$

$$B = \frac{1}{a} \frac{\dot{\phi}}{H} - 2\nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\phi} \right) (8\pi G)^3$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\phi}}{H}$$

$$B = \frac{1}{a} \frac{\dot{\phi}}{H} - 2\nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\phi} \right) (8\pi G)^3$$



$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\varphi}}{H}$$

$$B = \frac{1}{a} \frac{\dot{\varphi}}{H} - a \nabla^{-2} \left( \frac{\dot{\varphi}^2}{2H^2} \dot{\varphi} \right) (8\pi G)^3$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\varphi}^2}{H^2} \left[ a^3 \dot{\varphi}^2 - a (\dot{\nabla} \varphi)^2 \right]$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical  
 $A = \frac{\dot{\phi}}{H}$      $B = \frac{1}{a} \frac{\dot{\phi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\phi} \right) (8\pi G)^3 \quad \ddot{\phi} + 3H\dot{\phi} + V' = 0$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\phi}^2 - a (\dot{\nabla} \phi)^2 \right]$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical  
 $A = \frac{\dot{\phi}}{H}$      $B = \frac{1}{a} \frac{\dot{\phi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\phi} \right) (8\pi G)^3 \quad \ddot{\phi} + 3H\dot{\phi} + V' = 0$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\phi}^2 - a (\dot{\nabla}\phi)^2 \right]$$



$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical  
 $A = \frac{\dot{\phi}}{H}$      $B = \frac{1}{a} \frac{\dot{\phi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^4} \dot{\phi} \right) (8\pi G)^3$      $\ddot{\phi} + 3H\dot{\phi} + V' = 0$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\phi}^2 - a (\dot{\nabla}\phi)^2 \right]$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical  
 $A = \frac{\dot{\varphi}}{H}$      $B = \frac{1}{a} \frac{\dot{\varphi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\varphi} \right) (8\pi G)^3$      $\ddot{\phi} + 3H\dot{\phi} + V' = 0$

$$\begin{aligned}
 S &= \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\varphi}^2 - a (\dot{\nabla}\varphi)^2 \right] \\
 &- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\varphi} \right) + a \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \varphi \right) = 0
 \end{aligned}$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\varphi}}{H} \quad B = \frac{1}{a} \frac{\dot{\varphi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\varphi} \right) (8\pi G)^3 \quad \underline{\underline{\ddot{\phi} + 3H\dot{\phi} + V' = 0}}$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\varphi}^2 - a (\nabla \varphi)^2 \right]$$

$$- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\varphi} \right) + a \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \varphi \right) = 0$$

$\Rightarrow$

$$\frac{\dot{\phi}^2}{H^2}$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\varphi}}{H} \quad B = \frac{1}{a} \frac{\dot{\varphi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\varphi} \right) (4\pi G)^3 \quad \underline{\underline{\dot{\phi} + 3H\dot{\phi} + V' = 0}}$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\varphi}^2 - a (\dot{\nabla} \varphi)^2 \right]$$

$$- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\varphi} \right) + a \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \varphi \right) = 0$$

$$E_H = 4\pi G \frac{\dot{\phi}^2}{H^2}$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\varphi}}{H} \quad B = \frac{1}{a} \frac{\varphi}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\varphi} \right) (4\pi G)^3 \quad \dot{\phi} + 3H\phi + V' = 0$$

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$$- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\varphi} \right) + a \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \varphi \right) = 0$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \dot{\epsilon}_H = 2H\epsilon(\epsilon - \eta) \ll 1$$



$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\phi}}{H} \quad B = \frac{1}{a} \frac{\dot{\phi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\phi} \right) (4\pi G)^3 \quad \dot{\phi} + 3H\dot{\phi} + V' = 0$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\phi}^2 - a (\nabla \dot{\phi})^2 \right]$$

$$- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\phi} \right) + a \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \dot{\phi} \right) = 0$$

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$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\varphi}}{H} \quad B = \frac{1}{a} \frac{\dot{\varphi}}{H} - a \nabla^{-2} \left( \frac{\dot{\phi}^2}{2H'} \dot{\varphi} \right) (8\pi G)^3 \quad \underline{\dot{\phi} + 3H\phi + V' = 0}$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\varphi}^2 - a (\nabla \varphi)^2 \right]$$

$$- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\varphi} \right) + a \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \varphi \right) = 0$$

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$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\varphi}^2 - a (\nabla \varphi)^2 \right] \quad f \equiv \frac{\dot{\phi}}{H} \varphi \propto \sqrt{\epsilon_H} \varphi$$

$$- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\varphi} \right) + 2\nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \varphi \right) = 0$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1$$

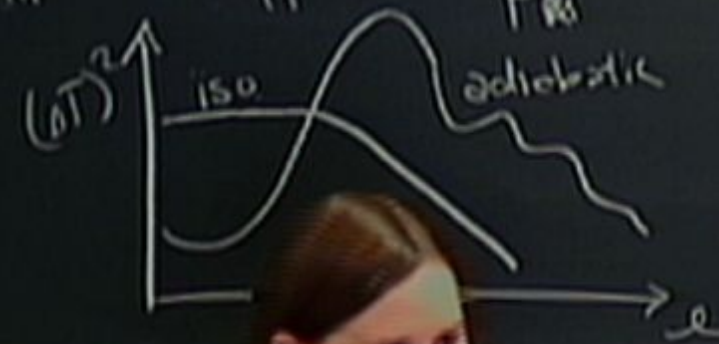
$$\dot{\epsilon}_H = 2H\epsilon(\epsilon - \eta) \ll 1$$

$$= -(1+2A)dt^2 - 2a\partial(B)dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2)\psi] dx^i dx^j$$

$$= ikB + \frac{k_i T_i}{k a(\rho+p)}$$

$$= -\Phi_H - \frac{iaH}{k} v_B$$

$$= -\Phi_H - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$$



$$\Phi_H = -\psi + aH(\beta - \frac{\partial \psi}{\partial \tau})$$

Outside the horizon ( $k \ll aH$ )  $f = 0$

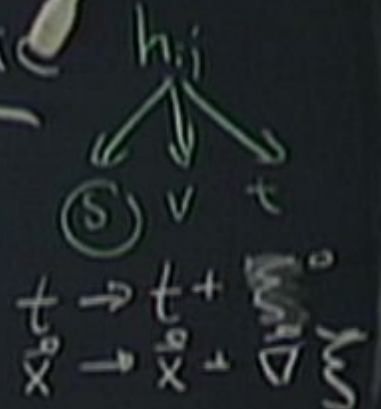
$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldecena 2002

inflation  $\delta \phi = 0$   
 $E = 0 \Rightarrow$

$$\mathcal{L} = \psi$$



$$E_{ij} = \frac{1}{2} \dot{h}_{ij} - \nabla_i N_j - \nabla_j N_i + \frac{1}{2N} (\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \partial_j \phi$$

$$E = E^i_i$$

$$= -(1+2A)dt^2 - 2a\partial(B)dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2)\psi] dx^i dx^j$$

$$= ikB + \frac{k^i T_i^0}{ka(\rho+p)}$$

$$\Phi_H = -\psi + aH(\psi - \frac{\partial\psi}{\partial t})$$

Outside the horizon ( $k \ll aH$ )  $\mathcal{S} = 0$   
 $p = w\rho \Rightarrow \delta p = w \delta\rho$

$$= -\Phi_H - \frac{iaH}{k} \psi_B$$

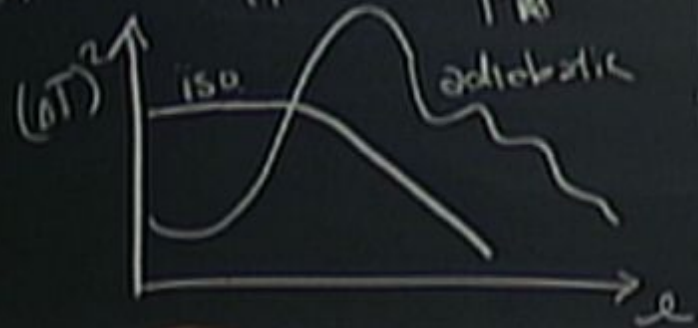
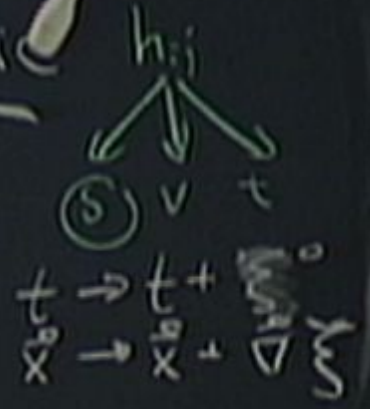
$$\mathcal{S}_M = -\Phi_H - H \frac{\delta p_M}{\dot{\rho}_M}$$

$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002

inflation  $\delta\phi = 0$   
 $E = 0 \Rightarrow$

$$\mathcal{S} = \psi$$



$$E_{ij} = \frac{1}{2} \dot{h}_{ij} - \nabla_i N_j - \nabla_j N_i + \frac{1}{2N} (\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \partial_j \phi$$

$$E = E^i_i$$

$$= -(1+2A)dt^2 - 2a\partial(B)dt dx^i + a^2[\delta_{ij}(1+2\psi) - 2(\nabla_i \nabla_j - \frac{1}{3}\nabla^2)\psi] dx^i dx^j$$

$$= ikB + \frac{k^i T_i^0}{ka(\rho+p)}$$

$$\Phi_H = -\psi + aH(\psi - \frac{\partial \psi}{\partial t})$$

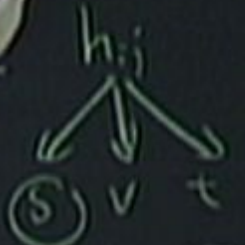
Outside the horizon ( $k \ll aH$ )  
 $p = w\rho \Rightarrow \delta p = w \delta \rho$

$$\mathcal{L} = 0$$

$$= -\Phi_H - \frac{iaH}{k} (V_B)$$

$$S_M = -\Phi_H - H \frac{\delta p_M}{\dot{\rho}_M}$$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

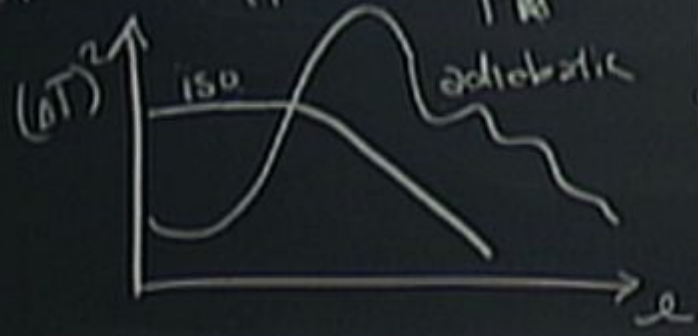


Maldacena 2002

inflation  $\delta\phi = 0$   
 $E = 0$

$$\mathcal{L} = \psi$$

$$\begin{matrix} t \rightarrow t + \Delta t \\ x^a \rightarrow x^a + \Delta x^a \end{matrix}$$



$$E_{ij} = \frac{1}{2} h_{ij} - \nabla_i N_j - \nabla_j N_i + \frac{1}{2N} (\dot{\phi} - N^i \partial_i \phi)^2 - N h^{ij} \partial_i \phi \partial_j \phi$$

$$E = E^i_i$$

$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$A = \frac{\dot{\varphi}}{H} \quad B = \frac{1}{a} \frac{\dot{\varphi}}{H} - 2\nabla^{-2} \left( \frac{\dot{\phi}^2}{2H'} \dot{\varphi} \right) (8\pi G)^3 \quad \dot{\phi} + 3H\phi + V' = 0$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\varphi}^2 - a (\nabla \varphi)^2 \right]$$

$$f \equiv \frac{\dot{\phi}}{H} \varphi \propto \sqrt{\epsilon_H} \varphi$$

$$\dot{f} = \frac{\dot{\phi}}{H} \dot{\varphi}$$

$$- \frac{1}{2} \int d^4x \left( \frac{\dot{\phi}^2}{H^2} \right) + 2\nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \varphi \right) = 0$$

$$\frac{\dot{\phi}^2}{H^2} \ll 1$$

$$\dot{\epsilon}_H = 2H\epsilon(\epsilon - \eta) \ll 1$$

$$= -(1+2A) \dot{\psi}^2 - 2a\dot{a}(\dot{B} + \dot{\psi}) + a^2 \left[ \delta_{ij} (\dot{\psi} + \dot{B})^2 - 2(\nabla_i \nabla_j - \frac{1}{3} \nabla^2) \psi \right] dx^i dx^j$$

$$= ikB + \frac{k^i \nabla_i \psi}{ka(\rho+p)}$$

$$\Phi_H \equiv -\psi + aH(B - \frac{\dot{\psi}}{aH})$$

Outside the horizon ( $k \ll aH$ )  $\boxed{j=0}$

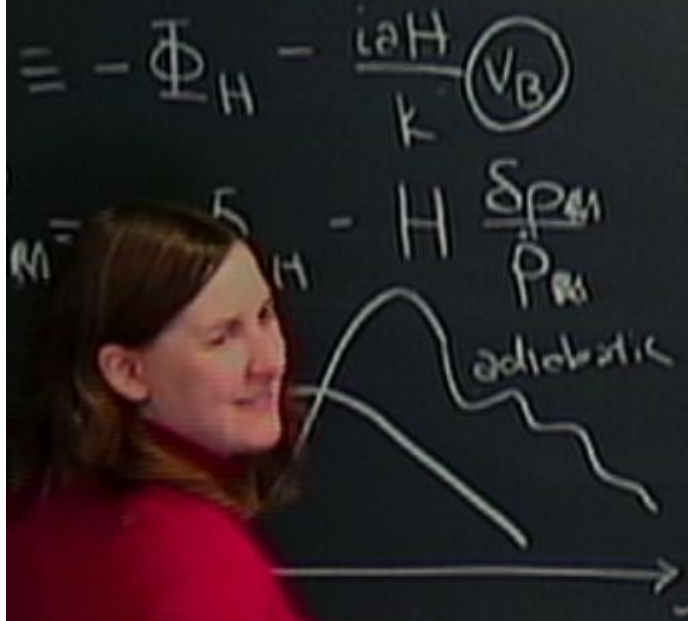
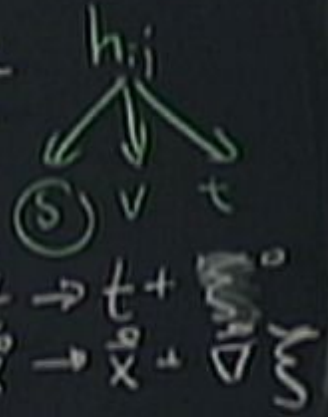
$$p = w\rho \Rightarrow \delta p = w \delta \rho$$

