Title: PSI 2017/2018 - Relativistic Quantum Information - Lecture 10

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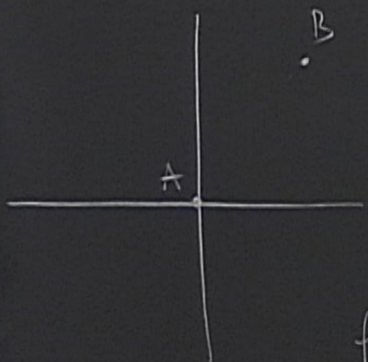
Abstract:

Communication through a massless Quantum field



$$\hat{m}_\nu = \left(\hat{\sigma}^+_\nu e^{i\Omega_\nu t} + \hat{\sigma}^-_\nu e^{-i\Omega t}\right)$$

$$\hat{H}_I = \sum_{\nu \in \{A,B\}} \lambda_\nu \chi_\nu(t)\, \hat{m}_\nu(t) \int d^n x\, F(\vec{x}-\vec{x}_\nu)\, \hat{\phi}(t,\vec{x})$$

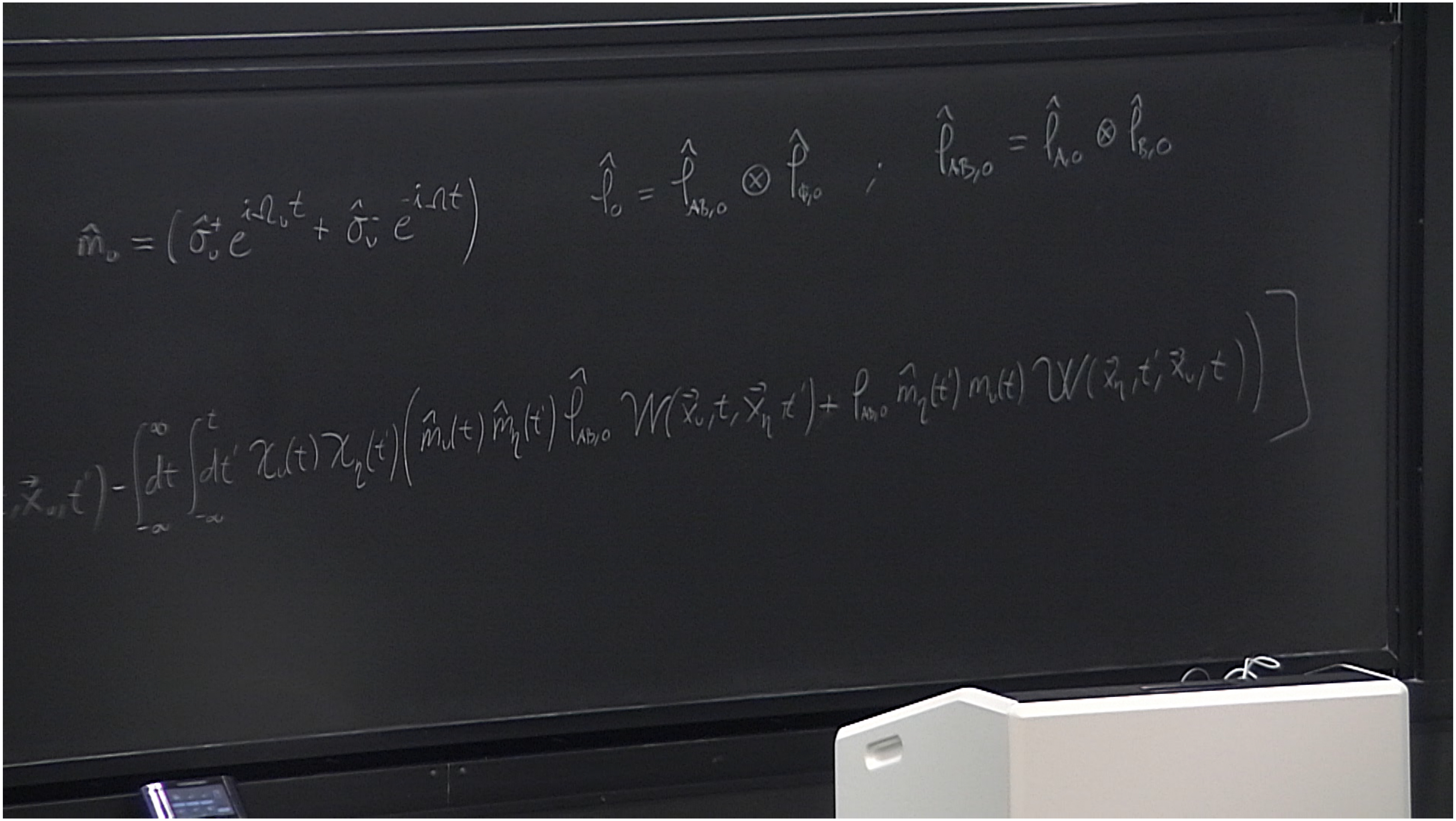
Dyson expansion: $\hat{\rho}_T = \hat{\rho}_0 + \hat{\rho}^{(1)}_T + \hat{\rho}^{(2)} + \mathcal{O}(\lambda_\nu^3)$

$$\hat{\rho}^{(2)}_{d,T} = \sum_{\nu,\eta} \lambda_\nu \lambda_\eta \Big[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt'\, \chi_\nu(t')\, \chi_\eta(t)\, \hat{m}_\nu(t')\, \hat{\rho}_{AB,0}\, \hat{m}_\eta(t)\, W(\vec{x}_\eta, t, \vec{x}_\nu, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt'\, \chi_\nu(t)\, \chi_\eta(t') \big(\hat{m}_\nu(t)\, \hat{m}_\eta(t')\, \hat{\rho}_{A}$$

$$\hat{m}_\nu = \left(\hat{\sigma}_\nu^{+} e^{i\Omega_\nu t} + \hat{\sigma}_\nu^{-} e^{-i\Omega t}\right)$$

$$\hat{\rho}_0 = \hat{\rho}_{AB,0} \otimes \hat{\rho}_{\Phi,0} \quad ; \quad \hat{\rho}_{AB,0} = \hat{\rho}_{A,0} \otimes \hat{\rho}_{B,0}$$

$$\ldots, \vec{x}_\nu, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt' \, \chi_\nu(t)\, \chi_\eta(t') \left(\hat{m}_\nu(t)\, \hat{m}_\eta(t')\, \hat{\rho}_{AB,0}\, W(\vec{x}_\nu, t, \vec{x}_\eta, t') + \rho_{AB,0}\, \hat{m}_\eta(t')\, m_\nu(t)\, W(\vec{x}_\eta, t', \vec{x}_\nu, t) \right)$$


$\hat{m}_\nu = \left(\hat{\sigma}_\nu^{+} e^{i\Omega_\nu t} + \hat{\sigma}_\nu^{-} e^{-i\Omega t} \right)$
$\hat{\rho}_0 = \hat{\rho}_{AB,0} \otimes \hat{\rho}_{\Phi,0}$; $\hat{\rho}_{AB,0} = \hat{\rho}_{A,0} \otimes \hat{\rho}_{B,0}$
$, \vec{x}_\nu, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt' \, \chi_\nu(t) \chi_\eta(t') \left(\hat{m}_\nu(t) \hat{m}_\eta(t') \hat{\rho}_{AB,0} \, W(\vec{x}_\nu, t, \vec{x}_\eta, t') + \rho_{AB,0} \, \hat{m}_\eta(t') m_\nu(t) \, W(\vec{x}_\eta, t', \vec{x}_\nu, t) \right) \Big]$

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$$\lambda_\nu \chi_\nu(t)\, \hat{m}_\nu(t) \int d^n x\, F(\vec{x}-\vec{x}_\nu)\, \hat{\phi}(t,\vec{x})$$

