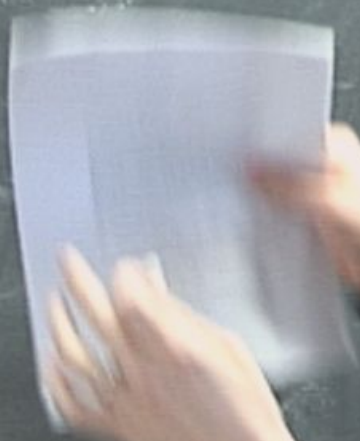


Title: Cosmology Review - Lecture 15

Date: Feb 11, 2011 11:30 AM

URL: <http://pirsa.org/11020098>

Abstract:







$$H^{-1}(t)$$



$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$

$$H^{-1}(t)$$



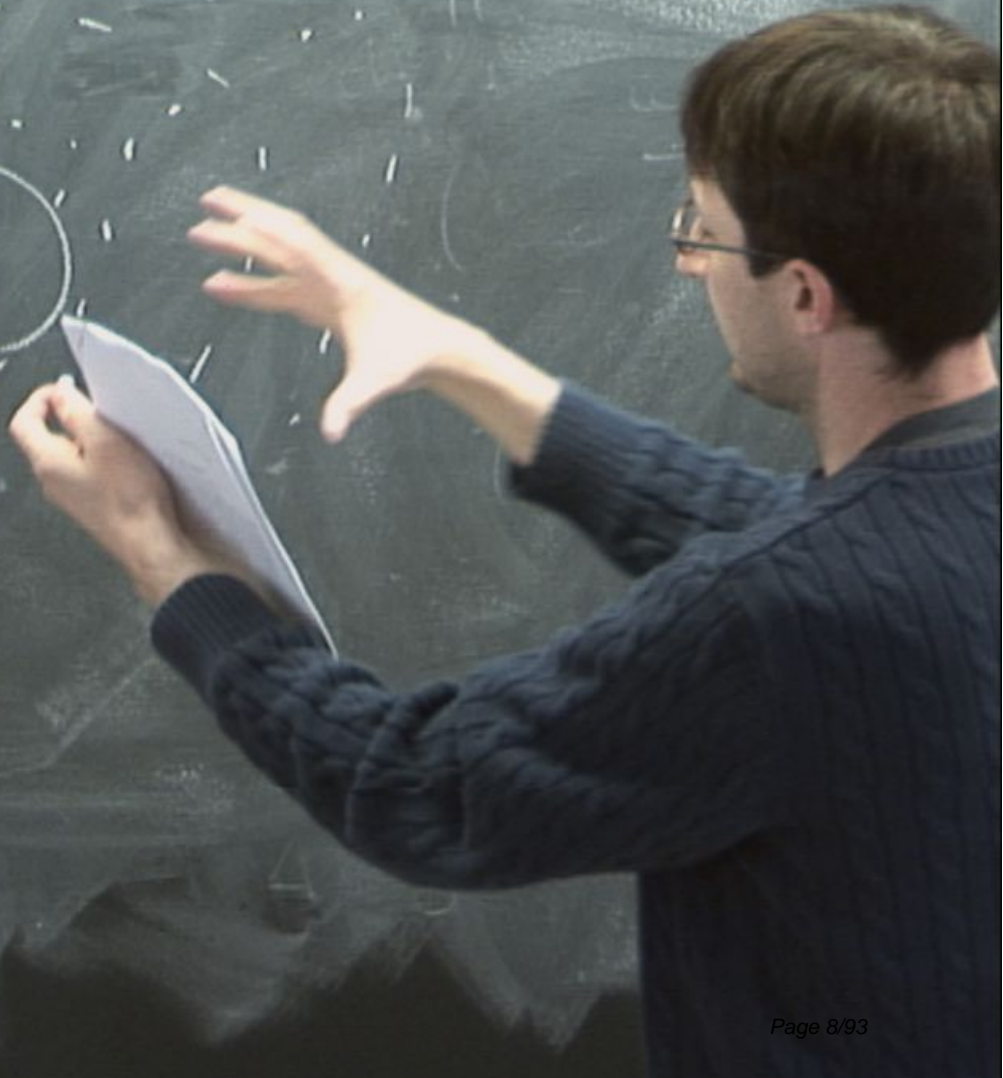
$$\frac{1}{aH} : \text{comoving}$$



$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$



$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$



$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$



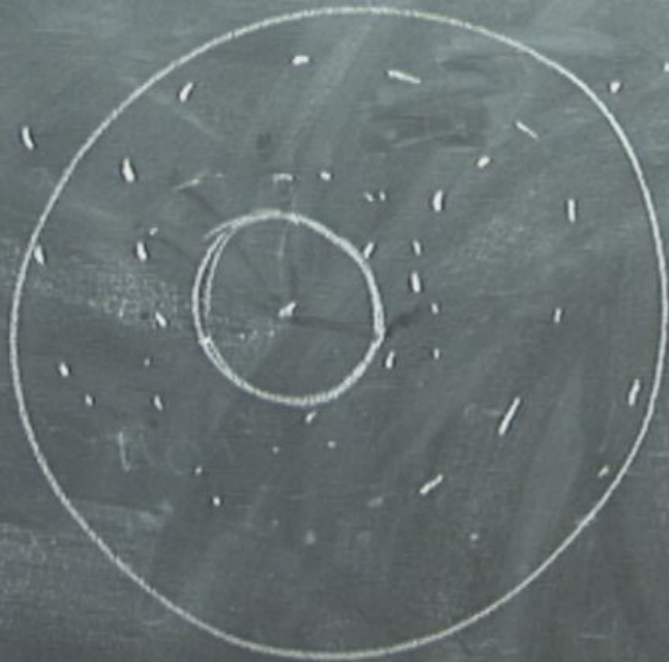
Horizon
Monopole
Flatness

$$\ddot{a} < 0$$

$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$



Horizon
Monopole
Flatness

$$\ddot{a} < 0$$
$$\ddot{a} > 0$$

$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$



Horizon
Monopole
Flatness

$$\ddot{a} < 0$$
$$\ddot{a} > 0$$

$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$



Horizon
Monopole
Flatness

$$\ddot{a} < 0$$
$$\ddot{a} > 0$$

$$\Omega < 1$$

$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$



Horizon
Monopole
Flatness

$$\ddot{a} < 0$$
$$\dot{a} > 0$$

$$H^{-1}(t)$$



$$\frac{1}{aH} : \text{comoving}$$

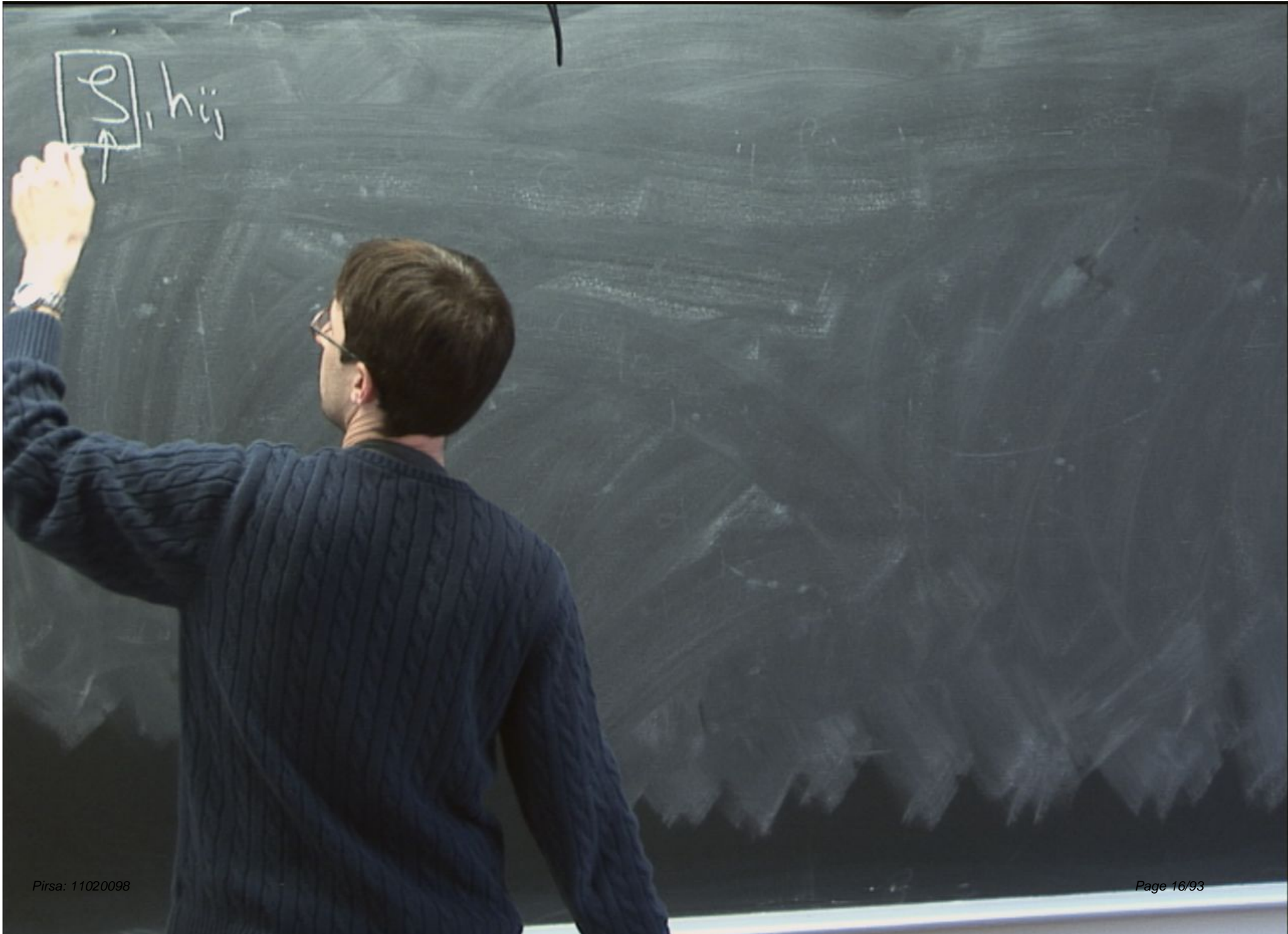


Horizon
Monopole
Flatness

$$\ddot{a} < 0$$

$$\ddot{a} > 0$$

$$e^{-2N}$$



$$10^5 \rightarrow \boxed{\sum_{i,j} h_{ij}}$$

105 → $\begin{matrix} \square & \square \\ \text{S} & \text{hij} \end{matrix}$