$\delta_i = \delta_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002

inflaton  $\delta\phi = 0$   
 $E = 0 \Rightarrow$

$$\boxed{\delta = \psi}$$





$$\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \right) + 2\pi^2 \left( \frac{\dot{\phi}}{H^2} \right) = 0$$

$$\dot{f} = \frac{\dot{\phi}}{H} \dot{\phi}$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1$$

$$\epsilon'_H = 2H\dot{\phi} (\epsilon - \eta) \ll 1$$

$$S = \frac{1}{2} \int dt d^3x \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f)^2 \right]$$

$$\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \right) + 2\dot{\eta}^2 \left( \frac{\phi}{H^2} \right) = 0$$

$$\dot{f} = \frac{\dot{\phi}}{H} \dot{\eta}$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1$$

$$\epsilon_H = 2H\dot{\eta} (\epsilon - \eta) \ll 1$$

$$S = \frac{1}{2} \int dt d^3x \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f)^2 \right]$$

$dt = a dt$        $d^4x = dt d^3x$

$$\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \right) + a^2 \nabla^2 \left( \frac{\phi}{H^2} \right) = 0 \quad \dot{f} = \frac{\dot{\phi}}{H^2}$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H^2 (k - \epsilon) \ll 1$$

$$S = \frac{1}{2} \int dt d^3x \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f)^2 \right]$$

$$\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \right) + 2\pi^2 \left( \frac{\dot{\phi}}{H^2} \right) = 0 \quad \dot{f} = \frac{\dot{\phi}}{H} \dot{f}$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H^2 (\epsilon - \eta) \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f)^2 \right]$$

$$\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \right) + 2\pi^2 \left( \frac{\dot{\phi}}{H^2} \right) = 0 \quad \left| \quad \dot{f} = \frac{\dot{\phi}}{H} \right.$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H^2 \left( \frac{\dot{\phi}}{H} \right)^2 \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f)^2 \right]$$

$$d^4x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \right) + 2\pi^2 \left( \frac{\dot{\phi}}{H^2} \right) = 0 \quad \dot{f} = \frac{\dot{\phi}}{H} \dot{\phi}$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H^2 \left( \frac{\dot{\phi}}{H} \right)^2 \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ a^3 \dot{f}^2 - a \left( a_{\text{comoving}} f \right)^2 \right]$$

$$d\tau d^3x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ a^2 (f')^2 - a^2 \left( a_{\text{comoving}} f \right)^2 \right]$$

$$-\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \partial^3 \phi \right) + 2\pi^2 \left( \frac{\dot{\phi}^2}{H^2} \phi \right) = 0 \quad \text{with } \dot{f} = \frac{\dot{\phi}}{H} \phi$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\dot{\phi}(\epsilon - \eta) \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4 x}{dt d^3 x} \left[ \partial^3 \dot{f}^2 - a (\partial_{\text{comoving}} f)^2 \right]$$

$$d\tau d^3 x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$S = \frac{1}{2} \int d\tau d^3 x \left[ \partial^2 (f')^2 - a^2 (\partial_{\text{comoving}} f)^2 \right]$$

$$-\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \partial^3 \phi \right) + 2\dot{\phi}^2 \left( \frac{\dot{\phi}}{H^2} \phi \right) = 0 \quad \dot{\phi} = \frac{\partial \phi}{\partial \tau}$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\dot{\phi} \left( \frac{\dot{\phi}}{H^2} \right) \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4 x}{dt d^3 x} \left[ \partial^3 \dot{f}^2 - a (\partial_{\text{comoving}} f)^2 \right]$$

$$d\tau d^3 x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$S = \frac{1}{2} \int d\tau d^3 x \left[ \partial^2 (f')^2 - a^2 (\partial_{\text{comoving}} f)^2 \right]$$



$$-\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \partial^3 \phi \right) + 2\dot{\phi}^2 \left( \frac{\phi}{H^2} \right) = 0 \quad \dot{f} = \frac{\dot{\phi}}{H \phi}$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\dot{\phi} \left( \frac{\epsilon - \eta \right) \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4 x}{dt d^3 x} \left[ \partial^3 \dot{f}^2 - a (\partial_{\text{comoving}} f)^2 \right]$$

$d\tau d^3 x \Rightarrow f' \equiv \frac{df}{d\tau}$

$$S = \frac{1}{2} \int d\tau d^3 x \left[ \partial^2 (f')^2 - a^2 (\partial_{\text{comoving}} f)^2 \right]$$

$$-\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \partial^3 \phi \right) + 2\dot{\phi}^2 \left( \frac{\dot{\phi}}{H^2} \phi \right) = 0 \quad \dot{f} = \frac{\dot{\phi}}{H^2} \phi$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\dot{\phi}(\epsilon - \eta) \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4 x}{dt d^3 x} \left[ \partial^3 \dot{f}^2 - a (\partial_{\text{comoving}} f)^2 \right]$$

$$d\tau d^3 x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$S = \frac{1}{2} \int d\tau d^3 x \left[ \partial^2 (f')^2 - a^2 (\partial_{\text{comoving}} f)^2 \right]$$

$$\dot{f} \equiv \frac{\dot{\phi}}{H^2} \phi$$

$$-\frac{d}{dt} \left( \frac{\dot{\phi}}{H^2} \partial^3 \psi \right) + 2\nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \psi \right) = 0$$

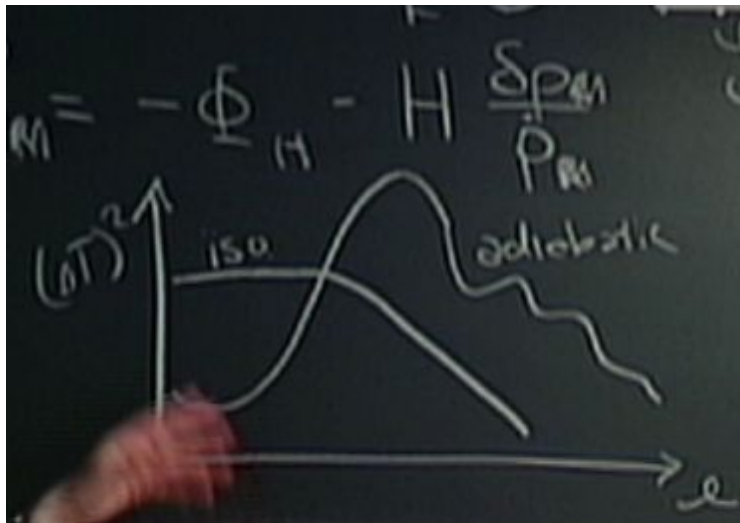
$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \dot{\epsilon}_H = 2H\dot{\epsilon}(\epsilon - \eta) \ll 1 \quad \bar{f} = \frac{\dot{\phi}}{H} \psi$$

$$S = \frac{1}{2} \int \frac{d^4 x}{dt d^3 x} \left[ \partial^3 \bar{f}^2 - a (\partial_{\text{comoving}} \bar{f})^2 \right]$$

$$d\tau d^3 x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$S = \frac{1}{2} \int d\tau d^3 x \left[ \partial^2 (f')^2 - a^2 (\partial_{\text{comoving}} f')^2 \right]$$

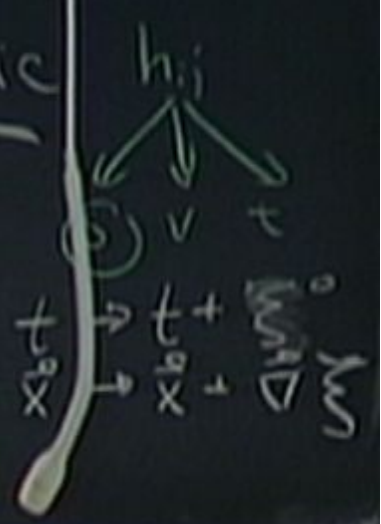
$$\bar{f} \equiv \frac{\dot{\phi}}{H} \psi$$



$\mathcal{L}_i = \mathcal{L}_i \quad \forall i \Rightarrow \text{adiabatic}$

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$



$\delta g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$

$m = -\frac{\phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_i \quad \forall i \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^a t^+$   
 $x^b t^+$   
 $x^c t^+$   
 $\Delta_{ij}$   
 $\mu_{ij}$

$\delta g_{\mu\nu} = h_{\mu\nu}$

A person in a red shirt is writing on the chalkboard. The rest of the board is mostly blank with some faint, illegible markings.

$\mathcal{L} = -\dot{\phi}^2 - H^2 \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_j \quad \forall i, j \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^{\text{pert}}$   
 $x^{\text{b.t.}}$   
 $\Delta_{\text{MSW}}$   
 $\mu_{\text{S}}$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_\times & 0 \\ 0 & h_\times & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$



$m = -\frac{\Phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_i \forall i \Rightarrow$  adiabatic

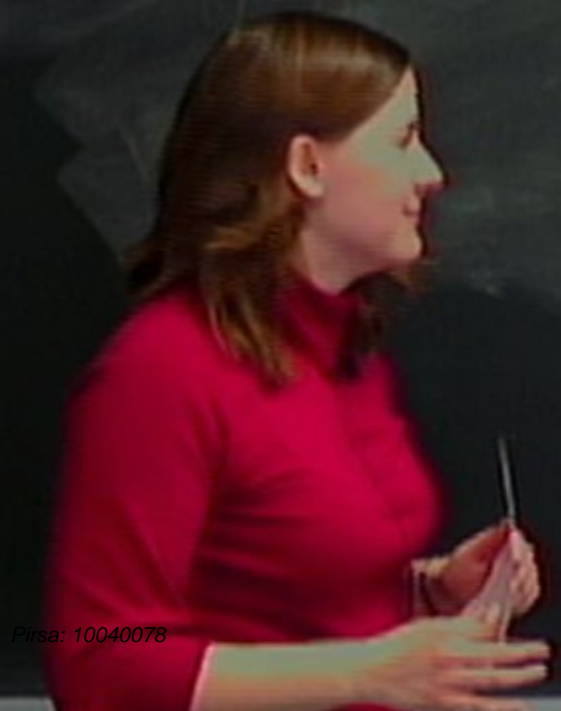
Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{L}$

$h_{ij}$   
 $x^a$   
 $x^b$   
 $x^c$   
 $x^d$   
 $x^e$   
 $x^f$   
 $x^g$   
 $x^h$   
 $x^i$   
 $x^j$   
 $x^k$   
 $x^l$   
 $x^m$   
 $x^n$   
 $x^o$   
 $x^p$   
 $x^q$   
 $x^r$   
 $x^s$   
 $x^t$   
 $x^u$   
 $x^v$   
 $x^w$   
 $x^x$   
 $x^y$   
 $x^z$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_\times & 0 \\ 0 & h_\times & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$



$\mathcal{L} = -\dot{\phi}^2 - H^2 \frac{\rho_{\text{pl}}}{\dot{\rho}_{\text{pl}}}$

$\mathcal{L}_i = \mathcal{L}_j \quad \forall i, j \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^{\mu} \rightarrow x^{\nu}$   
 $\Delta$   
 $\mu, \nu$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$S_h = \frac{1}{64\pi G} \int d^3x (h^i_j h^j_i)$

A woman in a red shirt is standing in front of the chalkboard, holding a clipboard and looking at the equations.



$m = -\frac{\phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\rightarrow \delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^a t^+$   
 $x^b t^+$   
 $x^c t^+$   
 $\Delta_{ij}$   
 $\Delta_{ij}$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x (h^i_j h^j_i - \dots)$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$\nabla_{\mu}^2 h_{\mu\nu} = \dots$

A person in a red shirt is writing on the chalkboard.

$m = -\frac{\Phi}{H} - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_i \forall i \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^{\text{act}}$   
 $x^{\text{bt}}$   
 $x^{\text{t}}$   
 $x^{\text{D}}$   
 $x^{\text{S}}$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$S_h = \frac{1}{64\pi} \int dt d^3x \left( \dot{h}^i_j \dot{h}^j_i - \left( \nabla_e^{\text{phys}} h^i_j \right) \left( \nabla^e_{\text{phys}} h^j_i \right) \right)$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$x$

A woman in a red top is pointing at the chalkboard.