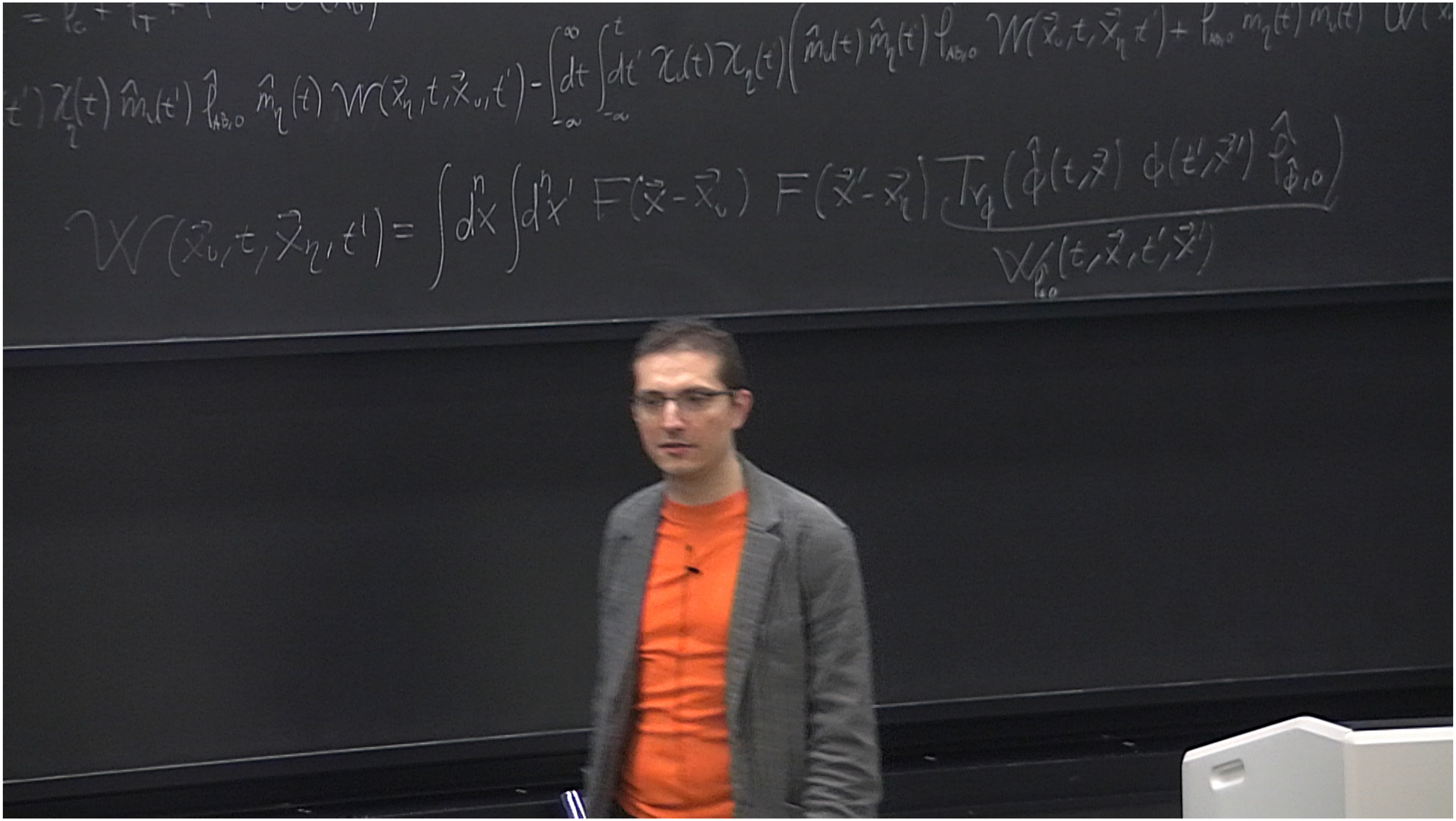
$$\hat{m}_\nu = \left(\hat{\sigma}_\nu^{+} e^{i\Omega_\nu t} + \hat{\sigma}_\nu^{-} e^{-i\Omega t}\right)$$

$$\hat{\rho}_0 = \hat{\rho}_{AB,0} \otimes \hat{\rho}_{\phi,0} \; ; \quad \hat{\rho}_{AB,...}$$

No signalling terms at $\mathcal{O}(\lambda_\nu)$

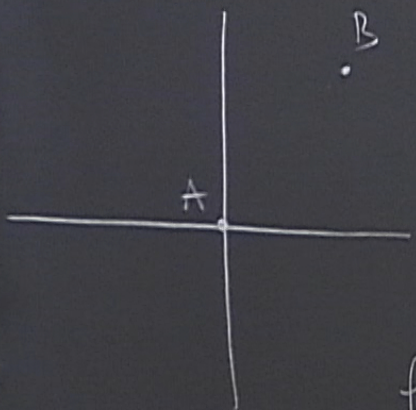
expansion. $\hat{\rho}_T = \hat{\rho}_0 + \hat{\rho}_T^{(1)} + \hat{\rho}^{(2)} + \mathcal{O}(\lambda_\nu^3)$

$$\lambda_\eta \Big[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt'\, \chi_\nu(t')\, \chi_\eta(t)\, \hat{m}_\nu(t')\, \hat{\rho}_{AB,0}\, \hat{m}_\eta(t)\, W(\vec{x}_\eta, t, \vec{x}_\nu, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt'\, \chi_\nu(t)\, \chi_\eta(t') \Big(\hat{m}_\nu(t)\, \hat{m}_\eta(t')\, \hat{\rho}_{AB,0}\, W(\vec{x}_\nu, t, \vec{x}_\eta, t') + \rho_{AB,0}\, \hat{m}_\eta(t')\, m ...$$


W(x_ν, t, x_η, t') = ∫ d^n x ∫ d^n x' F(x - x_ν) F(x' - x_η) Tr_φ(φ̂(t, x) φ(t', x') ρ̂_φ̂,0)
W_ρ̂,0(t, x, t', x')

Separate (local) Noise from signal : $\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{\text{pre-signal}}$

Communication through a massless Quantum field



$$\hat{H}_I = \sum_{\nu\in\{A,B\}} \lambda_\nu \chi_\nu(t)\, \hat{m}_\nu(t) \int d^n x\, F(\vec{x}-\vec{x}_\nu)\, \hat{\phi}(t,\vec{x})$$