$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$$

$$\varphi = \hat{\varphi}(t) + \delta \hat{\varphi}(t, \vec{x})$$

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

$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$$

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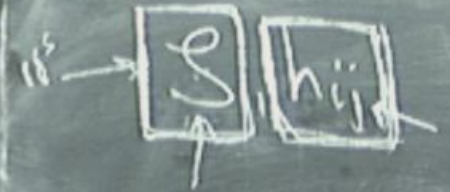
$$\phi = \hat{\phi}(t) + \delta \hat{\phi}(t, \vec{x})$$

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$$h_{ij} =$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} =$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\sigma}$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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$$\gamma_{ij} = a^2(t) e^{2\sigma} e^{2h_{ij}}$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\mathcal{Y}} e^{2h_{ij}}$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\mathcal{I}} e^{2h} \mathbb{1}$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

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$$\gamma_{ij} = a^2(t) e^{2\sigma} e^{2h}$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\beta} e^{2\alpha} \text{Tr}[\sigma]$$

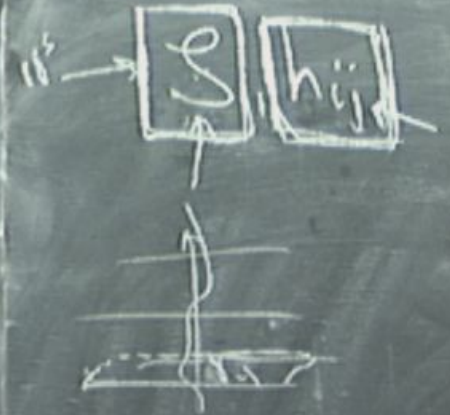


$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\mathcal{E}} e^{2\mathcal{H}} \quad \text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

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$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