$\mathcal{L} = -\Phi_H - H \frac{\delta p_{\text{eff}}}{\delta \dot{\phi}}$

$\mathcal{L}_i = \mathcal{L}_j \quad \forall i, j \Rightarrow$  adiabatic

Maldecena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_i = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^i t + x^j t + \dots$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_\times & 0 \\ 0 & h_\times & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_{ij} \dot{h}_{ij} - \left( \nabla_e^{\text{phys}} h_{ij} \right) \left( \nabla_e^{\text{phys}} h_{ij} \right) \right)$

x

$\mathcal{L} = -\dot{\phi}^2 - H \frac{\delta p_{\text{eff}}}{\delta \dot{\phi}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldecena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_* = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^a t$   
 $x^b t$   
 $x^c t$   
 $\Delta_{\text{phys}}$   
 $\Delta_{\text{phys}}$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_{ij} \dot{h}_{ij} - \left( \nabla_e^{\text{phys}} h_{ij} \right) \left( \nabla_e^{\text{phys}} h_{ij} \right) \right)$

$h_{ij} \dot{h}_{ij} = 2\dot{h}_+^2 + 2\dot{h}_x^2$

x

$\mathcal{L} = -\dot{\phi}^2 - H^2 \frac{\delta p_{\text{eff}}}{\delta \dot{\phi}}$

$\mathcal{L}_i = \mathcal{L}_j \quad \forall i, j \Rightarrow$  adiabatic

Maldecena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_i = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^a t$   
 $x^b t$   
 $x^c t$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_{ij} \dot{h}^{ij} - \left( \nabla_e^{\text{phys}} h_{ij} \right) \left( \nabla^e h^{ij} \right) \right)$

$h_{ij} h^{ij} = 2h_+^2 + 2h_x^2$

$\rho = -\Phi_H - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L} = \mathcal{L}_s \quad \forall i \Rightarrow$  adiabatic

Maldecena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_* = a\vec{x} \quad E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^a t$   
 $x^b t$   
 $x^c t$   
 $\Delta_{\text{phys}}$   
 $\Delta_{\text{phys}}$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_{ij} \dot{h}_{ij} - \left( \nabla_e^{\text{phys}} h_{ij} \right) \left( \nabla_{\text{phys}}^e h_{ij} \right) \right)$

$h_{ij} h_{ij} = 2h_+^2 + 2h_x^2$

$\mathcal{L} = -\dot{\phi}^2 - H^2 \frac{\delta p_{\text{eff}}}{\delta \dot{\phi}^2}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldecena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_i = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^0 t$   
 $x^1 t$   
 $x^2 t$   
 $x^3 t$   
 $x^0 x^1$   
 $x^0 x^2$   
 $x^0 x^3$   
 $x^1 x^2$   
 $x^1 x^3$   
 $x^2 x^3$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_{ij} \dot{h}_{ij} - \left( \nabla_e^{\text{phys}} h_{ij} \right) \left( \nabla_e^{\text{phys}} h_{ij} \right) \right)$

$h_{ij} h_{ij} = 2h_+^2 + 2h_x^2$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$$\delta g_{\mu\nu} = h_{\mu\nu}$$

$$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x (h_{ij})$$

$$h_{ij} = 2h_{tt} + 2h_{xx}$$

$$= \frac{1}{32\pi G} \int$$



$$\delta g_{\mu\nu} = h_{\mu\nu}$$

$$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_{ij} \dot{h}_{ij} - \left( \nabla_e^{\text{phys}} \right)^2 h_{ij} \right)$$

$$h_{ij} \dot{h}_{ij} = 2\dot{h}_+^2 + 2\dot{h}_x^2$$

$$S_h = \frac{1}{32\pi G} \int$$

$$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & h_+ & h_x \\ 0 & 0 & h_+ & h_x \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

$$\delta g_{\mu\nu} = h_{\mu\nu}$$

$$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x (h^i_j h^j_i - (\nabla_e^{\text{phys}} h^i_j)(\nabla_e^{\text{phys}} h^j_i))$$

$$h^i_j h^j_i = 2h^+_t h^-_t + 2h^+_x h^-_x$$

$$S_h = \frac{1}{32\pi G} \int$$

$$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & h^+_t & h^-_t & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

$$\delta g_{\mu\nu} = h_{\mu\nu}$$

$$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_{ij} \dot{h}_{ij} - \left( \nabla_e^{\text{phys}} h_{ij} \right) \left( \nabla_e^e h_{ij} \right) \right)$$

$$h_{ij} \dot{h}_{ij} = 2\dot{h}_+ \dot{h}_+ + 2\dot{h}_x \dot{h}_x$$

$$S_h = \frac{1}{32\pi G} \int$$

$$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & h_+ & 0 \\ 0 & 0 & 0 & h_x \end{pmatrix}$$

$M = -\Phi_H - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldecena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_i = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^a t$   
 $x^b t$   
 $x^c t$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$S_h = \frac{1}{64\pi G} \int d^3x dt \left( \dot{h}_i^j \dot{h}_j^i - \left( \nabla_e^{\text{phys}} h_i^j \right) \left( \nabla_{\text{phys}}^e h_j^i \right) \right)$

$h_i^j h_j^i = 2h_+^2 + 2h_x^2$

$S_h = \frac{1}{32\pi G} \int dt d^3\vec{r} \left( \dot{h}^2 - \left( \nabla_{\text{phys}}^e h \right)^2 \right)$

$\mathcal{L} = -\dot{\phi}^2 - H^2 \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L}_i = \mathcal{L}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r} = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^{\text{act}}$   
 $x^{\text{bct}}$   
 $\Delta_{\text{phys}}$   
 $\Delta_{\text{fid}}$

$\delta g_{\mu\nu} = h_{\mu\nu}$

$h_{\mu\nu} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_x & 0 \\ 0 & h_x & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$

$S_h = \frac{1}{64\pi G} \int a^3 dt d^3x \left( \dot{h}_i^j \dot{h}_j^i - \left( \nabla_e^{\text{fid}} h_i^j \right) \left( \nabla_{\text{phys}}^e h_j^i \right) \right)$

$h_i^j h_j^i = 2h_+^2 + 2h_x^2$

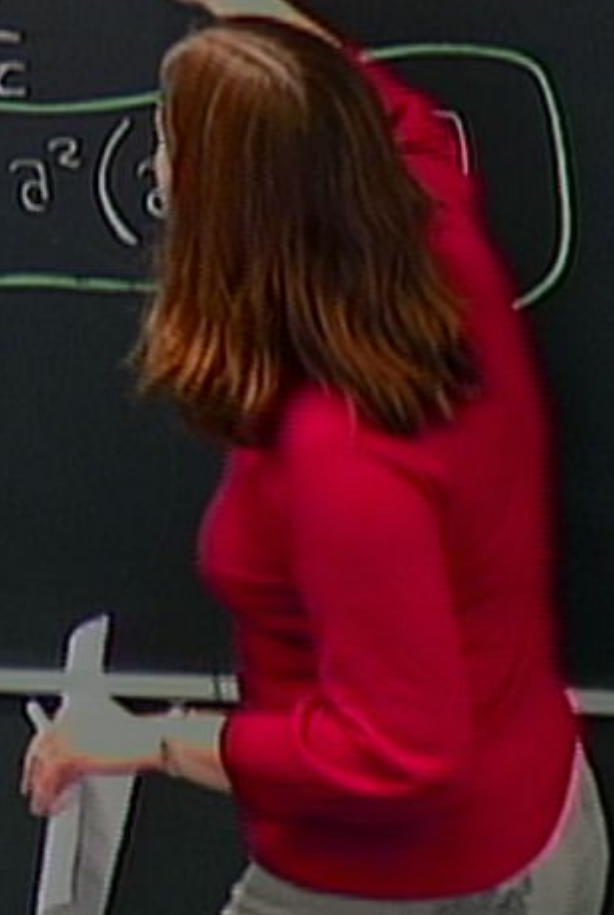
$S_h = \frac{1}{32\pi G} \int dt d^3\vec{r} \left( \dot{h}^2 - \left( \nabla_{\text{phys}}^e h \right)^2 \right) \quad f = \frac{h}{\sqrt{16\pi G}}$

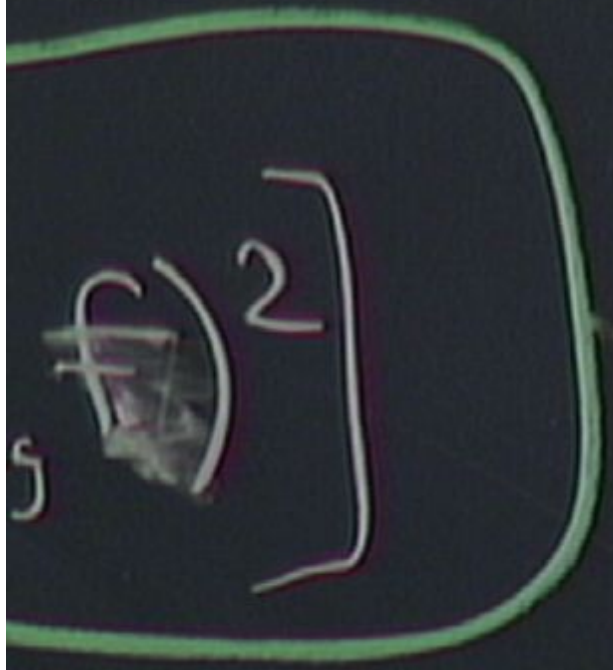
$$S = \frac{1}{2} \int \underbrace{d^4x}_{dt d^3x} \left[ a^3 \dot{f}^2 - a \left( \partial_{\text{comoving}} f \right)^2 \right]$$

$$d\tau d^3x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ a^2 (f')^2 - a^2 \left( \partial_{\text{comoving}} f \right)^2 \right]$$

$$f' \equiv \frac{df}{d\tau}$$

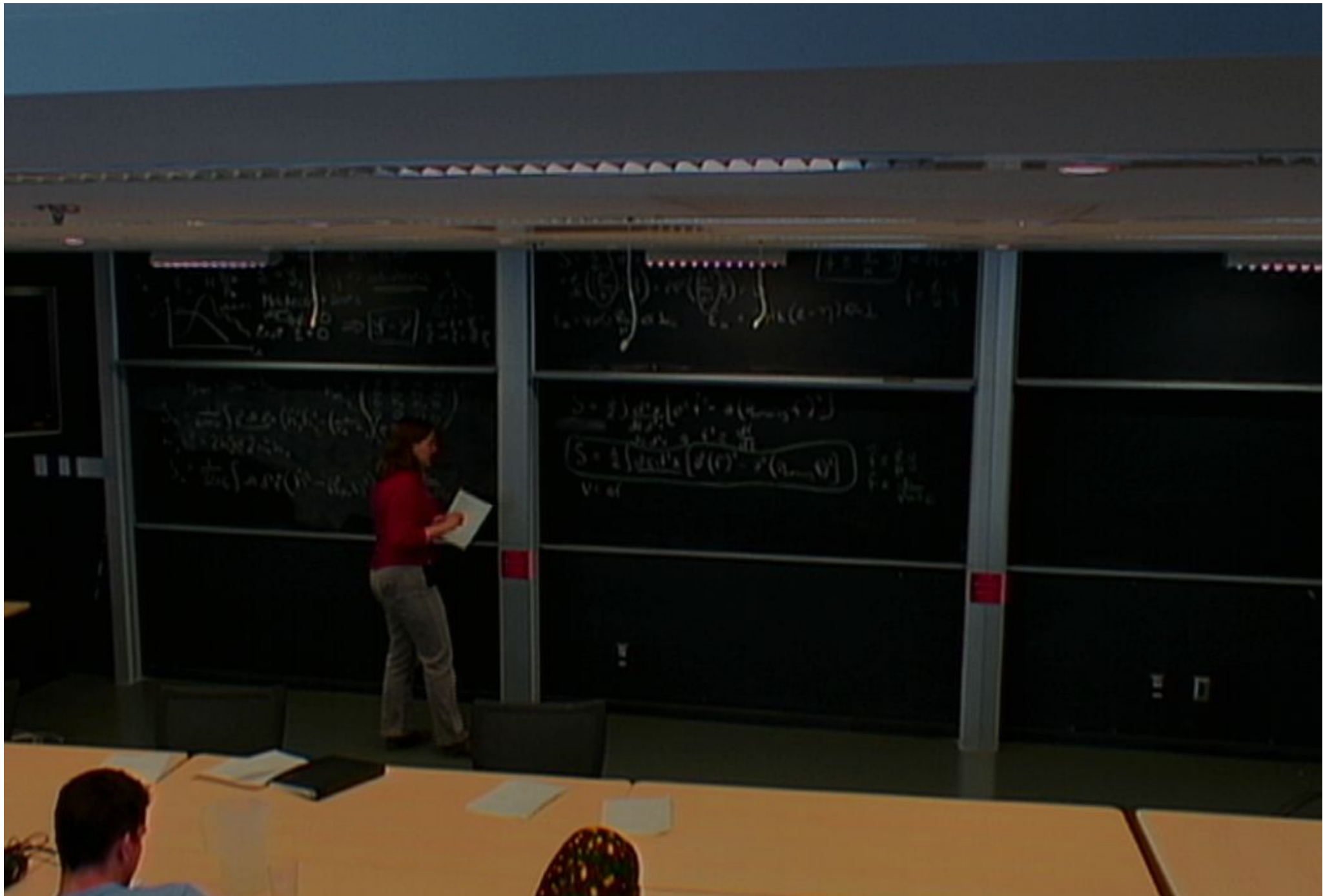




$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$   
 $\frac{1}{f} = \frac{1}{\infty} + \frac{1}{v}$   
 $\frac{1}{f} = 0 + \frac{1}{v}$   
 $\frac{1}{f} = \frac{1}{v}$   
 $v = f$







$$-\frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} \partial^3 \psi \right) + 2H^2 \left( \frac{\dot{\phi}^2}{H^2} \psi \right) = 0$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1$$

$$\beta_H = 2H^2 (\epsilon - \eta) \ll 1$$

$$f = \frac{\dot{\phi}}{H} \psi$$

$$S = \frac{1}{2} \int \frac{d^4 x}{dt d^3 x} \left[ \partial^3 \dot{f}^2 - \partial (\partial_{\text{comoving}} f)^2 \right]$$

$$d\tau d^3 x \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$\frac{1}{2} \int d\tau d^3 x \left[ \partial^2 (f')^2 - \partial^2 (\partial_{\text{comoving}} f)^2 \right]$$

$$f' \equiv \frac{\dot{\phi}}{H} \dot{\psi}$$

$$f \equiv \frac{h}{\sqrt{16\pi G}}$$

$$-\frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} \partial^3 \psi \right) + 2\pi^2 \left( \frac{\dot{\phi}^2}{H^2} \psi \right) = 0$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H^2 (\epsilon - \eta) \ll 1$$