$\hat{m}_\nu = (\hat{\sigma}_\nu^+ e^{i\Omega_\nu t} + \hat{\sigma}_\nu^-$

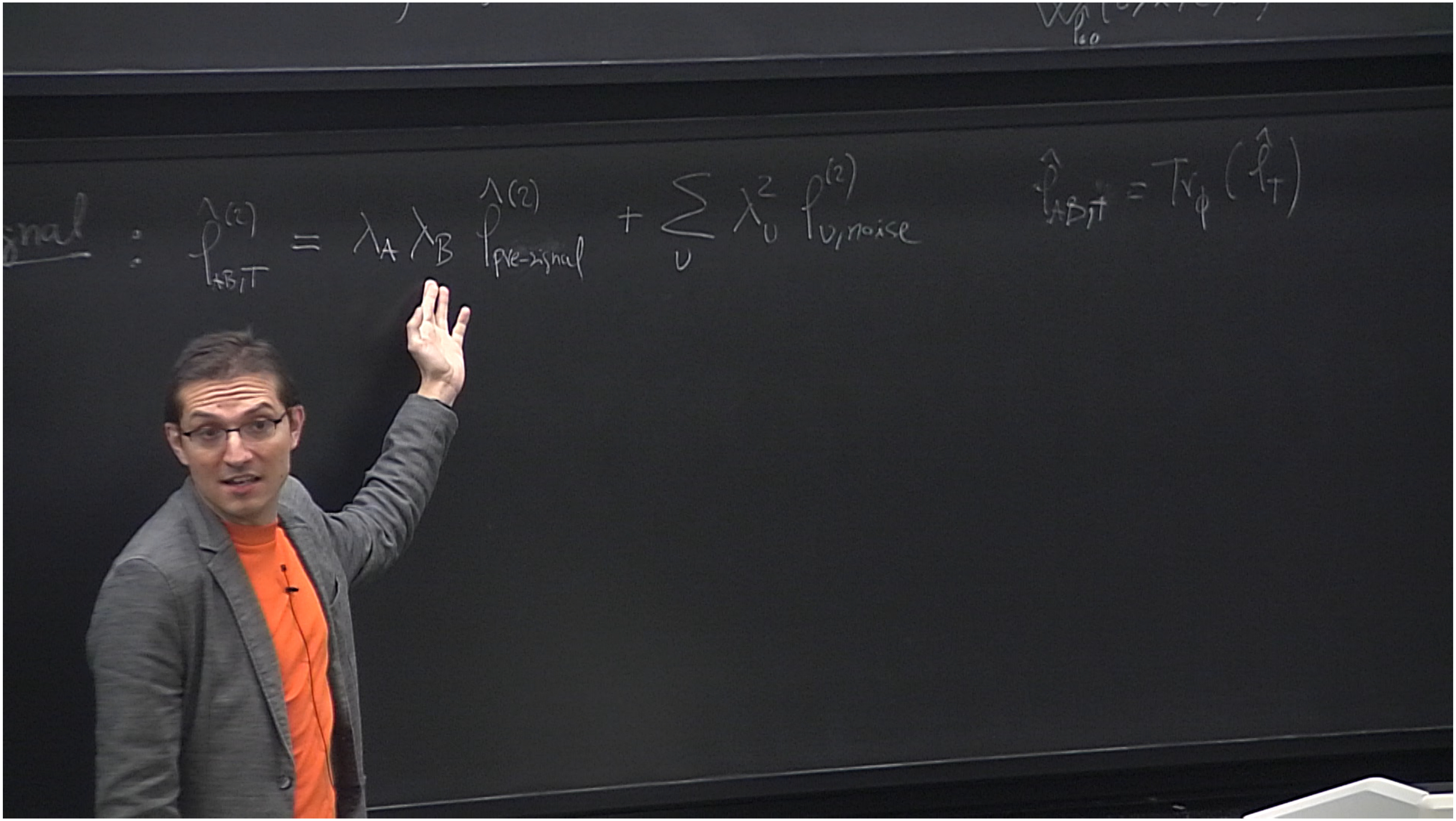
No signalling ter

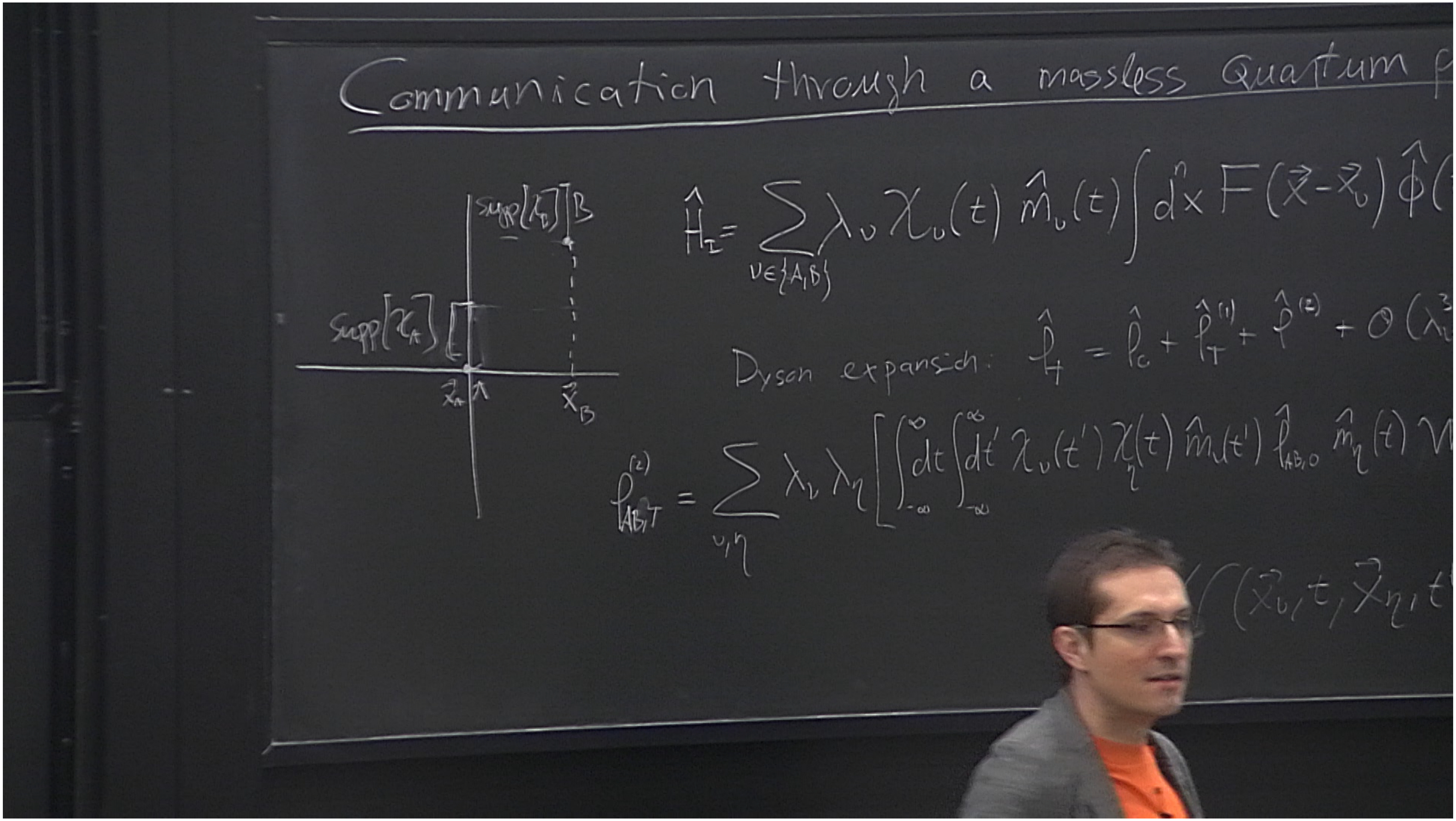
Dyson expansion: $\hat{\rho}_T = \hat{\rho}_0 + \hat{\rho}_T^{(1)} + \hat{\rho}^{(2)} + \mathcal{O}(\lambda_\nu^3)$

$$\rho^{(2)}_{AB,T} = \sum_{\nu,\eta} \lambda_\nu \lambda_\eta \Big[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt'\, \chi_\nu(t')\chi_\eta(t)\, \hat{m}_\nu(t')\, \hat{\rho}_{AB,0}\, \hat{m}_\eta(t)\, W(\vec{x}_\eta, t, \vec{x}_\nu, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt'\, \chi_\nu(t)\chi_\eta(t)$$

$$W(\vec{x}_\nu, t, \vec{x}_\eta, t') = \int d^n x \int d^n x'\, F(\vec{x}-\vec{x}_\nu)\ F$$

(local) Noise from signal. $\hat{\rho}^{(2)} = \lambda_A \lambda_B \hat{\rho}^{(2)} + \sum \lambda_\nu^2$


$\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{pre-signal} + \sum_{\upsilon} \lambda_{\upsilon}^2 \rho^{(2)}_{\upsilon,noise}$
$\hat{\rho}_{AB,T} = Tr_{\phi}(\hat{\rho}_T)$