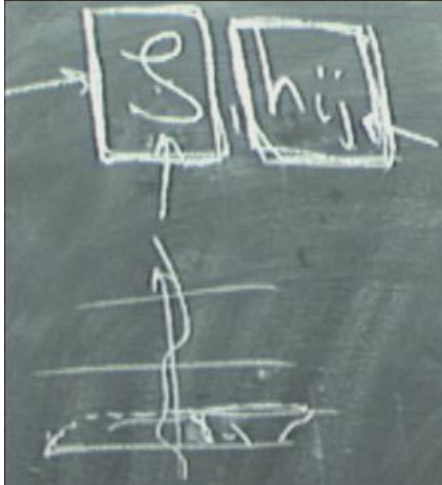
$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\beta} e^{2\alpha} \quad \text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$

$$S = \underbrace{S_g + S_h}_{S} + \dots \quad S_g = -\frac{1}{2} \int d\eta d^3\vec{x} \left[\dot{z}^2 + \eta^{\mu\nu} S_{,\mu} S_{,\nu} \right]$$





$$[\begin{matrix} m, v \\ S_{,m} S_{,v} \end{matrix}]$$

$$z = z(m)$$

$$[z] = \frac{a^2 \hat{\phi}'}{a'}$$



$$\partial_\nu \varphi - V(\varphi)$$

$$N^i dt)(dx^i + N^i dt)$$

$$\text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$

$$S_{\Sigma} = -\frac{1}{2} \int d\eta d^3 \vec{x} [z^2 \eta^{mv} \zeta_{,m} \zeta_{,v}]$$



$$z = z(\eta)$$

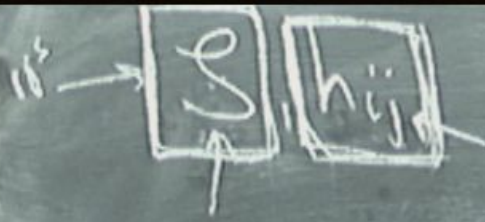
$$\frac{a^2 \hat{\phi}'}{a'}$$

$$\partial_\nu \varphi - V(\varphi)$$

$$N^i dt)(dx^i + N^i dt)$$

$$\text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$

$$S_{\Sigma} = -\frac{1}{2} \int d\eta d^3 \vec{x} \left[\frac{z^2}{z} \eta^{mv} S_{,m} S_{,v} \right]$$



$$z = z(\eta)$$

$$[Z] = \left(\frac{a^2 \hat{\phi}'}{a'} \right)$$

$$S = \int dt L(q_i, \dot{q}_i)$$

$$p_i = \frac{\partial L}{\partial \dot{q}_i}$$

$$[\hat{q}_i, \hat{q}_j] = [\hat{p}_i, \hat{p}_j] = 0$$

$$[\hat{q}_i, \hat{p}_j] = i\hbar \delta_{ij}$$

$$S = \int dt L(q_i, \dot{q}_i)$$

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$$[\hat{q}_i, \hat{q}_j] = [\hat{p}_i, \hat{p}_j] = 0$$

$$[\hat{q}_i, \hat{p}_j] = i\hbar \delta_{ij}$$

$$\varphi(\vec{x}, t)$$

$$\Pi(\vec{x}, t) = \frac{\partial \varphi(\vec{x}, t)}{\partial t}$$

$$S = \int \sqrt{-g} d^4x \left(\frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right)$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\sigma} e^{2h_{ij}} \quad \partial^i h_{jk} = 0$$

$$S = \dots + \underbrace{S_\sigma + S_h + \dots}$$

$$S = \int d\eta d^3\vec{x} \left[\mathcal{L}(\eta, \gamma_{ij}, \pi^{ij}) \right]$$

$$\pi^{ij}(\eta, \vec{x}) = \dot{\gamma}^{ij}(\eta, \vec{x}) S'(\dots)$$



$$S = \int \sqrt{-g} d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h} \quad \text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$

$$S = \dots + \underbrace{S_\zeta + \dots}_{S_\zeta} + \dots \quad S_\zeta = -\frac{1}{2} \int d\eta d^3\vec{x} \left[\frac{1}{2} \eta^{mn} \zeta_{,m} \zeta_{,n} \right]$$

$$\zeta(\vec{x}, \eta) \quad \pi(\vec{x}, \eta) = \dot{\zeta}(\eta) \zeta'(\vec{x}, \eta)$$



$$S = \int \sqrt{-g} d^4x \left(\frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right)$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\mathcal{I}} e^{2h} \quad \text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$

$$S = \dots + \underbrace{S_{\mathcal{I}} + \dots}_{S_{\mathcal{I}}} + \dots \quad S_{\mathcal{I}} = -\frac{1}{2} \int d\eta d^3\vec{x} \left[\mathcal{I}^2 \eta^{mn} \zeta_{,m} \zeta_{,n} \right]$$

$$\zeta(\vec{x}, \eta) \quad \pi(\vec{x}, \eta) = \dot{\zeta}(\vec{x}, \eta)$$

$$[\zeta(\vec{x}, \eta), \zeta(\vec{x}', \eta)] = [\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)]$$

$$[\zeta(\vec{x}, \eta), \pi(\vec{x}', \eta)] = i\hbar \delta^{(3)}(\vec{x} - \vec{x}')$$



$$S = \int \sqrt{-g} d^4x \left(\frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right)$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\mathcal{I}} e^{2h} \quad \text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$

$$S = \dots + \underbrace{S_{\mathcal{I}} + \dots}_{S_{\mathcal{I}}} + \dots \quad S_{\mathcal{I}} = -\frac{1}{2} \int d\eta d^3\vec{x} \left[\mathcal{I}^2 \eta^{\mu\nu} \zeta_{,\mu} \zeta_{,\nu} \right]$$

$$\mathcal{I}(\vec{x}, \eta) \quad \pi(\vec{x}, \eta) = \mathcal{I}'(\vec{x}, \eta)$$

$$[\mathcal{I}(\vec{x}, \eta), \mathcal{I}(\vec{x}', \eta)] = [\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$$

$$[\mathcal{I}(\vec{x}, \eta), \pi(\vec{x}', \eta)] = i\hbar \delta^{(3)}(\vec{x} - \vec{x}')$$



$$S = \int \sqrt{-g} d^4x \left(\frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right)$$

$$\phi = \hat{\phi}(t) + \delta\hat{\phi}(t, \vec{x})$$

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

$$\gamma_{ij} = a^2(t) e^{2\mathcal{E}} e^{2h} \quad \text{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$$