$$f = \frac{\dot{\phi}}{H} \psi$$

$$S = \frac{1}{2} \int \frac{d^4 x}{dt d^3 x} \left[ \partial^3 \dot{f}^2 - \partial (\partial_{\text{comoving}} f)^2 \right]$$

$$S = \frac{1}{2} \int d\tau d^3 x \left[ \partial^2 (f')^2 - \partial^2 (\partial_{\text{comoving}} f)^2 \right]$$

$$f' \equiv \frac{\dot{\phi}}{H} \dot{\psi}$$

$$f \equiv \frac{h}{\sqrt{16\pi G}}$$

$$V \equiv \partial f \quad S = \frac{1}{2} \int d\tau d^3 x [V$$

$$S = \frac{1}{2} \int d^4x \frac{1}{H^2} \left[ \partial_\mu \dot{\phi} - \partial_\mu \left( \frac{\dot{\phi}^2}{H^2} \right) \right]^2 + 2\eta^2 \left( \frac{\dot{\phi}^2}{H^2} \right) = 0$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \beta_H = 2H\dot{\phi}(\epsilon - \eta) \ll 1 \quad T \gg \frac{1}{H}$$

$$f = \frac{\dot{\phi}}{H} \psi$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ \partial^3 \dot{f}^2 - \partial (a_{\text{comoving}} f)^2 \right]$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \partial^2 (f')^2 - \partial^2 (a_{\text{comoving}} f)^2 \right]$$

$$f' \equiv \frac{\dot{\phi}}{H} \psi$$

$$f \equiv \frac{h}{\sqrt{16\pi G}}$$

$V \equiv a\dot{f}$

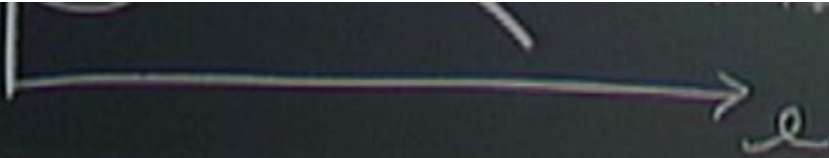
$$S = \frac{1}{2} \int d\tau d^3x \left[ (V')^2 - (\nabla V)^2 + \frac{\partial^2}{\partial \tau^2} V^2 \right]$$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{v}(\tau, \vec{x}) = \int [v_k(\tau) e^{i\vec{k} \cdot \vec{x}}$$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{v}(\tau, \vec{x}) = \int [v_k(\tau) e^{i\vec{k} \cdot \vec{x}}$$


$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{v}(\tau, \vec{x}) = \int [v_k(\tau) e^{i\vec{k} \cdot \vec{x}} a_k +$$

$\mathcal{L} = -\Phi_H$   $\kappa (V_B)$  w.o.p

$\mathcal{L}_M = -\Phi_H - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$   $\mathcal{L}_i = \mathcal{L}_i, \forall i \Rightarrow$  adiabatic

Maldecena 2002  $\delta\phi = 0$   $E = 0$   $\Rightarrow \mathcal{L} = \mathcal{Y}$

$\vec{r} = a\vec{x}$  inflation  $\Rightarrow$   $x_{\text{eff}}^+$   $x_{\text{eff}}^-$   $\Delta_{\text{eff}}$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{V}(\tau, \vec{x}) = \int [v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^+] \frac{d^3k}{(2\pi)^3}$$



$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ \partial^3 \dot{\phi}^2 - \partial \left( \frac{\dot{\phi}^2}{H^2} \partial^3 \dot{\phi} \right) + 2\nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \dot{\phi} \right) \right] = 0$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\dot{\phi}(\epsilon - \eta) \ll 1$$

$$f = \frac{\dot{\phi}}{H} \dot{\phi}$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ \partial^3 f^2 - \partial \left( \text{something } f \right)^2 \right]$$

$$\frac{d^4x}{dt d^3x} \Rightarrow f' \equiv \frac{df}{dt}$$

$$S = \frac{1}{2} \int dt d^3x \left[ \partial^2 (f')^2 \right]$$

$$f' \equiv \frac{\dot{\phi}}{H} \dot{\phi}$$

$$f' \equiv \frac{h}{\sqrt{16\pi G}}$$

V = of  $S = \frac{1}{2} \int dt$

$$S = \frac{1}{2} \int d^4x \frac{\phi}{H^2} \left[ \partial^3 \dot{\phi}^2 - \partial \left( \frac{\dot{\phi}^2}{H^2} \partial^3 \dot{\phi} \right) + \partial \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \dot{\phi} \right) \right] = 0$$

$\propto \sqrt{\epsilon_H} \dot{\phi}$   
 $f = \frac{\dot{\phi}}{H} \dot{\phi}$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\dot{\phi}(\epsilon - \eta) \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ \partial^3 \dot{f}^2 - \partial \left( \partial_{\text{comoving}} f \right)^2 \right] \quad \partial^3 \dot{f} = \frac{2}{\tau^2}$$

$\frac{d^4x}{dt d^3x} \Rightarrow f' \equiv \frac{df}{d\tau}$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \partial^2 (f')^2 - \partial^2 \left( \partial_{\text{comoving}} f \right)^2 \right]$$

$f' \equiv \frac{\dot{\phi}}{H} \dot{\phi}$   
 $\equiv \frac{h}{\sqrt{16\pi G}}$

$v = \text{of}$

$$S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{\partial''}{\tau^2} v^2 \right]$$



$$S = \frac{1}{2} \int d^4x \frac{\phi}{H^2} \left[ \partial^3 \dot{\phi}^2 - \partial \left( \frac{\dot{\phi}^2}{H^2} \partial^3 \dot{\phi} \right) + 2\pi^2 \left( \frac{\dot{\phi}^2}{H^2} \right) \right] = 0$$

$\propto \sqrt{\epsilon_H} \dot{\phi}$   
 $f = \frac{\dot{\phi}}{H} \dot{\phi}$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\dot{\phi}(\epsilon - \eta) \ll 1$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ \partial^3 \dot{f}^2 - \partial \left( \partial_{\text{comoving}} f \right)^2 \right] \quad \frac{\partial^3}{\partial t^3} = \frac{2}{\tau^3}$$

$\frac{d^4x}{dt d^3x} \Rightarrow f' \equiv \frac{df}{d\tau}$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \partial^2 (f')^2 - \partial^2 \left( \partial_{\text{comoving}} f \right)^2 \right] \quad f' \equiv \frac{\dot{\phi}}{H} \dot{\phi}$$

$\equiv \frac{h}{\sqrt{16\pi G}}$

$v \equiv$  of

$$S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{\partial^3}{\partial \tau^3} v^2 \right]$$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{V}(\tau, \vec{x}) = \int \left[ v_k(\tau) e^{i\vec{k} \cdot \vec{x}} a_k + v_k^* e^{-i\vec{k} \cdot \vec{x}} a_k^+ \right] \frac{d^3 k}{(2\pi)^3}$$

$$v_k'' + \left( k^2 - \frac{\partial''}{\partial} \right) v_k$$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{V}(\tau, \vec{x}) = \int \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^* e^{-i\vec{k}\cdot\vec{x}} a_k^+ \right] \frac{d^3k}{(2\pi)^3}$$

$$v_k'' + \left( k^2 - \frac{\partial''}{\partial} \right) v_k = 0$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ \partial^3 \dot{\phi}^2 - \partial (\nabla^2 \phi) \right]$$

$$- \frac{d}{dt} \left( \frac{\dot{\phi}^2}{H^2} \partial^3 \dot{\phi} \right) + \partial \nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \phi \right) = 0$$

$$\epsilon_H = 4\pi G \frac{\dot{\phi}^2}{H^2} \ll 1 \quad \epsilon_H = 2H\epsilon(\epsilon - \eta) \ll 1$$

$$k\tau \gg 1$$

$f \equiv \frac{\dot{\phi}}{H} \phi \propto \sqrt{\epsilon_H} \phi$   
 $f' \equiv \frac{\dot{\phi}}{H} \dot{\phi}$

$$S = \frac{1}{2} \int dt d^3x \left[ \partial^3 f^2 - \partial (\partial_{\text{comoving}} f) \right]$$

$$\frac{\partial}{\partial t} = \frac{1}{a} \frac{\partial}{\partial \tau}$$

$$\frac{dt d^3x}{dc d^3x} \Rightarrow f' \equiv \frac{df}{d\tau}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \partial^2 (f')^2 - \partial^2 (\partial_{\text{comoving}} f)^2 \right]$$

$$f \equiv \frac{\dot{\phi}}{H} \phi$$

$$f' \equiv \frac{\dot{\phi}}{\sqrt{4\pi G}}$$

$v \equiv$  of  $S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{e''}{a^2} v^2 \right]$



$\mathcal{L} = -\dot{\Phi}^2 - H^2 \left( \frac{v_B}{f} \right)^2$   
 $\mathcal{L}_M = -\dot{\Phi}^2 - H^2 \frac{\rho_{\text{eff}}}{\rho_{\text{pl}}}$

$\mathcal{L} = \mathcal{L}_S + \mathcal{L}_V \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_0 = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $v$   
 $x^{\text{act}}$   
 $x^{\text{pl}}$   
 $\Delta$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{\phi}(\vec{x}, \tau) = \int \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^+ \right] \frac{d^3k}{(2\pi)^3}$$

$$\left( k^2 - \frac{a''}{a} \right) v_k = 0$$



$\mathcal{L} = -\dot{\Phi}_H - \frac{1}{k} (V_0)$   
 $\mathcal{L}_M = -\dot{\Phi}_H - H \frac{\delta p_{\text{eff}}}{\rho_M}$

$\mathcal{L} = \mathcal{L}_0 \forall \dot{\phi} \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_0 = a\vec{x}$   $E = 0$

$\Rightarrow \boxed{\mathcal{L} = \mathcal{Y}}$

w.o.p.  
 $h_{ij}$   
 $x^{\text{act}}$   
 $t + \frac{a^2}{x}$   
 $\Delta$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

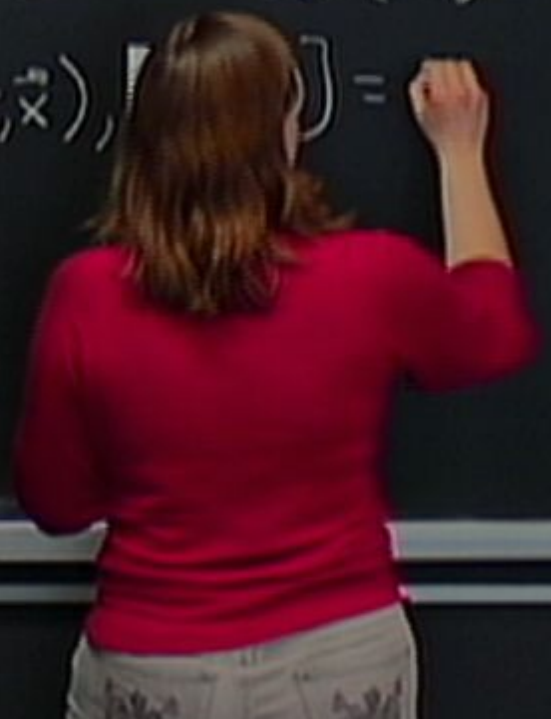
$$\hat{V}(\tau, \vec{x}) = \int [v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^* e^{-i\vec{k}\cdot\vec{x}} a_k^+] \frac{d^3k}{(2\pi)^3}$$

$$v_k'' + (k^2 - \frac{a''}{a}) v_k = 0$$



$\mathcal{L} = -\Phi_H - \frac{1}{2} \dot{\phi}^2 - \frac{1}{2} \nabla^2 \phi^2 - V(\phi)$   
 $\mathcal{L}_M = -\Phi_H - H \frac{\delta p_{\text{eff}}}{\delta \rho_M}$   
 $\mathcal{L} = \mathcal{L}_S \Rightarrow$  adiabatic  
 Maldecena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r}_s = a\vec{x}$   $E = 0$   $\Rightarrow \mathcal{L} = \mathcal{Y}$   
 w.o.p  
 $h_{ij}$   
 $\rightarrow \frac{t}{x} + \frac{t}{x} + \dots$   
 $\rightarrow \frac{t}{x} + \frac{t}{x} + \dots$

$\hat{V}(\tau, \vec{x}) = \int [v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger] \frac{d^3k}{(2\pi)^3}$   
 $v_k'' + (k^2 - \frac{a''}{a})v_k = 0$   $[\hat{V}(\tau, \vec{x}), \dots] =$



$\mathcal{L} = -\Phi_H - \frac{1}{k} \left( \frac{v_B}{v} \right)$   
 $\mathcal{L}_M = -\Phi_H - H \frac{\delta p_{\text{eff}}}{\rho_M}$

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{v} = a\vec{x}$   $E = 0$

$\Rightarrow \boxed{\mathcal{L} = \mathcal{L}_0}$

w.o.p.  
 $h_{ij}$   
 $x^{\text{act}}$   
 $x^{\text{ax}}$   
 $x^{\text{ax}}$   
 $x^{\text{ax}}$

$$\hat{V}(\tau, \vec{x}) = \int \left( v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right) \frac{d^3k}{(2\pi)^3}$$

$$v_k'' + \left( k^2 - \frac{a''}{a} \right) v_k = 0 \quad \left[ \hat{V}(\tau, \vec{x}), \hat{\pi}(\tau, \vec{y}) \right] = i\delta(\vec{x} - \vec{y})$$