Communication through a massless Quantum f
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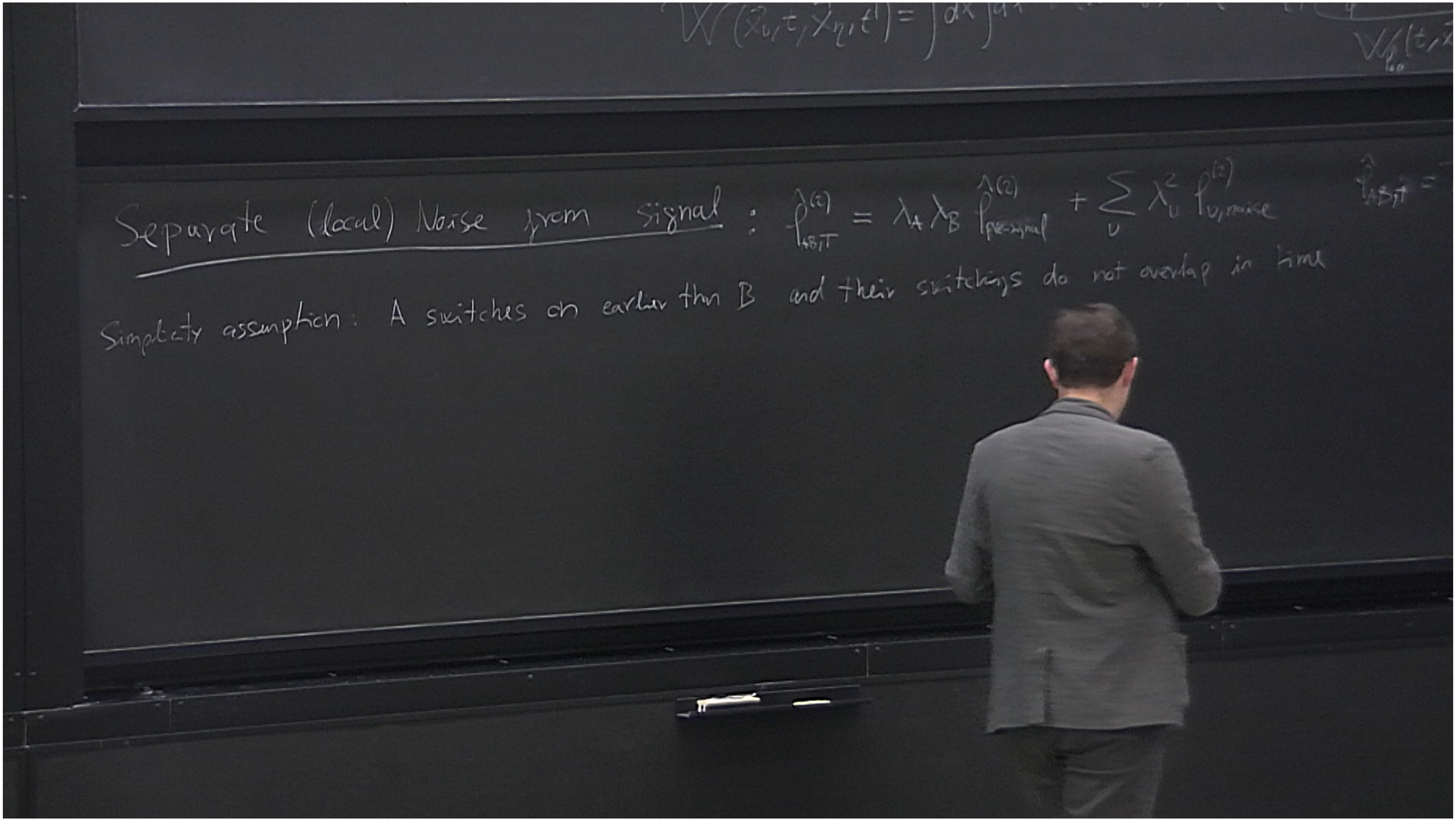
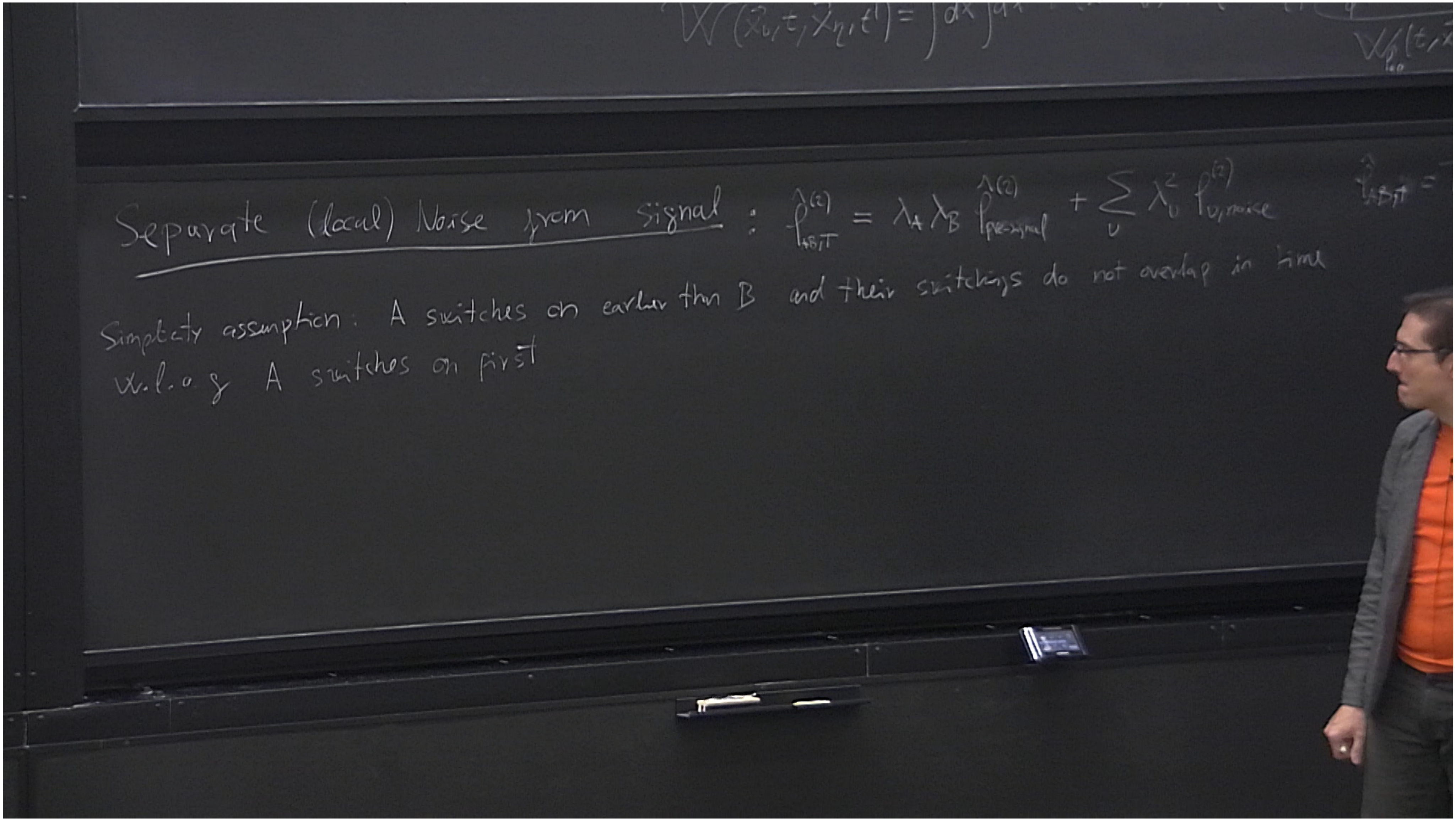
supp$[\chi_B]$ B
supp$[\chi_A]$
$\vec{x}_A$ A $\vec{x}_B$
Dyson expansion: $\hat{\rho}_T = \hat{\rho}_0 + \hat{\rho}_T^{(1)} + \hat{\rho}^{(2)} + \mathcal{O}(\lambda_\nu^3$
$\rho_{AB,T}^{(2)} = \sum_{\nu,\eta} \lambda_\nu \lambda_\eta \Big[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt'\, \chi_\nu(t')\, \chi_\eta(t)\, \hat{m}_\nu(t')\, \hat{\rho}_{AB,0}\, \hat{m}_\eta(t)$
$(\vec{x}_\nu, t, \vec{x}_\eta, t$


Separate (local) Noise from signal : $\hat{\rho}^{(2)}_{A,B,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{\text{pre-signal}} + \sum_{\nu} \lambda_\nu^2 \rho^{(2)}_{\nu,\text{noise}}$
Simplicity assumption: A switches on earlier than B and their switchings do not overlap in time


Separate (local) Noise from signal : $\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{\text{pre-signal}} + \sum_{\nu} \lambda_{\nu}^2 \rho^{(2)}_{\nu,\text{noise}}$
Simplicity assumption: A switches on earlier than B and their switchings do not overlap in time
w.l.o.g A switches on first

$$\mathcal{W}(\vec{x}_\nu, t, \vec{x}_\eta, t') = \int d^n x \int d^n x' \, F(\vec{x}-\vec{x}_\nu)\, F(\vec{x}'-\vec{x}_\eta) \underbrace{\mathrm{Tr}_\phi\left(\hat{\phi}(t,\vec{x})\, \hat{\phi}(t',\vec{x}')\, \hat{\rho}_{\phi,0}\right)}_{\mathcal{W}_{\hat{\rho}_{\phi,0}}(t,\vec{x},t',\vec{x}')}$$

Separate (local) Noise from signal : $\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{\text{pre-signal}} + \sum_\nu \lambda_\nu^2 \hat{\rho}^{(2)}_{\nu,\text{noise}}$ $\qquad \hat{\rho}_{AB,T} = \mathrm{Tr}_\phi(\hat{\rho}_T)$