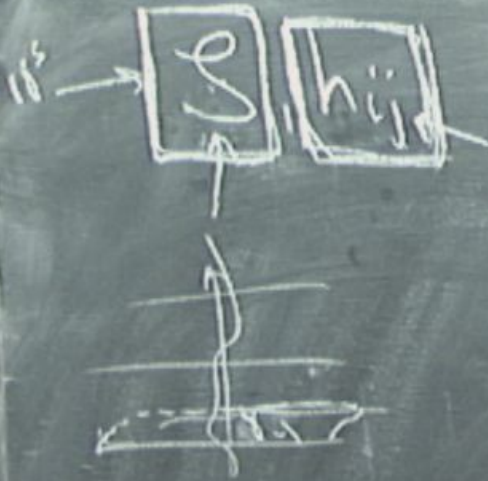
$$S = \dots + \underbrace{S_{\mathcal{E}} + \dots}_{S_{\mathcal{E}}} + \dots \quad S_{\mathcal{E}} = -\frac{1}{2} \int d\eta d^3\vec{x} \left[\mathcal{E}^2 - \eta^{mn} \mathcal{E}_{,m} \mathcal{E}_{,n} \right]$$

$$\mathcal{E}(\vec{x}, \eta) \quad \pi(\vec{x}, \eta) = \mathcal{E}'(\vec{x}, \eta)$$

$$[\mathcal{E}(\vec{x}, \eta), \mathcal{E}(\vec{x}', \eta)] = [\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$$

$$[\mathcal{E}(\vec{x}, \eta), \pi(\vec{x}', \eta)] = i\hbar \delta^{(3)}(\vec{x} - \vec{x}')$$





$$g(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \tilde{g}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

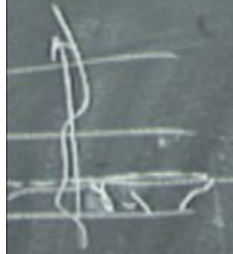
$$[\tilde{z} \eta^{mv} \tilde{g}_{,m} \tilde{g}_{,v}]$$

$$\eta) \tilde{g}'(\vec{x}, \eta)$$

$$[\Pi(\vec{x}, \eta)] = 0$$

$$^{(3)}(\vec{x}, \vec{x}')$$

\hat{g} h_{ij}



$$\hat{g}(M, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(M) e^{i \vec{k} \cdot \vec{x}}$$

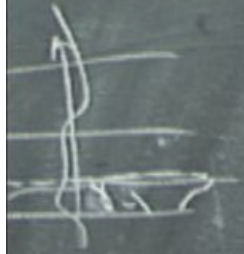
$$g_{\vec{k}} = g_{-\vec{k}}^*$$

$S_{,m} S_{,v}$

$$g = g^*$$

$] = 0$

S_{ij}



$S_{,m} S_{,v}$

$] = 0$

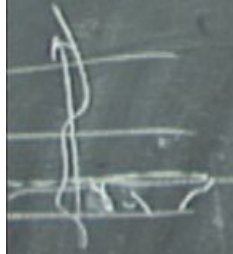
$$\hat{g}(M, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(M) e^{i \vec{k} \cdot \vec{x}}$$

$$g = g^T$$

$$g_{\vec{k}} = g_{-\vec{k}}^*$$

$g_{\vec{k}}$

S_{ij}



$S_{,m} S_{,v}$

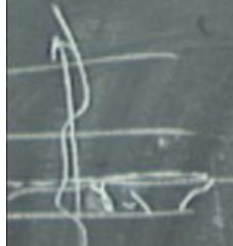
$] = 0$

$$\hat{g}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}} \quad \hat{g}_{\vec{k}} = \hat{g}_{-\vec{k}}^\dagger$$

$\hat{g}_{\vec{k}}(\eta)$

$g = g^\dagger$

S_{ij}



$S_{,m} S_{,v}$

$] = 0$

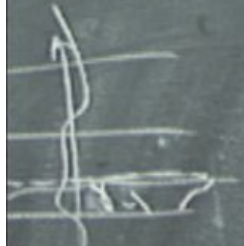
$$\hat{g}(M, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(M) e^{i \vec{k} \cdot \vec{x}}$$

$$g = g^\dagger$$

$$g_{\vec{k}} = g_{-\vec{k}}^\dagger$$

$$\hat{g}_{\vec{k}}(M) =$$

S_{ij}



$S_{,m} S_{,v}$

$] = 0$

$$\hat{g}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$g = g^\dagger$$

$$g_{\vec{k}} = g_{-\vec{k}}^\dagger$$

$$\hat{g}_{\vec{k}}(\eta) = g_{\vec{k}}(\eta) \hat{g}_{\vec{k}}$$

h_{ij}

$$\hat{g}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{g}_{\vec{k}} = \hat{g}_{-\vec{k}}^\dagger$$

$$g = g^\dagger$$

$$\hat{g}_{\vec{k}}(\eta) = \hat{g}_{\vec{k}}(\eta) \hat{a}_{\vec{k}} + \hat{g}_{-\vec{k}}^*(\eta) \hat{a}_{\vec{k}}^\dagger$$

$m \delta_{\mu\nu}$

0

h_{ij}

$$\hat{g}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{g}_{\vec{k}} = \hat{g}_{-\vec{k}}^*$$

$$g = g^T$$

$$\hat{g}_{\vec{k}}(\eta) = \hat{g}_{\vec{k}}(\eta) \hat{a}_{\vec{k}} + \hat{g}_{-\vec{k}}^*(\eta) \hat{a}_{-\vec{k}}$$

$m \delta_{\mu\nu}$

$= 0$

h_{ij}

$$\hat{g}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{g}_{\vec{k}} = \hat{g}_{-\vec{k}}^\dagger$$

$$\hat{g}_{\vec{k}}(\eta) = \hat{g}_{\vec{k}}(\eta) \hat{a}_{\vec{k}} + \hat{g}_{-\vec{k}}^*(\eta) \hat{a}_{-\vec{k}}^\dagger$$

$$g = g^\dagger$$

$m \hat{g}_{i,j}$

0

h_{ij}

$$\hat{f}(\mathcal{N}, \vec{x}) = \hat{f}_k(\mathcal{N}) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{S}_k = \hat{S}_{-k}^\dagger$$

$$\hat{S}_k(\mathcal{N}) = S_k(\mathcal{N}) \hat{a}_k + S_{-k}^*(\mathcal{N}) \hat{a}_{-k}^\dagger$$

$m S_{i,v}$

$$S = \dots$$

h_{ij}

$$\hat{g}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{g}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{g}_{\vec{k}} = \hat{g}_{-\vec{k}}^\dagger$$