$\Downarrow$



$\mathcal{L} = -\Phi_H - \frac{1}{k} (V_B)$

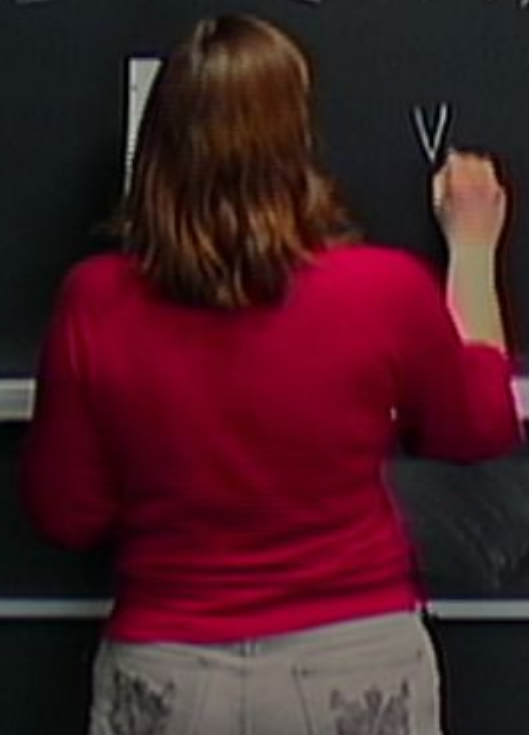
$\mathcal{L}_M = -\Phi_H - H \frac{\delta p_{\text{eff}}}{\rho_M}$

$\mathcal{L} = \mathcal{L}_S \quad \forall \quad \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{r} = a\vec{x} \quad E = 0 \Rightarrow \boxed{\mathcal{L} = \mathcal{Y}}$

w.o.p  
 $h_{ij}$   
 $x^{\text{act}} \rightarrow t + \frac{a^2}{x} + \dots$

$$V_k'' + \left(k^2 - \frac{a''}{a}\right)V_k = 0 \quad \left[\hat{V}(t, \vec{x}), \hat{\pi}(t, \vec{y})\right] = i\delta(\vec{x} - \vec{y})$$



$\mathcal{L} = -\dot{\Phi} - H$   $\frac{V_B}{K}$  w.o.p  
 $\mathcal{L}_M = -\dot{\Phi} - H \frac{\delta p_{\text{eff}}}{\rho_M}$   $\Rightarrow$  adiabatic  
 Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{p} = a\vec{x}$   $E = 0$   $\Rightarrow$   $\mathcal{L} = \mathcal{Y}$

$$V_k'' + (k^2 - \frac{a''}{a})V_k = 0$$

$$[\hat{V}(t, \vec{x}), \hat{\Pi}(t, \vec{y})] = i\delta(\vec{x} - \vec{y})$$

$$\Downarrow$$

$$V_k V_k^* - V_k^* V_k = i$$





$N, N'$  are not dynamical  $\Rightarrow A, B$  are not dynamical

$$\left( A = \frac{\dot{\psi}}{H} \right) \quad B = \frac{1}{a} \frac{\dot{\psi}}{H} - 2\nabla^{-2} \left( \frac{\dot{\phi}^2}{2H^2} \dot{\psi} \right) (8\pi G)^{1/2} \quad \ddot{\phi} + 3H\dot{\phi} + V' = 0$$

$$S = \frac{1}{2} \int d^4x \frac{\dot{\phi}^2}{H^2} \left[ a^3 \dot{\psi}^2 - a (\nabla \psi)^2 \right] \quad \boxed{f \equiv \frac{\dot{\phi}}{H} \psi} \propto \sqrt{\epsilon_+} \psi$$

$$\left( \frac{\dot{\phi}^2}{H^2} a^3 \dot{\psi} \right) + 2\nabla^2 \left( \frac{\dot{\phi}^2}{H^2} \psi \right) = 0$$

$$G \frac{\dot{\phi}^2}{H^2} \ll 1$$

$$\dot{\epsilon}_H = 2H\epsilon (\epsilon - \eta) \ll 1$$

$$k\tau \gg 1$$

$$\dot{f} = \frac{\dot{\phi}}{H} \dot{\psi}$$

N 111

$$V_E(\tau) = \Gamma_E(\tau) e^{i\omega(\tau)}$$

11021

N/A

$$V_E(\tau) = r_E(\tau) e^{\alpha(\tau)}$$

$$\alpha = -\frac{1}{2r^2}$$

(2)

$$E_r \propto |V_E|^2 +$$



$N \propto \frac{1}{r^2}$

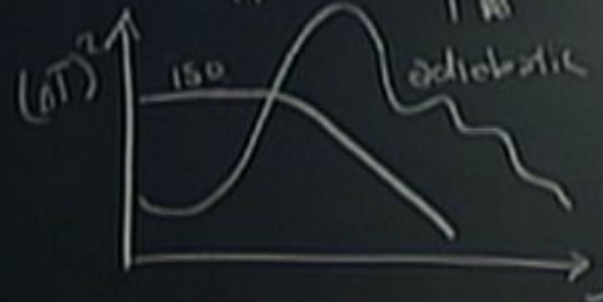
$$V_E(t) = r_k(t) e^{i\omega t}$$

$$\alpha = -\frac{1}{2r^2}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

$$\mathcal{L} = -\Phi_H - \frac{1}{2} \dot{\phi}^2 - \frac{1}{2} \nabla^2 \phi^2 - V(\phi)$$

$$\mathcal{L}_M = -\Phi_H - \frac{1}{2} \dot{\phi}^2 - \frac{1}{2} \nabla^2 \phi^2 - V(\phi)$$

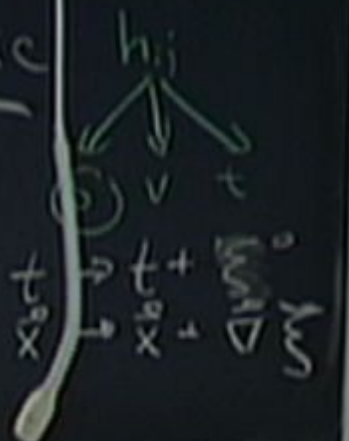


$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 \Rightarrow$  adiabatic

Maldacena 2002

$$\delta\phi = 0, \quad E = 0$$

$$\mathcal{L} = \mathcal{Y}$$



$$\hat{V}(\tau, \vec{x}) = \int \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right] \frac{d^3k}{(2\pi)^3}$$

$$v_k'' + \left( k^2 - \frac{\partial^2 V}{\partial \phi^2} \right) v_k = 0$$

$$[\hat{V}(\tau, \vec{x}), \hat{\pi}(\tau, \vec{y})] = i\delta(\vec{x} - \vec{y})$$

$$\omega_k^2 = k^2; \quad k\tau \gg 1$$

$$(v_k v_k^* - v_k^* v_k) = i$$

$\mathcal{L} = -\dot{\Phi} \dot{H} - H \frac{\delta \mathcal{L}_{\text{M}}}{\delta \dot{\Phi}}$

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 \Rightarrow$  adiabatic

Maldacena 2002

$\delta\phi = 0$   
 $E = 0$

$\mathcal{L} = \mathcal{Y}$

$\vec{x} = a\vec{x}$

$h_{ij}$

$\Delta_{\text{sub}} \Delta_{\text{hor}} \Delta_{\text{Hubble}}$

$$\hat{V}(\tau, \vec{x}) = \int \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right] \frac{d^3k}{(2\pi)^3}$$

$$v_k'' + (k^2 - \dots) v_k = 0 \quad \left[ \hat{V}(\tau, \vec{x}), \hat{\pi}(\tau, \vec{y}) \right] = i\delta(\vec{x} - \vec{y})$$

$\Downarrow$

$$\left( v_k v_k^* - v_k^* v_k \right) = i$$

subhorizon

$\tau \gg 1$

N 111

$$V_E(z) = r_E(z) e^{i\alpha(z)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$E_x \propto |V_E'|^2 + \omega^2 |V_E|^2$$

$$V_k(t) = r_k(t) e^{i\alpha(t)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

$$E_k(t_k) \Rightarrow r_k'(t_k) = 0$$

$$r_k(t_k) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(t) = r_k(t) e^{i\alpha(t)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

$$\text{Minimize } E_k(t_k) \Rightarrow r_k'(t_k) = 0 \quad r_k(t_k) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau) = r_k(\tau) e^{i\alpha(\tau)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

$$\text{Minimize } E_k(\tau_k) \Rightarrow r_k'(\tau_k) = 0 \quad r_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\alpha(\tau_k)} \quad V_k' = -i$$

$$V_k(\tau) = r_k(\tau) e^{i\alpha(\tau)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

$$\text{Minimize } E_k(\tau_k) \Rightarrow r_k'(\tau_k) = 0$$

$$r_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\alpha(\tau_k)}$$

$$V_k' = -i \sqrt{\frac{\omega}{2}} e^{i\alpha(\tau_k)}$$

$$2) \frac{d}{d\tau} \left[ (V')^2 - (\nabla V)^2 + \frac{\omega}{2} V^2 \right]$$



$$V_k(\tau) = r_k(\tau) e^{i\alpha(\tau)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

$$\text{Minimize } E_k(\tau_k) \Rightarrow r_k'(\tau_k) = 0 \quad r_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\alpha(\tau_k)}$$

$$V_k' = -i \sqrt{\frac{\omega}{2}} e^{i\alpha(\tau_k)}$$

$$2) \int d\tau dx \left[ (V')^2 - (\nabla V)^2 + \frac{\omega}{2} V^2 \right]$$

$$V_k(t) = \dots$$

$$E_k \propto |v_k'|^2 + \omega_k^2 |v_k|^2$$

Minimize  $E_k(\tau_k) \Rightarrow r_k'(\tau_k) = 0 \quad r_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}}$

$$v_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\omega_k \tau_k} \quad v_k' = +i \sqrt{\frac{\omega_k}{2}} e^{i\omega_k \tau_k}$$

$$\omega \approx k$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \dot{f}^2 - a^2 (\nabla_{\text{commoving}} f)^2 \right]$$

$$f = \frac{\phi}{H} y$$

$$f = \frac{h}{\sqrt{16\pi G}}$$

$$v = \dot{a}f$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ (\dot{v})^2 - (\nabla v)^2 + \frac{a''}{a} v^2 \right]$$

$$E_k \propto |v_k'|^2 + \omega_k^2 |v_k|^2$$

$$\text{Minimize } E_k(\tau_k) \Rightarrow r_k'(\tau_k) = 0 \quad r_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}}$$

$$v_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\omega_k \tau_k} \quad v_k' = +i \sqrt{\frac{\omega_k}{2}} e^{i\omega_k \tau_k}$$

$$\left\{ \begin{array}{l} \omega \approx k \\ v_k(\tau) = \frac{1}{\sqrt{2k}} e^{ik\tau} \end{array} \right.$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \dot{f}^2 - a^2 (\nabla_{\text{commoving}} f)^2 \right] \quad \begin{array}{l} f \equiv \frac{\phi}{H} \\ f \equiv \frac{h}{\sqrt{16\pi G}} \end{array}$$

$$v \equiv \dot{a}f$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{a''}{a} v^2 \right]$$

$$E_k \propto |v_k'|^2 + \omega_k^2 |v_k|^2$$

Minimize  $E_k(\tau_k) \Rightarrow r_k'(\tau_k) = 0$       $r_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}}$

$$v_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\omega_k(\tau_k)} \quad v_k' = +i \sqrt{\frac{\omega_k}{2}} e^{i\omega_k(\tau_k)}$$

$$\left\{ \begin{array}{l} \omega \approx k \end{array} \right.$$

$$v_k(\tau) = \frac{1}{\sqrt{2k}} e^{ik\tau}$$

$$k\tau \gg 1$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \dot{f}^2 - a^2 (\nabla_{\text{commoving}} f)^2 \right]$$

$$f \equiv \frac{\phi}{H} \psi$$

$$f \equiv \frac{h}{\sqrt{16\pi G}}$$

$$v \equiv \dot{a}f$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{a''}{a} v^2 \right]$$

$\mathcal{L}_M = -\Phi_H - H \frac{\delta p_M}{\dot{\rho}_M}$

$\mathcal{L} = \mathcal{L}_i \forall i \Rightarrow$  adiabatic

Maldacena 2002

inflaton  $\delta\phi = 0$   
 $\vec{k} = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{L}$

$\hat{V}(\tau, \vec{x}) = \int \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^* e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right] \frac{d^3k}{(2\pi)^3}$

$v_k'' + \left( k^2 - \frac{a''}{a} \right) v_k = 0$

$\left[ \hat{V}(\tau, \vec{x}), \hat{\Pi}(\tau, \vec{y}) \right] = i\delta(\vec{x} - \vec{y})$

$\Downarrow$

$(v_k v_k^* - v_k^* v_k) = i$

$\omega_k^2$   
 $\approx k^2$  subhorizon  
 $k\tau \gg 1$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

Minimize  $E_k(\tau_k) \Rightarrow r_k'(\tau_k) = 0$       $r_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}}$

$$V_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\omega_k \tau_k} \quad V_k' = -i \sqrt{\frac{3}{2}} e^{i\omega_k \tau_k}$$

$\omega \approx k$       $V_k(\tau) = \frac{1}{\sqrt{2}k} e^{ik\tau}$       $k\tau \gg 1$

$$S = \frac{1}{2} \int d\tau d^3x \left[ \dot{\phi}^2 - a^2 (\partial_{\text{spatial}} \phi)^2 \right]$$