Simplicity assumption: A switches on earlier than B and their switchings do not overlap in time

w.l.o.g A switches on first, we can then write

$$\hat{\rho}^{(2)}_{\text{pre-signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t)\, \chi_B(t') \Big[\mathcal{W}(\vec{x}_B, t', \vec{x}_A, t)\left(\hat{m}_A(t)\, \hat{\rho}_{AB,0}\, \hat{m}_B(t') - \hat{m}_B(t')\, \hat{m}_A(t)\, \hat{\rho}_{AB,0}\right) + \mathcal{W}(\vec{x}_A, t, \vec{x}_B, t')\left(\hat{m}_B(t')\, \hat{\rho}_{AB,0}\, \hat{m}_A(t) - \hat{\rho}_{AB,0}\, \hat{m}_A(t)\, \hat{m}_B(t')\right) \Big]$$

Separate (local) Noise from signal : $\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{\text{pre-signal}} + \sum_{\nu} \lambda_{\nu}^{2}$

Simplicity assumption: A switches on earlier than B and their switchings do not overl

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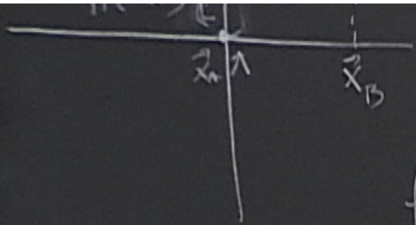
$$\hat{\rho}^{(2)}_{\text{pre-signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t) \chi_B(t') \Big[W(\vec{x}_B, t', \vec{x}_A, t) \big(\hat{m}_A(t) \hat{\rho}_{AB,0} \hat{m}_B(t') - \hat{m}_B(t') \hat{m}_A(t) \rho_{AB,0} \big) + W(\vec{x}_A, t$$

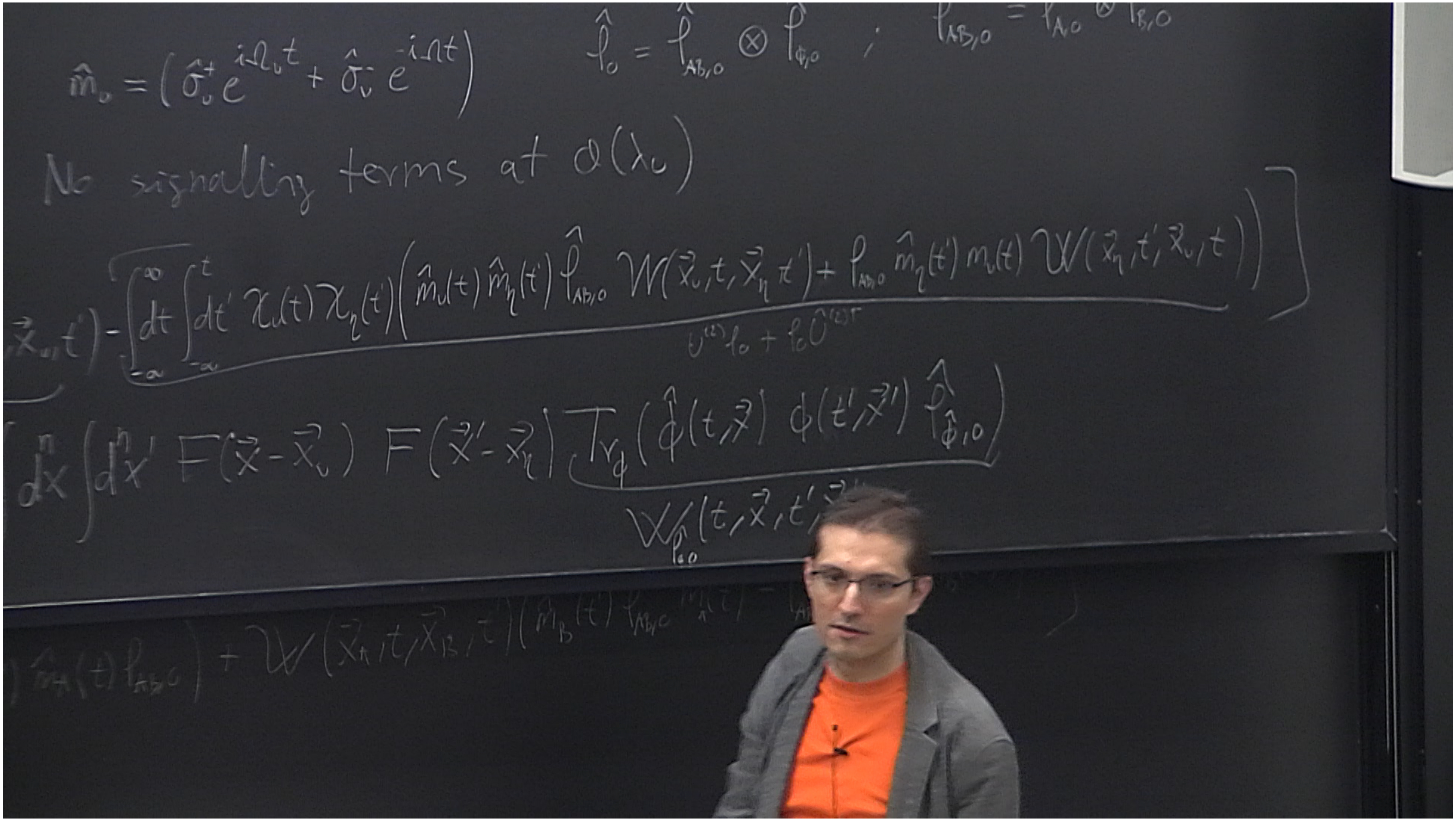


Dyson expansion: $\rho_f = \rho_0 + \rho_T$

$$\rho^{(2)}_{AB,T} = \sum_{\nu,\eta} \lambda_\nu \lambda_\eta \Big[\underbrace{\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_\nu(t')\chi_\eta(t)\, \hat{m}_\nu(t')\, \hat{\rho}_{AB,0}\, \hat{m}_\eta(t)\, W(\vec{x}_\eta, t, \vec{x}_\nu, t')}_{U^{(1)}\rho_0 U^{(1)T}} - \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt' \, \chi_\nu(t)\chi_\eta(t'$$