$m_{\mu\nu}$

$$g = g^\dagger$$

$$\hat{g}_{\vec{k}}(\eta) = \hat{g}_{\vec{k}}(\eta) \hat{a}_{\vec{k}}^\dagger + \hat{g}_{-\vec{k}}^*(\eta) \hat{a}_{\vec{k}}$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = -\delta^{(3)}(\vec{k} - \vec{k}')$$

0

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\hat{\psi}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{\psi}_{\vec{k}} = \hat{\psi}_{-\vec{k}}^\dagger$$

$$\hat{\psi}_{\vec{k}}(\eta) = \hat{\psi}_{\vec{k}}(\eta) \hat{a}_{\vec{k}} + \hat{\psi}_{-\vec{k}}^*(\eta) \hat{a}_{\vec{k}}^\dagger$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\psi_k'' + 2 \frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\hat{\psi}(\mathcal{N}, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{N}) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{\psi}_{\vec{k}} = \hat{\psi}_{-\vec{k}}^\dagger$$

$$\hat{\psi}_{\vec{k}}(\mathcal{N}) = \hat{\psi}_{\vec{k}}(\mathcal{N}) \hat{a}_{\vec{k}} + \hat{\psi}_{-\vec{k}}^*(\mathcal{N}) \hat{a}_{\vec{k}}^\dagger$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\psi_k'' + 2\frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\hat{\psi}(\mathcal{M}, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{M}) e^{i \vec{k} \cdot \vec{x}}$$

$$\psi_{\vec{k}} = \psi_{\vec{k}}^+$$

$$\hat{\psi}_{\vec{k}}(\mathcal{M}) = \psi_{\vec{k}}^+(\mathcal{M}) + \psi_{-\vec{k}}^*(\mathcal{M})$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\psi_k'' + 2 \frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\phi} + 3H\dot{\phi} + m^2 \phi = 0$$

$$\hat{\psi}(\mathcal{M}, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{M}) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{\psi}_{\vec{k}} = \hat{\psi}_{-\vec{k}}^\dagger$$

$$\hat{\psi}_{\vec{k}}(\mathcal{M}) = \hat{\psi}_{\vec{k}}(\mathcal{M}) \hat{a}_{\vec{k}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\psi_k'' + 2\frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\phi} + 3\dot{a} \dot{\phi} + m^2 \phi = 0$$

$$\hat{\psi}(\mathcal{M}, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{M}) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{\psi}_{\vec{k}} = \hat{\psi}_{-\vec{k}}^\dagger$$

$$\hat{\psi}_{\vec{k}}(\mathcal{M}) = \hat{\psi}_{\vec{k}}(\mathcal{M}) \hat{a}_{\vec{k}} + \hat{\psi}_{-\vec{k}}^*(\mathcal{M}) \hat{a}_{\vec{k}}^\dagger$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\psi_k'' + 2 \frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\varphi} + \omega^2 \varphi = 0$$

$$\hat{\psi}(\mathcal{M}, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{M}) e^{i \vec{k} \cdot \vec{x}}$$

$$\psi = \sum_{\vec{k}} \psi_{\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(\mathcal{M}) = \int d^3 x \hat{\psi}_{\vec{k}}^{\dagger}(\mathcal{M}) \psi(\mathcal{M}, \vec{x})$$

$$\psi = \psi^{\dagger}$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^{\dagger}] = [\hat{a}_{\vec{k}}^{\dagger}, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^{\dagger}] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\psi_k'' + 2\frac{z'}{z}\psi_k' + k^2\psi_k = 0$$

$$\ddot{\phi} + 3\dot{a}\phi + m^2\phi = 0$$

$$\hat{\psi}(\mathcal{M}, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{M}) e^{i\vec{k}\cdot\vec{x}}$$

$$\hat{\psi}_{\vec{k}} = \hat{\psi}_{-\vec{k}}^\dagger$$

$$\psi = \psi^\dagger$$

$$\hat{\psi}_{\vec{k}}(\mathcal{M}) = \hat{\psi}_{\vec{k}}(\mathcal{M}) \hat{a}_{\vec{k}}^\dagger + \hat{\psi}_{-\vec{k}}^*(\mathcal{M}) \hat{a}_{\vec{k}}^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\psi_k'' + 2\frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\phi} + 3\dot{a} \dot{\phi} + m^2 \phi = 0$$

$$= \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{\psi}_{\vec{k}} = \hat{\psi}_{-\vec{k}}^\dagger$$

$$\hat{\psi}_{\vec{k}}(\eta) = \psi_{\vec{k}}(\eta) \hat{a}_{\vec{k}} + \psi_{-\vec{k}}^*(\eta) \hat{a}_{\vec{k}}^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$V(\varphi) = \frac{1}{2} m \omega^2 \varphi^2$$

$$\varphi_k'' + 2 \frac{z'}{z} \varphi_k' + \dots$$

$$\ddot{\varphi} + 3 \dot{a} \dot{\varphi} + m^2 \varphi$$

$$= \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\varphi}_{\vec{k}} e^{i \vec{k} \cdot \vec{x}}$$

$$\hat{\varphi}_{\vec{k}} = \hat{\varphi}_{-\vec{k}}$$

$$\hat{\varphi}_{\vec{k}}(\eta) = \hat{\varphi}_{\vec{k}}(\eta) + \hat{\varphi}_{-\vec{k}}^*(\eta)$$

$$= \delta^{(3)}(\vec{k} - \vec{k}')$$

$$\varphi(\vec{x}, \eta) = 0$$

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$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$N^j dt$
 $\partial_i h_{jk} = 0$

$$d\eta d^3 \vec{x} \left[\frac{1}{2} \dot{\eta}^2 - \eta (\zeta_{,m} \zeta_{,m}) \right]$$