$v = a\dot{\phi}$

$$d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{a^2}{2} v^2 \right]$$

Minimize  $E_k(\tau) \Rightarrow r'_k(\tau)$

$$V_k(\tau) = \frac{1}{\sqrt{2\omega_k}} e^{i\omega_k(\tau)}$$

$$V'_k = -i \frac{\omega_k}{2} e^{i\omega_k(\tau)}$$

$$\omega \approx k$$

$$V_k(\tau) = \frac{1}{\sqrt{2k}} e^{ik\tau}$$

$$k\tau \rightarrow 1$$

$$S = \frac{1}{2} \int \frac{d^4x}{dt d^3x} \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f)^2 \right]$$

$$\frac{a''}{a} = \frac{2}{\tau^2}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ a^2 (\dot{f})^2 - a^2 (a_{\text{comoving}} f)^2 \right]$$

$$\dot{f} = \frac{\dot{\phi}}{H} \psi$$

$$f = \frac{h}{\sqrt{4\pi G}}$$

$v \equiv \dot{\phi}$

$$S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\vec{\nabla} v)^2 + \frac{a''}{a} v^2 \right]$$

$$r_k(\tau_i) = \frac{1}{\sqrt{2\omega_k}}$$

$$\sqrt{\frac{\omega}{2}}$$

$$\rho_{i\alpha}(\tau_i)$$

$$\tau = \frac{1}{\omega}$$





$f) 2]$

$$\frac{2}{\sqrt{2}} = \frac{2}{\sqrt{2}}$$

$\frac{2}{\sqrt{2}}$

$$\frac{2}{\sqrt{2}} = \frac{2}{\sqrt{2}}$$

$$V_k(\tau) = r_k(\tau) e^{i\alpha(\tau)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

Minimize  $E_k(\tau_i) \Rightarrow r_k'(\tau_i) = 0$

$$r_k(\tau_i) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau) = \frac{1}{\sqrt{2\omega_k}} e^{i\alpha(\tau)}$$

$$V_k' = -i \sqrt{\frac{\omega}{2}} e^{i\alpha(\tau)}$$

$$\omega \approx k$$

$$V_k(\tau) = \frac{1}{\sqrt{2k}} e^{ik\tau}$$

$$k\tau \gg 1$$

$$\int d\tau d^3x \left[ (V')^2 - (\nabla V)^2 + \frac{1}{2} V^2 \right]$$

$\mathcal{L} = -\dot{\Phi}^2 - H^2 \frac{S_{\text{DBI}}}{P_{\text{DBI}}}$

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 \rightarrow$  adiabatic

Maldacena 2002

$\delta\phi = 0$   
 $E = 0$

$\vec{v} = a\vec{x}$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $\rightarrow$   $\delta h_{ij}$   
 $\rightarrow$   $\delta g_{\mu\nu}$   
 $\rightarrow$   $\delta \Gamma$

$$\pi = \frac{\partial \mathcal{L}}{\partial v^i} = v^i$$

$$\hat{V}(\tau, \vec{x}) = \int \frac{d^3k}{(2\pi)^3} \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right]$$

$$\left[ \hat{V}(\tau, \vec{x}), \hat{\pi}(\tau, \vec{y}) \right] = i\delta(\vec{x} - \vec{y})$$

$$(v_k v_k^* - v_k^* v_k) = i$$

subhorizon

$k\tau \gg 1$

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$$V_k(\tau) = r_k(\tau) e^{i\alpha(\tau)}$$

$$\left\{ \alpha' = -\frac{1}{2r^2} \right\}$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

Minimize  $E_k(\tau_i) \Rightarrow r_k'(\tau_i) = 0$

$$r_k(\tau_i) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau) = \frac{1}{\sqrt{2\omega_k}} e^{i\alpha(\tau)}$$

$$V_k' = -i \sqrt{\frac{3}{2}} e^{i\alpha(\tau)}$$

$$\tau = \frac{-1}{2H}$$

$$\left\{ \begin{array}{l} \omega \approx k \end{array} \right.$$

$$V_k(\tau) = \frac{1}{\sqrt{2}k} e^{ik\tau}$$

$$k\tau \gg 1$$

$$\int d\tau d^3x \left[ (V')^2 - (\nabla V)^2 + \frac{1}{2} V^2 \right]$$

$\mathcal{L} = -\Phi_H$   $\frac{1}{k} (V_B)$  = w.o.p

$\mathcal{L}_M = -\Phi_H - H \frac{\delta p_M}{\delta \dot{\phi}}$   $\mathcal{L} = \mathcal{L}_0, \forall \dot{\phi} \Rightarrow$  adiabatic

Maldacena 2002 inflation  $\delta\phi = 0$   $E = 0$   $\Rightarrow \mathcal{L} = \mathcal{Y}$

$\vec{v} = a\vec{x}$  h<sub>ij</sub> x<sup>a</sup>t + x<sup>b</sup>t + ...

$\pi = \frac{\partial \mathcal{L}}{\partial \dot{\phi}} = v$   $a_k |0\rangle = 0$

$\hat{V}(\tau) = \int \frac{d^3k}{(2\pi)^3} \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right]$

$\boxed{v_k'' + \dots} v_k = 0$   $[\hat{V}(\tau, \vec{x}), \hat{\pi}(\tau, \vec{y})] = i\delta(\vec{x} - \vec{y})$

horizon  $\Downarrow$   $(v_k v_k^* - v_k^* v_k) = i$

$k\tau \gg 1$

$\mathcal{L} = -\dot{\Phi}_H$   $\frac{1}{k} (V_B)$  wop

$\mathcal{L}_M = -\dot{\Phi}_H - H \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$   $\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 \Rightarrow$  adiabatic

Maldacena 2002 adiabatic

$\delta\phi = 0$  inflation  $\Rightarrow \mathcal{L} = \mathcal{L}_0$

$\vec{k} = a\vec{x}$   $E = 0$   $\Rightarrow$

$h_{ij}$  +  $\Delta$  +  $\Delta$  +  $\Delta$

$x^0 + a\vec{x}$  +  $\Delta$  +  $\Delta$  +  $\Delta$

$$\pi = \frac{\partial \mathcal{L}}{\partial v'} = v'$$

$$\hat{V}(\tau, \vec{x}) = \int \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right] \frac{d^3k}{(2\pi)^3}$$

$$a_k |0\rangle = 0$$

$$v_k'' + \left( k^2 - \frac{a''}{a} \right) v_k = 0$$

$$[\hat{V}(\tau, \vec{x}), \hat{\pi}(\tau, \vec{y})] = i\delta(\vec{x} - \vec{y})$$

$\omega_k^2 = k^2$  subhorizon

$$(v_k v_k^* - v_k^* v_k) = i$$

$k^2 : k\tau \gg 1$

Minimize  $E_k(\tau_k) \rightarrow \delta E_k(\tau_k) = 0$

$$V_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\omega_k(\tau_k)}$$

$$V_k' = -i \sqrt{\frac{3}{2}} e^{i\omega_k(\tau_k)}$$

$$\tau = \frac{1}{\omega_k}$$

$$\omega \approx k$$

$$V_k(\tau) = \frac{1}{\sqrt{2}k} e^{ik\tau}$$

$$k\tau \gg 1$$

$$S = \frac{1}{2} \int dt d^3x \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f')^2 \right]$$

$dc d^3x \Rightarrow f' \equiv \frac{df}{d\tau}$

$$\frac{a'}{a} = \frac{2}{3H^2}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ a^2 (\dot{f})^2 - a^2 (a_{\text{comoving}} f')^2 \right]$$

$$f' \equiv \frac{df}{d\tau}$$

$$v \equiv a\dot{f}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{a''}{2} v^2 \right]$$

Minimize  $E_k(\tau_k) \rightarrow I_k(\tau_k) = 0$

$$V_k(\tau_k) = \frac{1}{\sqrt{2\omega_k}} e^{i\omega_k(\tau_k)}$$

$$V_k' = -i \frac{\omega_k}{2} e^{i\omega_k(\tau_k)}$$

$$\tau = \frac{1}{\omega_k}$$

$$\omega \approx k$$

$$V_k(\tau) = \frac{1}{\sqrt{2k}} e^{ik\tau}$$

$$k\tau \gg 1$$

$$S = \frac{1}{2} \int dt d^3x \left[ a^3 \dot{f}^2 - a (a_{\text{comoving}} f')^2 \right]$$

$$\frac{a}{a'} = \frac{2}{c^2}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ a^2 (\dot{f}')^2 - a^2 (a_{\text{comoving}} f')^2 \right]$$

$$f' = \frac{\partial f}{\partial x}$$

$$f = \frac{h}{\sqrt{16\pi G}}$$

$$v = a\dot{f}$$

$$S = \frac{1}{2} \int d\tau d^3x \left[ (v')^2 - (\nabla v)^2 + \frac{a''}{2a} v^2 \right]$$



$$V_k = \frac{e^{-ik\tau}}{\underline{\quad}}$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right]$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right]$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-\omega e^{iL\tau}}{\sqrt{2} k^{3/2}}$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-\omega e^{iL\tau}}{\sqrt{2} k^{3/2}}$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-\tau e^{i k \tau}}{\sqrt{2} k^{3/2} \tau}$$

$$|V_k|^2 = \frac{1}{2k^3 \tau^2} = a|$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-i e^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$|V_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\alpha^3 H^2}{2k^3}$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-ie^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$|V_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\alpha^3 H^2}{2k^3}$$

Recall



$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-\tau e^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$|V_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\partial^2 H^2}{2k^3}$$

Recall  $v = \partial f \Rightarrow |f_k|^2 = \frac{1}{2k^3}$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-\tau e^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$|V_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\partial^2 H^2}{2k^3}$$

Recall  $v = \partial f \Rightarrow$

$$\boxed{|f_k|^2 = \frac{H^2}{2k^3}}$$

$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-\tau e^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$|V_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\partial^3 H^2}{2k^3}$$

Recall  $v = \partial f \Rightarrow$

$$|f_k|^2 = \frac{H^2}{2k^3}$$

$m \ll H$

$$\left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$\frac{e^{iL\tau}}{k^{3/2} \tau} \quad |v_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\partial^2 H^2}{2k^3}$$

$$\text{df} \Rightarrow \boxed{|f_k|^2 = \frac{H^2}{2k^3}} \quad m \ll H$$



$\mathcal{L} = -\dot{\phi}^2 - H^2 \frac{\delta p_{\text{eff}}}{\rho_{\text{eff}}}$

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 \Rightarrow$  adiabatic

Maldacena 2002  
 inflation  $\delta\phi = 0$   
 $\vec{k} = a\vec{x}$   $E = 0$

$\mathcal{L} = \mathcal{Y}$

$h_{ij}$   
 $x^{\text{act}}$   
 $x^{\text{lat}}$   
 $\Delta_{\text{lat}}$

$\hat{V}(\tau, \vec{x}) = \int \left[ v_k(\tau) e^{i\vec{k}\cdot\vec{x}} a_k + v_k^*(\tau) e^{-i\vec{k}\cdot\vec{x}} a_k^\dagger \right] \frac{d^3k}{(2\pi)^3}$

$V_k'' + \left( \frac{2''}{a} \right) v_k = 0$

$[\hat{V}(\tau, \vec{x}), \hat{\pi}(\tau, \vec{y})] = i\delta(\vec{x} - \vec{y})$

$(v_k v_k^* - v_k^* v_l) = i$

subhorizon  $k \gg 1$

$a_k |0\rangle = 0$

$$V_k'' + \left(k^2 - \frac{a''}{a}\right)V_k = 0 \quad \left[ V(t, x), \psi(t, y) \right] = i\delta(x - y)$$

$\omega_L^2$   
 $\approx$  subhorizon  
 $k^2$ ;  $k\tau \gg 1$

$$\left( V_k V_k^* - V_k^* V_L \right) = c$$

$$\langle \hat{V}_k + \hat{V}_L \rangle = |V_k|^2 \langle 0 | 2_k | 0 \rangle$$



$$V_k'' + \left(k^2 - \frac{a''}{a}\right) V_k = 0 \quad \left( V(L, x), \psi(L, y) \right) = i \delta(x - y)$$

$\omega_L^2$   
 $\approx$  subhorizon  
 $k^2$ ;  $k\tau \gg 1$

$$\left( V_k V_k^* - V_k^* V_L \right) = c$$

$$\langle \hat{v}_k^+ \hat{v}_k \rangle = |v_k|^2 \langle 0 | a_k a_k^\dagger | 0 \rangle$$



$$V_k'' + \left(k^2 - \frac{a''}{a}\right) V_k = 0 \quad (V(L, x), (L, y)) = i\delta(x_3 - y_3)$$

$\omega_L^2$   
 $\equiv$  subhorizon  
 $k^2$ ;  $k\tau \gg 1$

$$(V_k V_k^* - V_k^* V_L) = c$$

$$\begin{aligned}
 \langle \hat{v}_k^+ \hat{v}_{k'} \rangle &= |v_k|^2 \langle 0 | a_k a_{k'}^\dagger | 0 \rangle \\
 &= (2\pi)^3 \delta(\vec{k} - \vec{k}') \cdot |v_k|^2 \equiv (2\pi)^3 \delta(\vec{k} - \vec{k}') \underline{P}_v(k)
 \end{aligned}$$



$$V_k'' + \left(k^2 - \frac{a''}{a}\right) V_k = 0 \quad \left( V(t, \vec{x}), V(t, \vec{y}) \right) = i \delta(\vec{x} - \vec{y})$$

$\omega_k^2$   
 $\approx k^2$  subhorizon  
 $; k\tau \gg 1$

$$\left( V_k V_k^* - V_k^* V_k \right) = c$$

$$\langle \hat{v}_k^+ \hat{v}_k \rangle = |v_k|^2 \langle 0 | a_k a_k^\dagger | 0 \rangle$$

$$= (2\pi)^3 \delta(\vec{k} - \vec{k}') \cdot |v_k|^2 \equiv (2\pi)^3 \delta(\vec{k} - \vec{k}') \underline{P_v(k)}$$

$$\langle \hat{v}(\vec{x}) \hat{v}(\vec{y}) \rangle = \int \underbrace{\frac{P_v(k) k^3}{2\pi^2}}_{P(k)} \frac{\sin(kr)}{kr} \frac{dk}{k}$$