$$W(\vec{x}_\nu, t, \vec{x}_\eta, t') = \int d^n x \int d^n x' \, F(\vec{x} -$$

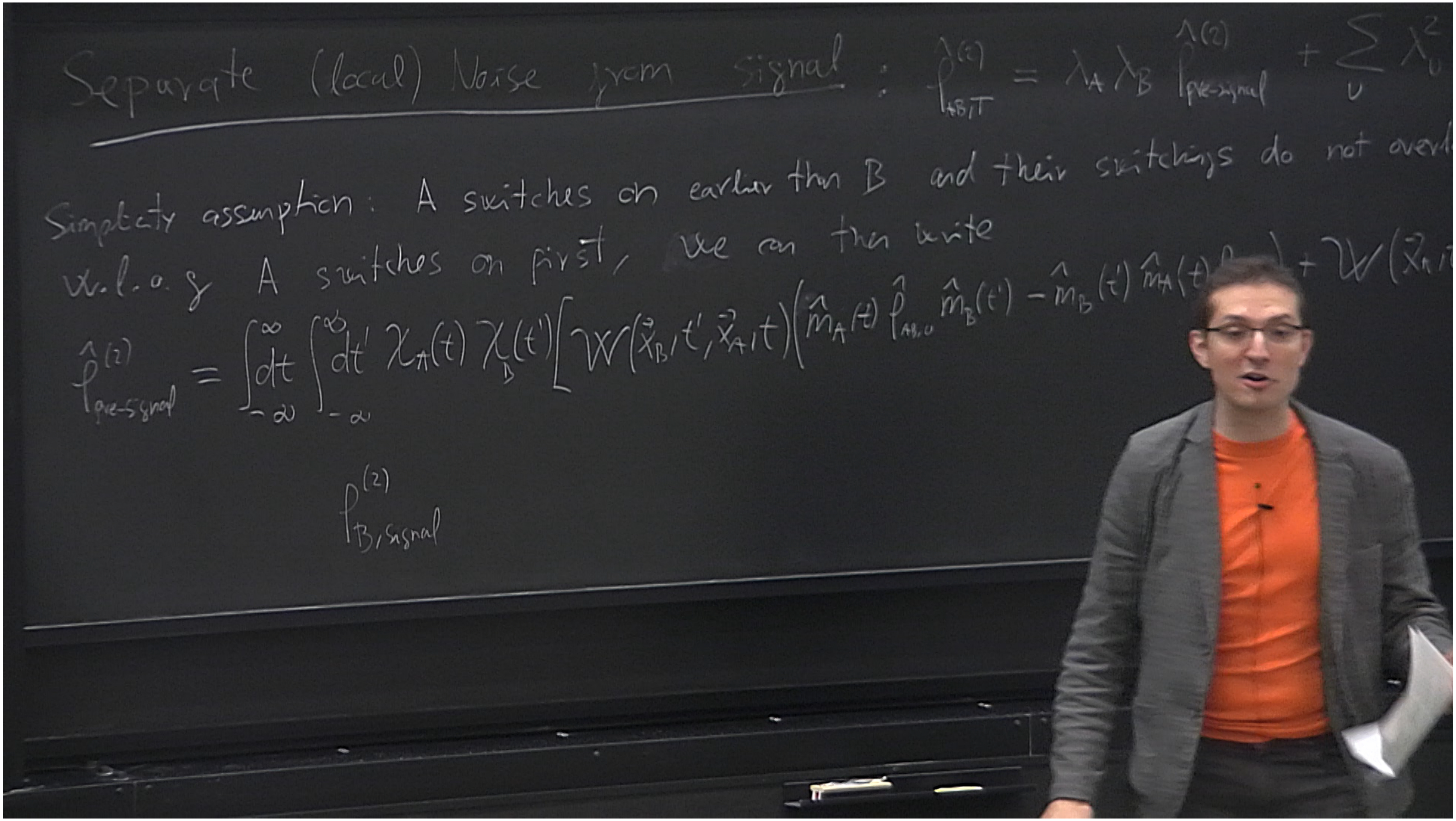
$$\hat{\rho}^{(2)}_{\text{pre-signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t)\,\chi_B(t') \Big[W(\vec{x}_B, t', \vec{x}_A, t) \Big(\hat{m}_A(t)\, \hat{\rho}_{AB,0}\, \hat{m}_B(t') - \hat{m}_B(t')\, \hat{m}_A(t)\, \rho_{AB,0} \Big) + W(\vec{x}_A,$$


No signalling terms at $\mathcal{O}(\lambda_\nu)$

$$\lambda_B\, \hat{\rho}^{(2)}_{\text{pre-signal}} + \sum_{\upsilon} \lambda_{\upsilon}^2\, \rho^{(2)}_{\upsilon,\text{noise}} \qquad \hat{\rho}_{AB,f} = \mathrm{Tr}_{\phi}\left(\hat{\rho}_T\right)$$

itchings do not overlap in time

$$\left.\left.\hat{m}_A(t)\, \rho_{AB,0}\right) + \mathcal{W}(\vec{x}_A, t, \vec{x}_B, t')\left(\hat{m}_B(t')\, \hat{\rho}_{AB,0}\, \hat{m}_A(t) - \rho_{AB,0}\, \hat{m}_A(t)\, \hat{m}_B(t')\right)\right]$$


Separate (local) Noise from signal : $\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{\text{pre-signal}} + \sum_{\nu} \lambda_{\nu}^{2}$
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$\hat{\rho}^{(2)}_{\text{pre-signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t) \, \chi_B(t') \Big[\mathcal{W}(\vec{x}_B, t', \vec{x}_A, t) \big(\hat{m}_A(t) \, \hat{\rho}_{AB,0} \, \hat{m}_B(t') - \hat{m}_B(t') \, \hat{m}_A(t)$
$\hat{\rho}^{(2)}_{B,\text{signal}}$

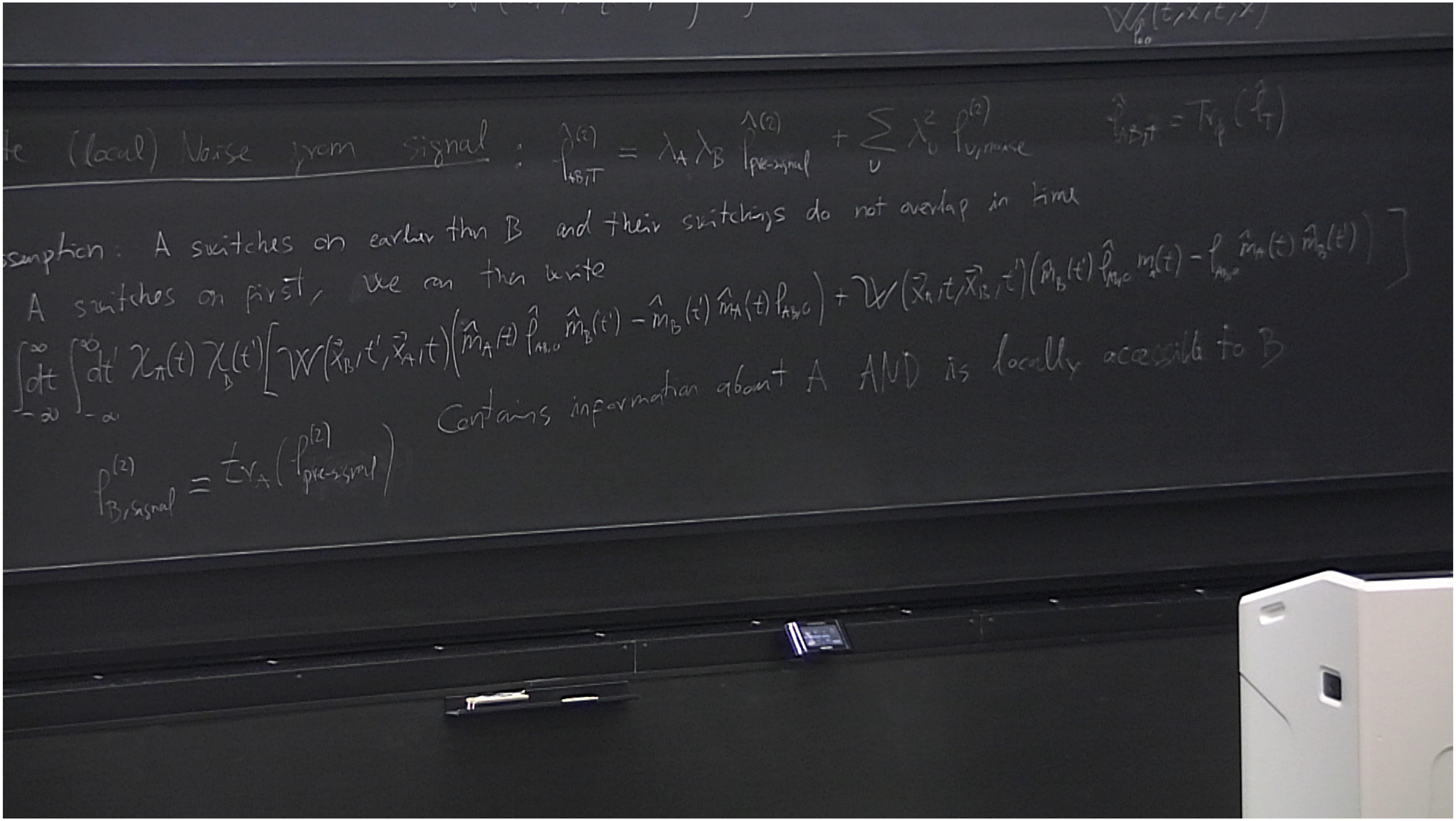
Separate (local) Noise from signal : $\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{\text{pre-signal}} + \sum_{\nu} \lambda_{\nu}^2$