$$z(\vec{x}, \eta) = z^z(\eta) \delta^z(\vec{x}, \eta)$$

$$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$$

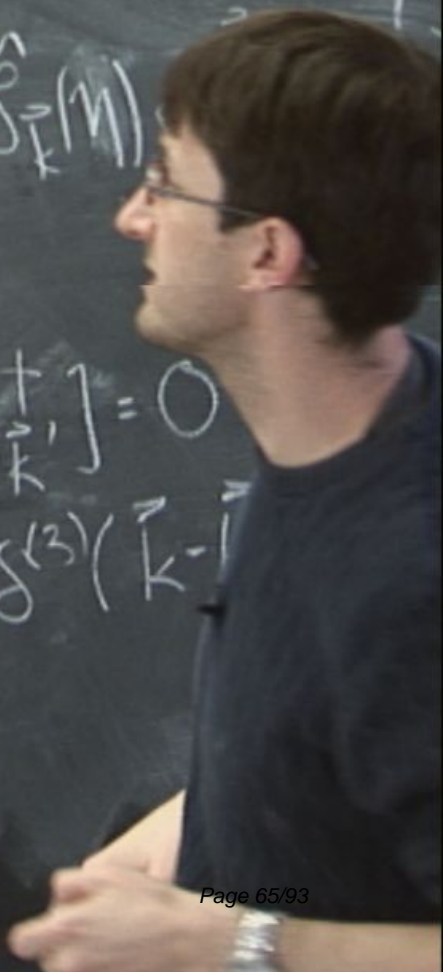
$$[\dots] = i \hbar \delta^{(3)}(\vec{x} - \vec{x}')$$

$$\hat{f}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{f}_{\vec{k}}(\eta)$$

$$f = f^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = i \delta^{(3)}(\vec{k} - \vec{k}')$$



$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$N^j dt)$
 $\partial_i h_{jk} = 0$

$$d\eta d^3 \vec{x} \left[\frac{1}{2} \dot{\eta}^2 - \eta (\mathcal{L}_{,m} \mathcal{L}_{,v}) \right]$$

$$z(\vec{x}, \eta) = z^z(\eta) \mathcal{S}'(\vec{x}, \eta)$$

$$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$$

$$] = i \hbar \delta^{(3)}(\vec{x} - \vec{x}')$$

$$\hat{\mathcal{S}}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\mathcal{S}}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\mathcal{S} = \mathcal{S}^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$\mathcal{S}_{\vec{k}} = \dots$
 $\mathcal{S}_{\vec{k}}(\eta)$

$\mathcal{S}_{\vec{k}}(\eta)$

$$a_k^\dagger |0\rangle$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$N(t)$$
$$a_k^\dagger h_{kk} = 0$$

$$d\eta d^3\vec{x} [z^2 \eta \zeta_{,m} \zeta_{,v}]$$

$$z(\vec{x}, \eta) = z^z(\eta) \zeta'(\vec{x}, \eta)$$

$$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$$

$$= i\hbar \delta^{(3)}(\vec{x} - \vec{x}')$$

$$\hat{f}(\eta, \vec{x}) = f(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$S = \int$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}$$

$$\int_{\vec{k}}$$
$$\phi$$

$$\int_{\vec{k}}$$

$$= 0$$

$$(\vec{k})$$

$$a_2|0\rangle = 0$$

$$\langle 0|e^{\dots}$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$N(t)$$
$$a_k h_{ik} = 0$$

$$d\eta d^3\vec{x} \left[\frac{1}{2} \eta \sum_{i,j} \xi_{i,j} \right]$$

$$z(\vec{x}, \eta) = z^2(\eta) \delta^3(\vec{x}, \eta)$$

$$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$$

$$= i\hbar \delta^{(3)}(\vec{x} - \vec{x}')$$

$$\hat{f}(\eta, \vec{x})$$

$$k(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$+ j = 0$$

$$\delta^3(\vec{k} - \vec{k}')$$

$$\sum_k \dots$$

$$\sum_k \dots$$

$$a_{\vec{k}}|0\rangle = 0$$

$$\langle 0 | \mathcal{S}(\vec{x}, \eta) | 0 \rangle =$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$N(d,t)$
 $\partial_i h_{jk} = 0$

$$d\eta d^3\vec{x} \left[\frac{1}{2} \dot{z}^2 - \eta \mathcal{L}_{,m} \mathcal{L}_{,v} \right]$$

$$z(\vec{x}, \eta) = z^z(\eta) \mathcal{S}(\vec{x}, \eta)$$

$$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$$

$$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = i\hbar \delta^{(3)}(\vec{x} - \vec{x}')$$

$$\hat{\mathcal{S}}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\mathcal{S}}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\mathcal{S} = \mathcal{S}^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}^\dagger] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$\mathcal{S}_{\vec{k}}$
 ϕ

$\mathcal{S}_{\vec{k}}$

$$\langle 0 | \psi(\vec{x}, t) | 0 \rangle =$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\sum_{\vec{k}} \phi''_{\vec{k}} + 2 \frac{\omega^2}{v^2} \phi'_{\vec{k}} + \phi_{\vec{k}} = 0$$

$$\ddot{\phi} + 3 \dot{\phi} + m^2 \phi = 0$$

$$\hat{\psi}(\mathcal{M}, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{M}) e^{i \vec{k} \cdot \vec{x}}$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(\mathcal{M}) = \psi_{\vec{k}}(\mathcal{M}) \hat{a}_{\vec{k}} + \psi_{-\vec{k}}^*(\mathcal{M}) \hat{a}_{-\vec{k}}^\dagger$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$\langle 0 | \psi(\vec{x}, t) | 0 \rangle = \int_0^\infty m k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\psi_k'' + 2 \frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\varphi} + 3 \frac{\dot{a}}{a} \dot{\varphi} + m^2 \varphi = 0$$

$$\hat{\psi}(\mathcal{M}, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\mathcal{M}) e^{i \vec{k} \cdot \vec{x}}$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}^\dagger$$

$$\hat{\psi}_{\vec{k}}(\mathcal{M}) = \psi_{\vec{k}}(\mathcal{M}) \hat{a}_{\vec{k}}^\dagger + \psi_{-\vec{k}}^*(\mathcal{M}) \hat{a}_{\vec{k}}$$