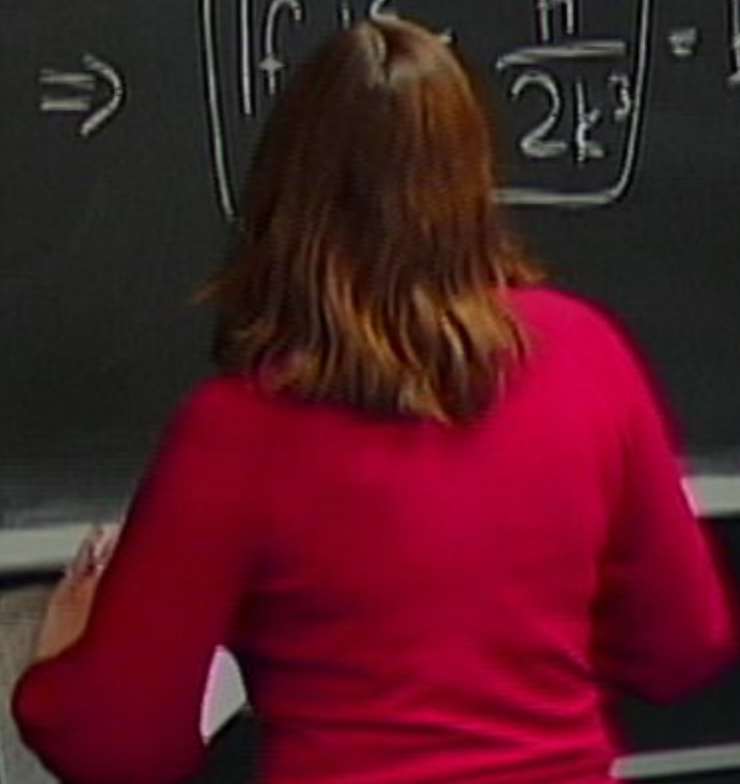
$$V_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right] \quad (k\tau \ll 1)$$

$$V_k^{\text{super}} = \frac{-\tau e^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$|V_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\partial^4 H^2}{2k^3}$$

Recall  $v = ef \Rightarrow$

$$\boxed{|f|^2 = \frac{H^2}{2k^3}} = P(k) \quad m \ll H$$



$$v_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right]$$

$$v_k^{\text{super}} = \frac{-ie^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$(k\tau \ll 1) \quad |v_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\partial^3 H^2}{2k^3}$$

Recall  $v = df \Rightarrow$

$$\boxed{|f_k|^2 = \frac{H^2}{2k^3}} = P(k) \quad m \ll H$$

$$v_k = \frac{e^{-ik\tau}}{\sqrt{2k}} \left[ 1 - \frac{i}{k\tau} \right]$$

$$v_k^{\text{super}} = \frac{-ie^{ik\tau}}{\sqrt{2} k^{3/2} \tau}$$

$$(k\tau \ll 1)$$

$$|v_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{\delta^3 H^2}{2k^3}$$

Recall  $v = df \Rightarrow$

$$|f_k|^2 = \frac{H^2}{2k^3} = P(k) \quad m \ll H$$

$$P(k) = \frac{H^2}{(2\pi)^2}$$

$$|v_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{a^2 H^2}{2k^3}$$

$$\Rightarrow |f_k|^2 = \frac{H^2}{2k^3} = P(k) \quad m \ll H$$

$$\delta\phi = \frac{H}{2\pi}$$

$$P(k) = \frac{H^2}{(2\pi)^2}$$

$$|v_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{a^2 H^2}{2k^3}$$

$$\Rightarrow |f_k|^2 = \frac{H^2}{2k^3} = P(k) \quad m \ll H$$

$$\delta\phi = \frac{H}{2\pi}$$

$$P(k) = \frac{H^2}{(2\pi)^2}$$

$$\left[ \frac{c}{k\tau} \right]$$

$$\tau$$
$$\frac{1}{2} \tau$$

$$(k\tau \ll 1)$$

$$|v_k|^2 = \frac{1}{2k^3 \tau^2} = \frac{a^2 H^2}{2k^3}$$

$\Rightarrow$

$$|f_k|^2 = \frac{H^2}{2k^3}$$

$$P(k) = \frac{H^2}{(2\pi)^2}$$

$$m \ll H$$
$$= P(k)$$

$$\delta\phi = \frac{H}{2\pi}$$

$$V_k'' + \left(L^2 - \frac{\partial^2}{\partial \tau^2}\right) V_k = 0 \quad \left( V_k(\tau, x), V_k(\tau, y) \right) = i \delta(Lx - y)$$

$\omega_k^2$   
 $\equiv$  subhorizon  
 $k^2; k\tau \gg 1$

$$\left( V_k V_k^* - V_k^* V_k \right) = C$$

$$\langle \hat{v}_k^+ \hat{v}_k \rangle = |v_k|^2 \langle 0 | a_k a_k^\dagger | 0 \rangle = (2\pi)^3 \delta(\mathbf{k} - \mathbf{k}') \cdot |v_k|^2 \equiv (2\pi)^3 \delta(\mathbf{k} - \mathbf{k}') \underline{P(k)}$$

$$\langle \hat{v}(\vec{x}) \hat{v}(\vec{y}) \rangle = \int \underbrace{\frac{P_k(k) k^3}{2\pi^2}}_{P(k)} \frac{\sin(kr)}{kr} \frac{dk}{k}$$

$$ds^2 = -(1+2\psi)dt^2 - 2a\partial_i \Phi dt dx^i + a^2 [\delta_{ij}(1+2\psi) - 2(\partial_i \partial_j - \frac{1}{3}\partial^2)\Phi] dx^i dx^j$$

$$v_B = k\psi + \frac{k \cdot \nabla \Phi}{i a (\rho + p)}$$

$$\mathcal{S} \equiv -\Phi_H - \frac{i a H}{k} v_B$$

$$\mathcal{S}_M = -\Phi_H - H \frac{\delta p_M}{\rho_M}$$



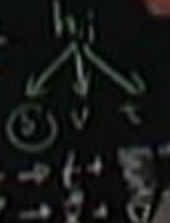
$$\Phi_H \equiv -\Psi + aH(B - \frac{\dot{\Phi}}{c})$$

Outside the horizon ( $k \ll \omega$ )  $\mathcal{S} = 0$   
 $\rho = w p \Rightarrow \delta \rho = w \delta p$

$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002

$$\delta \Phi = 0 \Rightarrow \mathcal{S} = \Psi$$





$$V_k'' + \left(k^2 - \frac{a''}{a}\right)V_k = 0 \quad \left( \frac{V_k(t, x)}{a(t, x)} \right) = \delta(x - x_0)$$

$\omega_k^2$   
 $\equiv$  subhorizon  
 $k^2; k \tau \gg 1$

$$(V_k V_k^* - V_k^* V_k) = c$$

$$\langle \hat{v}_k^+ \hat{v}_k \rangle = |v_k|^2 \langle 0 | a_k a_k^\dagger | 0 \rangle$$

$$= (2\pi)^3 \delta(\vec{k} - \vec{k}') \cdot |v_k|^2 = (2\pi)^3 \delta(\vec{k} - \vec{k}') \underline{P_k(k)}$$

$$\langle \hat{v}(\vec{x}) \hat{v}(\vec{y}) \rangle = \int \underbrace{\frac{P_k(k)}{2\pi^2}}_{P(k)} \frac{\sin(kr)}{kr} \frac{dk}{k}$$

$$ds^2 = -(1+2\Phi)dt^2 - 2a\partial_i \Psi dt dx^i + a^2 [\delta_{ij}(1+2\Phi) - 2(\partial_i \partial_j - \frac{1}{3}\partial^2)\Psi] dx^i dx^j$$

$$v_B = k\mathcal{B} + \frac{k \cdot \vec{I}}{i\omega(\rho+p)}$$

$$\mathcal{S} \equiv -\Phi_H - \frac{i\omega H}{k} \mathcal{V}_B$$

$$\mathcal{S}_M = -\Phi_H - H \frac{\delta p_M}{\rho_M}$$

$$\Phi_H \equiv -\Psi + \partial_t \left( \mathcal{B} - \frac{\mathcal{E}}{2c} \right)$$

Outside the horizon ( $k \ll aH$ )  $\mathcal{S} = 0$   
 $\rho = w p \Rightarrow \delta \rho = w \delta p$

$\mathcal{S}_i = \mathcal{S}_j \forall i, j \Rightarrow$  adiabatic

Maldacena 2002

$$\delta \Phi = 0 \Rightarrow \mathcal{S} = \Psi$$



Minimize E

$$V_k(\tau) =$$

$\omega > k$

$$S = \frac{1}{2} \int dt$$

$$S = \frac{1}{2} \int d$$

$V_k$  of

$$P_{\text{gs}} = \frac{H^2}{\dot{\Phi}^2} \left( \frac{H^2}{2k^3} \right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H}$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\dot{\phi}^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H} \propto V(p)$$

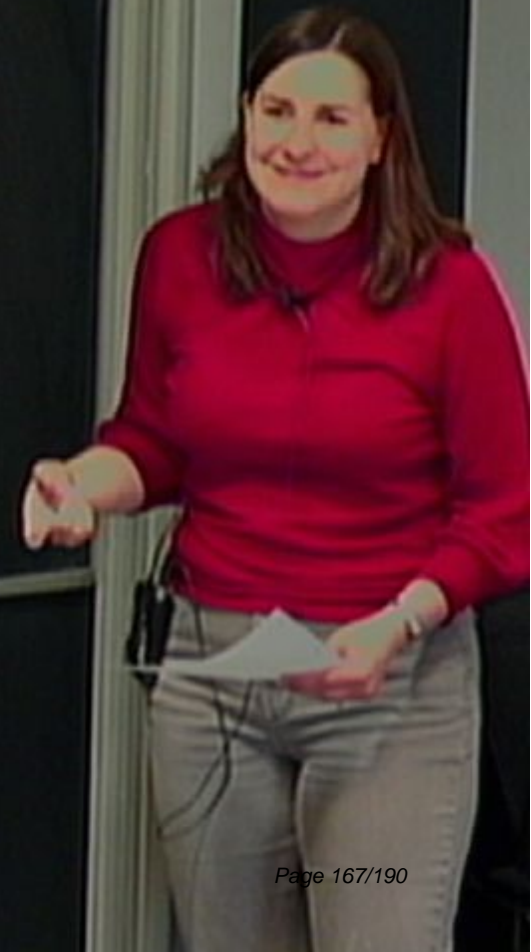


$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H} \propto \frac{V(\rho)}{\epsilon} = 2 \times 10^{-9}$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{8H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H} \propto \frac{V(\rho)}{\epsilon} = 2 \times 10^{-9}$$



$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H} \propto \frac{V(\rho)}{\epsilon} = 2 \times 10^{-9}$$

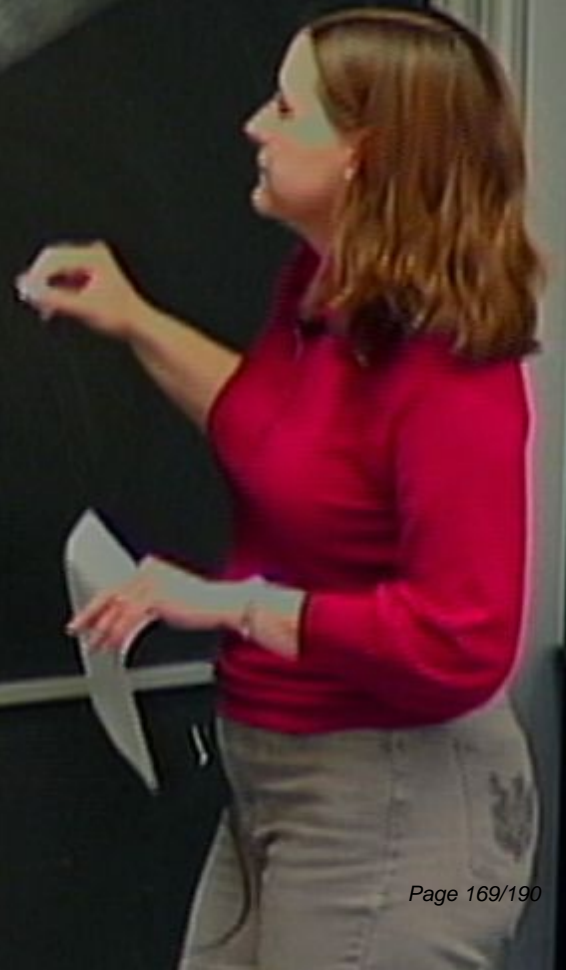
$$H^2 = \frac{8\pi G}{3} \rho$$



$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H}$$

$$H^2 = \frac{8\pi G}{3} \rho$$



$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_{\zeta}(\theta) = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=2H}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$H(a)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_f(k) = \frac{1}{\phi^2} \left( \frac{1}{2k^3} \right)$$

$$\epsilon_H \left( \frac{1}{2k^3} \right) |_{k=aH}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

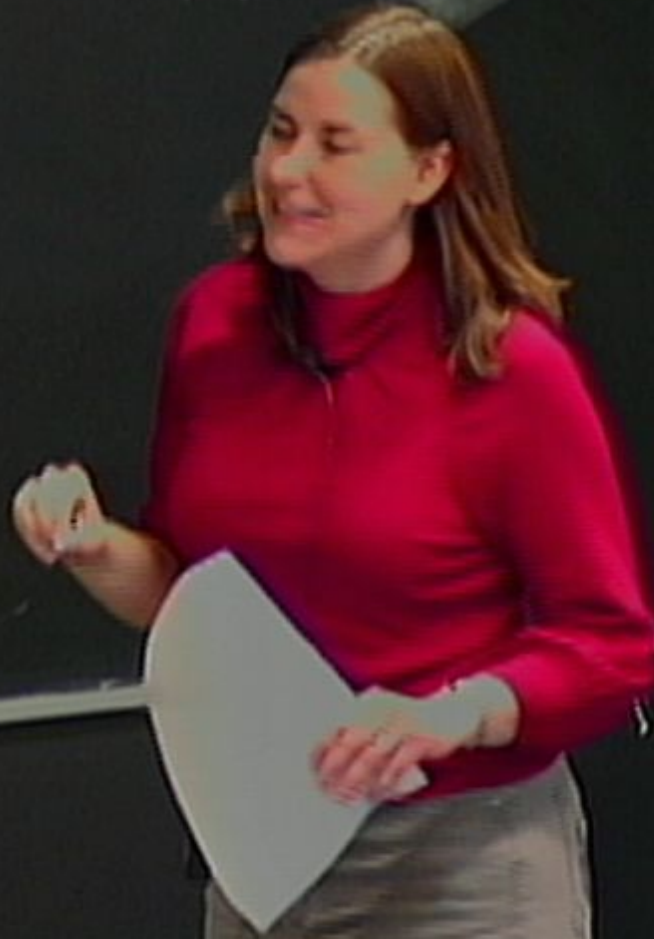
$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g(t) = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH}$$

$$H^2 = \frac{8\pi G}{3} \rho$$



$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g(\theta) = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g \approx \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \Rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH}$$