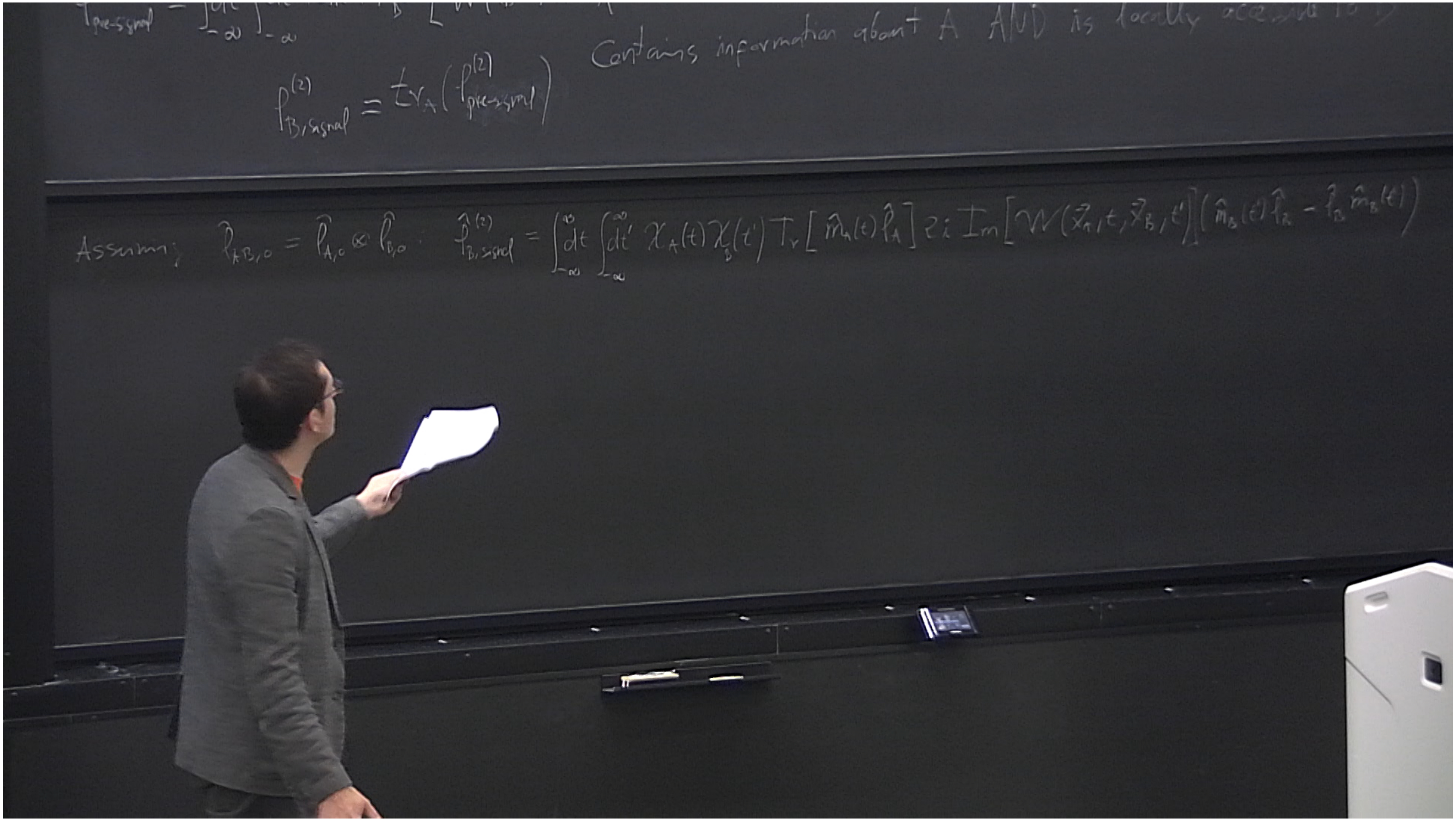
Simplicity assumption: A switches on earlier than B and their switchings do not overl

w.l.o.g A switches on first, we can then write

$$\hat{\rho}^{(2)}_{\text{pre-signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t)\, \chi_B(t') \Big[W(\vec{x}_B, t', \vec{x}_A, t) \Big(\hat{m}_A(t)\, \hat{\rho}_{AB,0}\, \hat{m}_B(t') - \hat{m}_B(t')\, \hat{m}_A(t)\, \rho_{AB,0} \Big) + W(\vec{x}_A, t$$

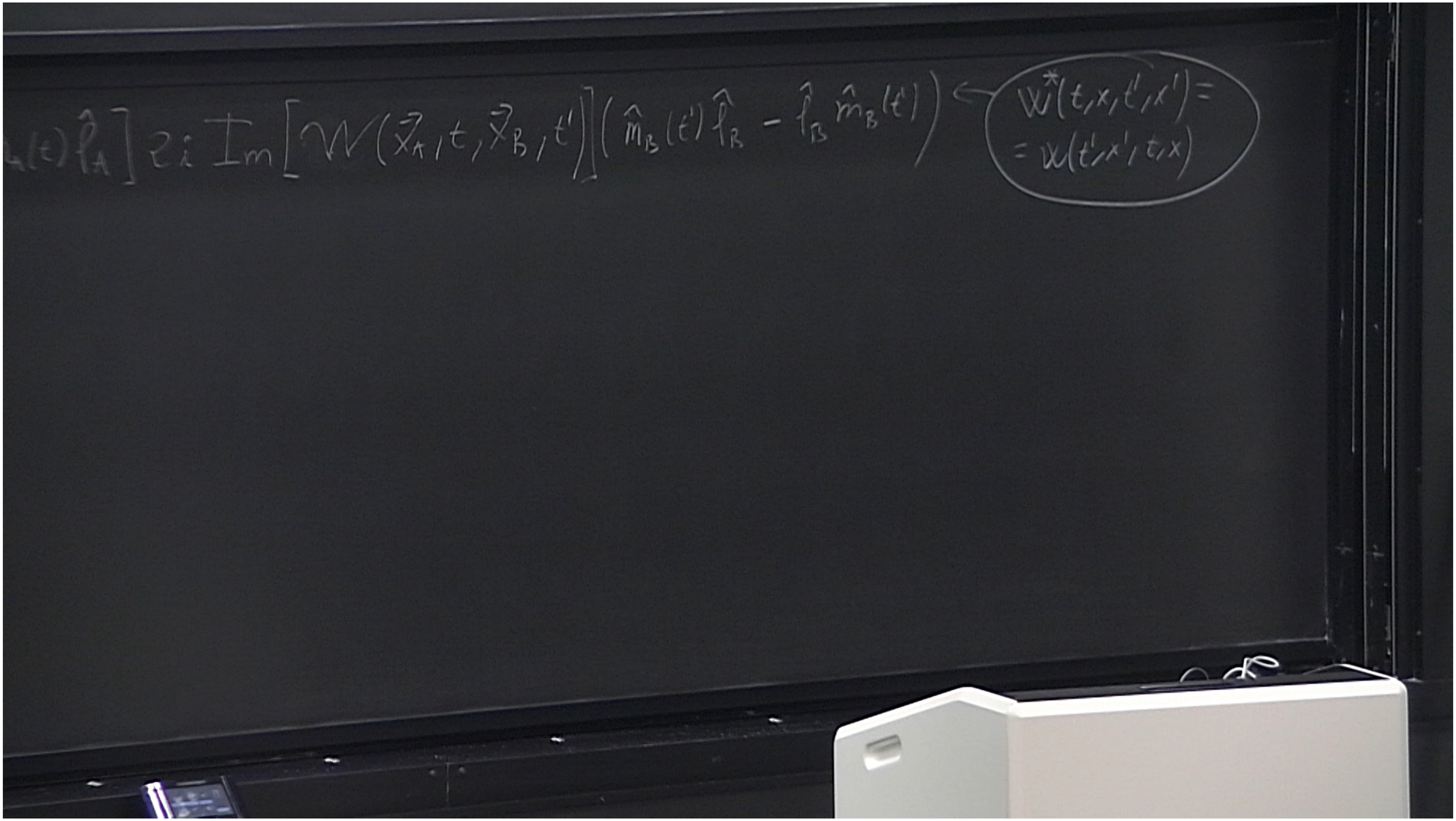
$$\rho^{(2)}_{B,\text{signal}} = \operatorname{tr}_A \left(\rho^{(2)}_{\text{pre-signal}} \right)$$


te (local) Noise from signal : $\hat{\rho}^{(2)}_{AB,T} = \lambda_A \lambda_B \hat{\rho}^{(2)}_{pre\text{-}signal} + \sum_{\nu} \lambda_{\nu}^2 \rho^{(2)}_{\nu,noise}$
$\hat{\rho}_{AB,T} = Tr_{\phi}(\hat{\rho}_T)$
ssumption: A switches on earlier than B and their switchings do not overlap in time
A switches on first, we can then write
$\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t) \chi_B(t') \Big[W(\vec{x}_B, t', \vec{x}_A, t) \big(\hat{m}_A(t) \hat{\rho}_{AB,0} \hat{m}_B(t') - \hat{m}_B(t') \hat{m}_A(t) \rho_{AB,0} \big) + W(\vec{x}_A, t, \vec{x}_B, t') \big(\hat{m}_B(t') \hat{\rho}_{AB,0} m_A(t) - \rho_{AB,0} \hat{m}_A(t) \hat{m}_B(t') \big) \Big]$
Contains information about A AND is locally accessible to B
$\rho^{(2)}_{B,signal} = tr_A \left(\rho^{(2)}_{pre\text{-}signal} \right)$