ψ_{ν}

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = i \delta^{(3)}(\vec{k} - \vec{k}')$$

$$\langle 0 | \psi^2(\vec{x}, \eta) | 0 \rangle = \int_0^\infty \eta k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \cdot \|^2 = \frac{k^2}{2\pi^2} |S_k|^2$$

$$\hat{\psi}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{S}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}^\dagger] = -\delta^{(3)}(\vec{k} - \vec{k}')$$

$$\psi_k'' + 2 \frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\phi} + 3 \frac{\dot{a}}{a} \dot{\phi} + m^2 \phi = 0$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{S}_{\vec{k}}(\eta) = \hat{S}_{\vec{k}}(\eta) + \hat{S}_{-\vec{k}}^*(\eta)$$

$$\langle 0 | \psi^2(\vec{x}, \eta) | 0 \rangle = \int_0^\infty 4\pi k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \psi \|^2 = \frac{k^3}{2\pi^2} |\psi_k|^2$$

$$\hat{\psi}(\eta, \vec{x}) = \int \frac{d^3 \vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i \vec{k} \cdot \vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = [\hat{a}_{\vec{k}_1}^\dagger, \hat{a}_{\vec{k}_2}] = 0$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = -\delta^{(3)}(\vec{k}_1 - \vec{k}_2)$$

$$\psi_k'' + 2 \frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\varphi} + 3 \frac{\dot{a}}{a} \dot{\varphi} + m^2 \varphi = 0 \quad \varphi = a^{-3/2} \psi$$

$$\hat{\psi}_{\vec{k}} = \dots$$

$$\hat{\psi}_{\vec{k}}(\eta) = \hat{\psi}_{\vec{k}}(\eta) \hat{a}_{\vec{k}} + \hat{\psi}_{-\vec{k}}^*(\eta) \hat{a}_{\vec{k}}^\dagger$$

$$\langle 0 | \psi^2(\vec{x}, \eta) | 0 \rangle = \int_0^\infty 4\pi k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \cdot \|^2 = \frac{k^3}{2\pi^2} |\psi_k|^2$$

$$\hat{\psi}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = [\hat{a}_{\vec{k}_1}^\dagger, \hat{a}_{\vec{k}_2}] = 0$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = \delta^{(3)}(\vec{k}_1 - \vec{k}_2)$$

$$\psi_k'' + 2\frac{z'}{z}\psi_k' + k^2\psi_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0 \quad \varphi = a^{-3/2} v$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(\eta) = \hat{\psi}_{\vec{k}}(\eta) + \hat{\psi}_{-\vec{k}}^*(\eta)$$

$$\langle 0 | \psi^2(\vec{x}, \eta) | 0 \rangle = \int_0^\infty 4\pi k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \psi \|^2 = \frac{k^3}{2\pi^2} |\psi_k|^2$$

$$\psi(\vec{x}, \eta) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_1'}^\dagger] = [\hat{a}_{\vec{k}_1}^\dagger, \hat{a}_{\vec{k}_1'}] = 0$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_1'}^\dagger] = -\delta^{(3)}(\vec{k}_1 - \vec{k}_1')$$

$$\psi_k'' + 2\frac{z'}{z}\psi_k' + k^2\psi_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0 \quad \varphi = a^{-3/2} \psi$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(\eta) = \hat{\psi}_{\vec{k}}(\eta) + \hat{\psi}_{-\vec{k}}^*(\eta)$$

$$\langle 0 | \psi^2(\vec{x}, \eta) | 0 \rangle = \int_0^\infty 4\pi k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \psi \|^2 = \frac{k^3}{2\pi^2} |\psi_k|^2$$

$$\psi(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}^\dagger] = -\delta^{(3)}(\vec{k} - \vec{k}')$$

$$\psi_k'' + 2\frac{z'}{z}\psi_k' + k^2\psi_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(\eta) = \hat{\psi}_{\vec{k}}(\eta) \hat{a}_{\vec{k}}^\dagger + \hat{\psi}_{-\vec{k}}^*(\eta)$$

$\varphi = a^{-3/2} v$

$$\langle 0 | \psi^2(\vec{x}, \eta) | 0 \rangle = \int_0^\infty 4\pi k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \cdot \|^2 = \frac{k^3}{2\pi^2} |\psi_k|^2$$

$$\hat{\psi}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = [\hat{a}_{\vec{k}_1}^\dagger, \hat{a}_{\vec{k}_2}] = 0$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = -\delta^{(3)}(\vec{k}_1 - \vec{k}_2)$$

$$\psi_k'' + 2\frac{z'}{z}\psi_k' + k^2\psi_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$$

$$\varphi = a^{-3/2} \cos mt$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(\eta) = \hat{\psi}_{\vec{k}}(\eta) \hat{a}_{\vec{k}} + \hat{\psi}_{-\vec{k}}^*(\eta) \hat{a}_{\vec{k}}^\dagger$$

$$\langle 0 | \psi^2(\vec{x}, \eta) | 0 \rangle = \int_0^\infty 4\pi k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \psi \|^2 = \frac{k^2}{2\pi^2} |\psi_k|^2$$

$$\hat{\psi}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = [\hat{a}_{\vec{k}_1}^\dagger, \hat{a}_{\vec{k}_2}] = 0$$

$$[\hat{a}_{\vec{k}_1}, \hat{a}_{\vec{k}_2}^\dagger] = -i \delta^{(3)}(\vec{k}_1 - \vec{k}_2)$$

$$\psi_k'' + 2\frac{z'}{z}\psi_k' + k^2\psi_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$$

$\varphi = a^{-3/2} \cos mt$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(\eta) = \hat{\psi}_{\vec{k}}(\eta) + \hat{\psi}_{-\vec{k}}^*(\eta)$$

$$\langle 0 | \psi^2(\vec{x}, t) | 0 \rangle = \int_0^\infty 4\pi k^2 dk (\dots)$$

$$= \int_0^\infty \frac{dk}{k} (\dots)$$

$$= \int_{-\infty}^\infty d(\ln k) (\dots)$$

$$\| \psi \|^2 = \frac{k^3}{2\pi^2} |\psi_k|^2$$

$$\psi(\vec{x}, t) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\psi}_{\vec{k}}(t) e^{i\vec{k}\cdot\vec{x}}$$

$$\psi = \psi^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = [\hat{a}_{\vec{k}}^\dagger, \hat{a}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}^\dagger] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$\psi_k'' + 2\frac{z'}{z} \psi_k' + k^2 \psi_k = 0$$

$$\ddot{\phi} + 3\frac{\dot{a}}{a} \dot{\phi} + m^2 \phi = 0$$

$$\phi = a^{-3/2} \cos mt$$

$$\psi_{\vec{k}} = \psi_{-\vec{k}}$$

$$\hat{\psi}_{\vec{k}}(t) = \hat{\psi}_{\vec{k}}(t) \hat{a}_{\vec{k}} + \hat{\psi}_{-\vec{k}}^*(t) \hat{a}_{\vec{k}}^\dagger$$

$$J_K = \frac{1}{Z} (A_{kp}^{(1)} e^{-ikT} + A_{ke}^{(2)} e^{+ikT})$$

$$a_k |0\rangle = 0$$



$$J_K = \frac{1}{Z} (A_{kR}^{(1)} - i k T + A_{kE}^{(2)} + i k T)$$

$$a_k |0\rangle = 0$$

$$P_j$$

$$J_k = \frac{1}{2} (A_k^{(1)} e^{-ikt} + A_k^{(2)} e^{ikt})$$

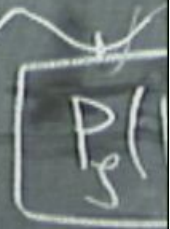
$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$[\varphi, \pi]$