$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_s \approx \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \Rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \propto V$$



$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_g(t) = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} V$$

$$r =$$

$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_{\text{total}} = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \Rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \propto V$$

$$r = \frac{\rho}{P} = 4\epsilon$$

$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_s \approx \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \approx 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \propto V$$

$$r = \frac{P_s}{P_h} = 4\epsilon < 0.25$$

$H(a)$  $H\left(\frac{k}{H}\right)$ 

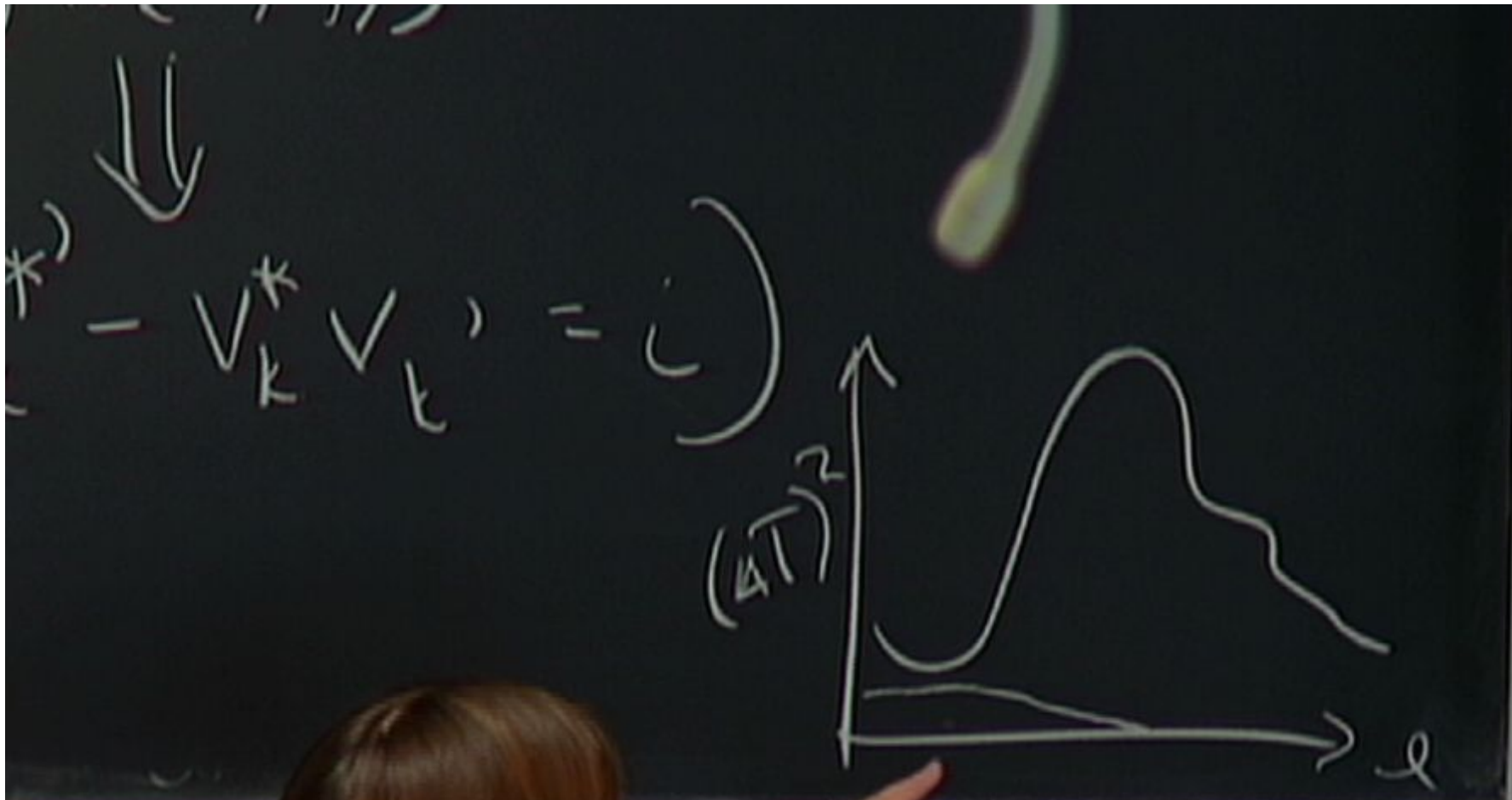
$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_{\text{total}} = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \propto V$$

$$r = \frac{P_{\text{total}}}{P_h} = 4\epsilon < 0.25$$



11  
( )

$(A_1)^2$



$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_{3H} = \frac{H^2}{\Phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \Rightarrow 2 \times 10^{-9} \sim \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH}$$

$$r = \frac{P_h}{P_r} = 4\epsilon < 0.25$$

$$H(a)$$

$$H\left(\frac{k}{H}\right)$$

$$\epsilon_H \equiv -\frac{\dot{H}}{H^2}$$

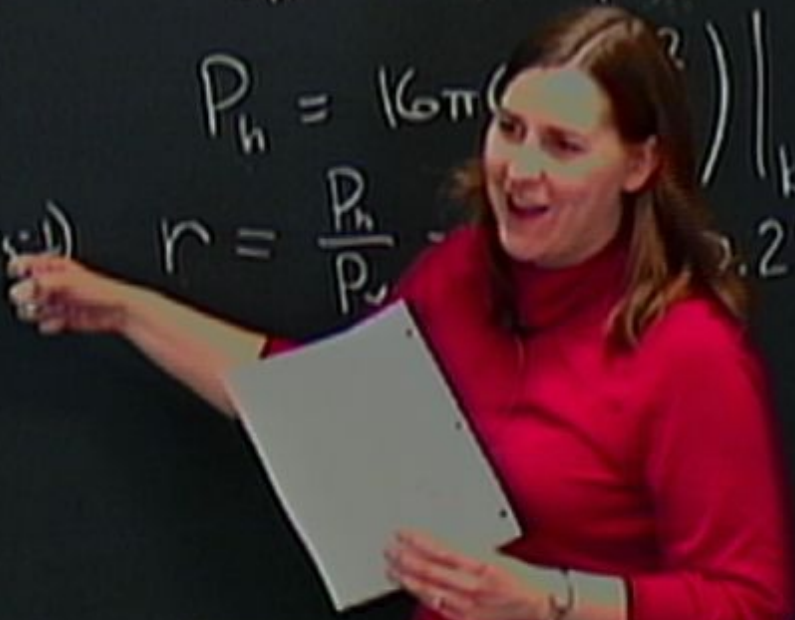
$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_S(H) = \frac{H^2}{\Phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \Rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \propto V$$

$$P_S = A_S k^{-3} k^{(n_s-1)} \quad r = \frac{P_h}{P_s} = 2.25$$





Recall

$$v = af \Rightarrow$$

$$|f_k|^2 = \frac{H^2}{2k^3} = P(k)$$

$$\delta\phi = \frac{H}{2\pi}$$

$$H(a)$$
  
$$H\left(\frac{k}{H}\right)$$

$$\epsilon_H \equiv -\frac{\dot{H}}{H^2}$$

$$P_f(k) = \frac{H^2}{(2\pi)^2}$$

$$P_S = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH}$$

$$10^{-9} \sim \frac{v}{\epsilon_H}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_n = 16\pi G \left( \frac{H^2}{2k^3} \right) v$$

$$P_S = A_S k^{-3} k^{(n_s-1)}$$

$$n = \frac{P}{P_r} = 4\epsilon < 0$$

N = 11

$$V_k(\tau) = r_k(\tau) e^{i\alpha(\tau)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$P \propto k$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

Minimize  $E_k(\tau) \Rightarrow r_k(\tau) = 0$

$$r_k(\tau) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau) = \frac{1}{\sqrt{2\omega_k}} e^{i\alpha(\tau)}$$

$$V_k' = -i \sqrt{\frac{3}{2}} e^{i\alpha(\tau)}$$

$$\tau = \frac{-1}{2H}$$

$$\omega \approx k$$

$$V_k(\tau) = \frac{1}{\sqrt{2k}} e^{ik\tau}$$

$$k\tau \gg 1$$



N 111

$$V_k(\tau) = r_k(\tau) e^{i\alpha(\tau)}$$

$$\alpha' = -\frac{1}{2r^2}$$

$$P \propto k$$

$$E_k \propto |V_k'|^2 + \omega_k^2 |V_k|^2$$

Minimize  $E_k(\tau_i) \Rightarrow r_k'(\tau_i) = 0$

$$r_k(\tau_i) = \frac{1}{\sqrt{2\omega_k}}$$

$$V_k(\tau_i) = \frac{1}{\sqrt{2\omega_k}} e^{i\alpha(\tau_i)}$$

$$V_k' = +i \sqrt{\frac{\omega}{2}} e^{i\alpha(\tau_i)}$$

$$\tau = \frac{-1}{\omega H}$$

$$\omega \approx k$$

$$V_k(\tau) = \frac{1}{\sqrt{2k}} e^{ik\tau}$$

$$k\tau \gg 1$$



$$H\left(\frac{k}{H}\right)$$

$$T_f(k) = \frac{1}{(2\pi)^2}$$

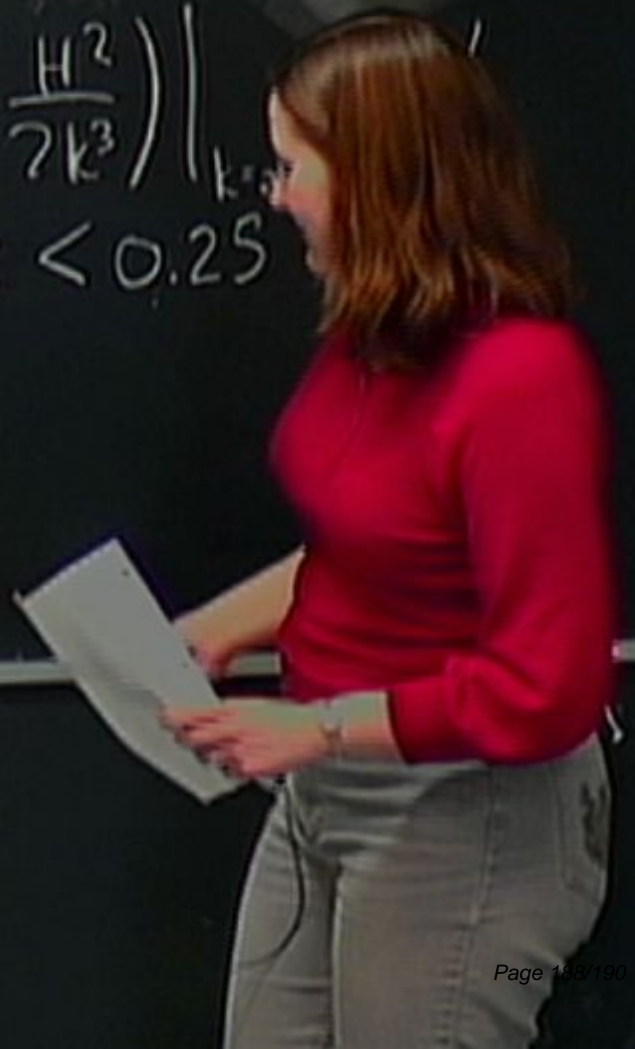
$$P_S(\omega) = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \Rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH}$$

$$P_S = A_S k^{-3} k^{(n_S-1)} \quad r = \frac{P_h}{P_S} = 4\epsilon < 0.25$$

$$n_S = 1 - 4\epsilon + 2\eta_H$$



$$H\left(\frac{k}{H}\right)$$

$$T_f(k) = \frac{1}{(2\pi)^2}$$

$$P_s(k) = \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \Rightarrow 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho$$

$$P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \propto V$$

$$P \quad k^{-3} \quad k^{(n_s-1)} \quad (r) = \frac{P_h}{P_s} = 4\epsilon < 0.25 \quad n_s = 0.96 \pm 0.05$$

$$\underline{n_s} = 1 - \frac{4\epsilon + 2\eta_H}{0.01} \lesssim 1$$

$$H\left(\frac{k}{H}\right)$$

$$T_f(k) = \frac{1}{(2\pi)^2}$$

$$P_S \approx \frac{H^2}{\phi^2} \left( \frac{H^2}{2k^3} \right) = \frac{4\pi G}{\epsilon_H} \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \approx 2 \times 10^{-9} \propto \frac{V}{\epsilon}$$

$$H^2 = \frac{8\pi G}{3} \rho \quad P_h = 16\pi G \left( \frac{H^2}{2k^3} \right) \Big|_{k=aH} \propto V$$

$$P_S \equiv A_S k^{-3} k^{(n_S-1)} \quad \textcircled{n} = \frac{P_h}{P_S} = 4\epsilon < 0.25 \quad n_S = 0.96 \pm 0.05$$

$$P_h = A_h k^{-3} k^{n_T} \quad \underline{n_S} = \underline{1 - 4\epsilon + 2\eta_H} \lesssim \underline{1} \quad n_T = -2\epsilon$$

0.01