$[a_k, a_k^\dagger]$

$$a_k |0\rangle = 0$$



$$J_k = \frac{1}{2} (A_k^{(1)} e^{-ikt} + A_k^{(2)} e^{ikt})$$

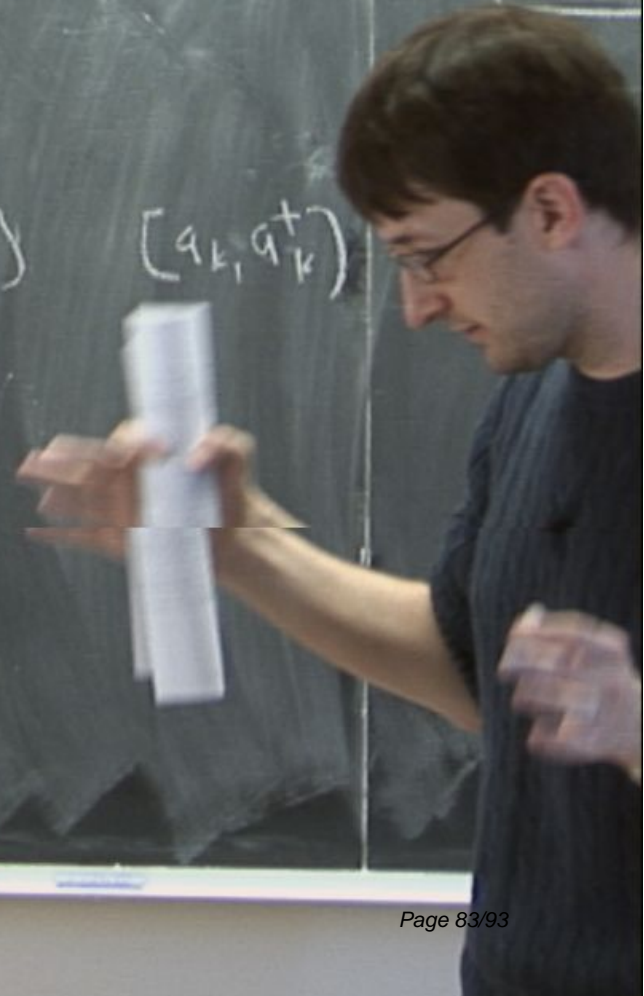
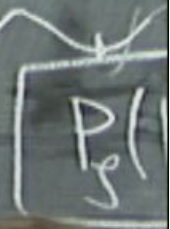
$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$[\varphi, \pi]$

$[a_k, a_k^\dagger]$

$$a_k |0\rangle = 0$$



$$\underline{e^{-i\omega t + ikx}}$$

$$a_2|0\rangle = 0$$

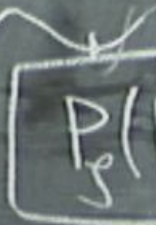
$$\int_K = \frac{1}{2\sqrt{2k}} e^{-ikt}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[\varphi, \pi]$$

$$[a_k, a_k^\dagger]$$



$$\underline{e^{-i\omega t + i\vec{k}\cdot\vec{x}}}$$

$$a_k|0\rangle = 0$$

$$\int_k \frac{1}{\sqrt{2k}} e^{-ikx}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[\varphi, \pi]$$

$$[a_k, a_k^\dagger]$$

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

$$a_k|0\rangle = 0$$

$$\int_K \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[\varphi, \pi]$$

$$[a_k, a_k^\dagger]$$

$$P(\varphi)$$

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

$$a_k|0\rangle = 0$$

$$J_k = \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[\rho, \pi]$$

$$[a_k, a_k^\dagger]$$



$$e^{-i\omega t + i\vec{k} \cdot \vec{x}}$$

$$a_k |0\rangle = 0$$

$$J_k = \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[\rho, \pi]$$

$$[a_k, a_k^\dagger]$$

$$P(\rho)$$

$$\underline{e^{-i\omega t + i\vec{k}\cdot\vec{x}}}$$

$$a_k|0\rangle = 0$$

$$J_k = \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$P_g = \frac{1}{2\epsilon} \left(\frac{H}{m\pi} \right)^2$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[g, \pi]$$

$$[a_k, a_k^+]$$

$$P_g$$

$$\underline{e^{-i\omega t + i\vec{k}\cdot\vec{x}}}$$

$$a_k|0\rangle = 0$$

$$\int_K \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$\rightarrow P_g = \frac{1}{2\epsilon} \left(\frac{H}{m\pi} \right)^2$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[\phi, \pi]$$

$$[a_k, a_k^\dagger]$$

$$e^{-i\omega t + i\vec{k} \cdot \vec{x}}$$

$$\lambda = \frac{2\pi}{k}$$

$$a_k |0\rangle = 0$$

$$\int_K \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$P_{\mathcal{F}}^{(k)} = \frac{1}{2\epsilon} \left(\frac{H}{m_{pl}} \right)^2$$

$$P_{\mathcal{F}}^{(k)}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$[\mathcal{F}, \pi]$$

$$[a_k, a_k^\dagger]$$

$$e^{-i\omega t + ikx}$$

$$\lambda = \frac{2\pi}{k}$$

$$a_k |0\rangle = 0$$

$$\int_k \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$P_g^{(k)} = \frac{1}{2\epsilon} \left(\frac{H}{m_{pl}} \right)^2$$

$$P_g$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$V(\phi)$$

$$[\phi, \pi]$$

$$[a_k, a_k^\dagger]$$

$$V(\phi) = \frac{1}{2} m^2 \phi^2$$

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

$$\lambda = \frac{2\pi}{k}$$

$$a_k |0\rangle = 0$$

$$\int_K \frac{1}{2\sqrt{2k}} e^{-ikx}$$

$$P_g^{(k)} = \frac{1}{2\epsilon} \left(\frac{H}{m_{pl}} \right)^2$$

$$P_g$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, A_k^{(2)} = 0$$

$$V(\phi)$$

$$[\varphi, \pi]$$

$$[a_k, a_k^\dagger]$$

$$V(\phi) = \frac{1}{2} m^2 \phi^2$$