Contains information about A AND is locally
$\rho^{(2)}_{B,signal} = tr_A\left(\rho^{(2)}_{pre-signal}\right)$
Assuming; $\hat{\rho}_{AB,0} = \hat{\rho}_{A,0} \otimes \hat{\rho}_{B,0}$: $\hat{\rho}^{(2)}_{B,signal} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t) \chi_B(t') \, Tr\left[\hat{m}_A(t) \hat{\rho}_A\right] 2i \, Im\left[W(\vec{x}_A, t, \vec{x}_B, t')\right] \left(\hat{m}_B(t') \hat{\rho}_B - \hat{\rho}_B \hat{m}_B(t')\right)$

$$\ldots(t)\,\hat{p}_A\Big]\, 2i\,\mathrm{Im}\Big[\mathcal{W}(\vec{x}_A, t, \vec{x}_B, t')\Big]\Big(\hat{m}_B(t')\,\hat{p}_B - \hat{p}_B\,\hat{m}_B(t')\Big)$$

$$\mathcal{W}^*(t,x,t',x') = $$
$$= \mathcal{W}(t',x',t,x)$$


$(t)\hat{p}_A \big] 2i\,\mathrm{Im}\big[W(\vec{x}_A, t, \vec{x}_B, t')\big]\big(\hat{m}_B(t')\hat{p}_B - \hat{p}_B\hat{m}_B(t')\big)$
$W^*(t,x,t',x') =$
$= W(t',x',t,x)$

$\hat{\rho}_{B,\text{signal}}$

Assuming $\hat{\rho}_{AB,0} = \hat{\rho}_{A,0} \otimes \hat{\rho}_{B,0}$: $\hat{\rho}^{(2)}_{B,\text{signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t)\chi_B(t') \, \mathrm{Tr}\left[\hat{m}_A(t)\hat{\rho}_A\right] 2i \, \mathrm{Im}\left[\mathcal{W}(\right.$

Matrix representation for B: $|g\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$; $|e\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \Rightarrow m_\nu(\tau) = \begin{pmatrix} 0 & e^{-i\Omega_\nu \tau} \\ e^{i\Omega_\nu \tau} & 0 \end{pmatrix}$

$$t' \, \chi_A(t)\, \chi_B(t')\, \mathrm{Tr}\left[\hat{m}_A(t)\hat{\rho}_A\right] 2i\, \mathrm{Im}\left[W(\vec{x}_A, t, \vec{x}_B, t')\right]\left(\hat{m}_B(t')\hat{\rho}_B - \hat{\rho}_B\, \hat{m}_B(t')\right) \leftarrow W^*(t,x,t',x') = W(t',x',t,x)$$

$$\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \Rightarrow m_\nu(z) = \begin{pmatrix} 0 & e^{-i\Omega_\nu z} \\ e^{i\Omega_\nu z} & 0 \end{pmatrix}; \quad \hat{\rho}_{AB,0} = \hat{\rho}_{A,0} \otimes \hat{\rho}_{B,0} = \begin{pmatrix} a_A & b_A \\ b_A^* & 1-a_A \end{pmatrix} \otimes \begin{pmatrix} a_B & b_B \\ b_B^* & 1-a_B \end{pmatrix}$$

$\hat\rho_{B,\text{signal}}$

Assuming $\hat\rho_{AB,0} = \hat\rho_{A,0} \otimes \hat\rho_{B,0}$: $\hat\rho^{(2)}_{B,\text{signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t) \chi_B(t') \, \mathrm{Tr}\left[\hat m_A(t) \hat\rho_A\right] 2i \, \mathrm{Im}\left[W(\right.$

Matrix representation for B: $|g\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$; $|e\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \Rightarrow m_\nu(\tau) = \begin{pmatrix} 0 & e^{-i\Omega_\nu \tau} \\ e^{i\Omega_\nu \tau} & 0 \end{pmatrix}$; $\hat\rho_{AB,0} =$

in this representation: $\mathrm{Tr}\left[\hat m_A(t) \hat\rho_A\right] = 2\,\mathrm{Re}\left(b_A e^{i\Omega_A t}\right)$ $\quad \left[\hat m_B(t'), \hat\rho_{B,0}\right] = \left(-2i\,\mathrm{Im}\left(b_B e^{i\Omega_B} \right. \right.$

$$\ldots_A(t)\hat{\rho}_A\Big]\, 2i\,\mathrm{Im}\Big[W(\vec{x}_A, t, \vec{x}_B, t')\Big]\Big(\hat{m}_B(t')\hat{\rho}_B - \hat{\rho}_B\,\hat{m}_B(t')\Big) \leftarrow W^*(t,x,t',x') = W(t',x',t,x)$$

$$= \begin{pmatrix} 0 & e^{-i\Omega_0\tau} \\ e^{i\Omega_0\tau} & 0 \end{pmatrix};\quad \hat{\rho}_{AB,0} = \hat{\rho}_{A,0}\otimes\hat{\rho}_{B,0} = \begin{pmatrix} a_A & b_A \\ b_A^* & 1-a_A \end{pmatrix} \otimes \begin{pmatrix} a_B & b_B \\ b_B^* & 1-a_B \end{pmatrix}$$

$$\ldots\hat{\rho}_{B,0}\Big] = \begin{pmatrix} -2i\,\mathrm{Im}\left(b_B e^{i\Omega_B t'}\right) & e^{-i\Omega_B t'}(1-2a_B) \\ (\qquad)^* & 2i\,\mathrm{Im}\left(b_B e^{i\Omega_B t'}\right) \end{pmatrix}$$

B,signal

Assuming $\hat\rho_{AB,0} = \hat\rho_{A,0} \otimes \hat\rho_{B,0}$: $\hat\rho^{(2)}_{B,\text{signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t)\chi_B(t') \, \mathrm{Tr}[\hat m_A(t)\hat\rho_A] \, 2i\,\mathrm{Im}[W($

Matrix representation for B: $|g\rangle = \begin{pmatrix}1\\0\end{pmatrix}$; $|e\rangle = \begin{pmatrix}0\\1\end{pmatrix} \Rightarrow m_\nu(\tau) = \begin{pmatrix}0 & e^{-i\Omega_\nu \tau}\\ e^{i\Omega_\nu \tau} & 0\end{pmatrix}$; $\hat\rho_{AB,0} =$

in this representation: $\mathrm{Tr}[\hat m_A(t)\hat\rho_A] = 2\,\mathrm{Re}\left(b_A e^{i\Omega_A t}\right)$ $\quad [\hat m_B(t'), \hat\rho_{B,0}] = \begin{pmatrix} -2i\,\mathrm{Im}(b_B e^{i\Omega_B} \\ \end{pmatrix}$

$$\rho^{(2)} = 2\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t)\chi_B(t') \, \mathrm{Re}\left(b_A e^{i\Omega_A t}\right) \left([m_B(t'), \hat\rho_{B,0}]\right) G(t,t')$$

$$G = i\int d^n x \int d^n x' \, F(\vec x - \vec x_A) \, F(\vec x' - \vec x_B) \, \langle [\hat\phi(t,\vec x), \phi(t',\vec x')] \rangle_{\rho_{\phi,0}}$$

$\rho_{B,\text{signal}}$

Assuming $\hat{\rho}_{AB,0} = \hat{\rho}_{A,0} \otimes \hat{\rho}_{B,0}$: $\hat{\rho}^{(2)}_{B,\text{signal}} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t) \chi_B(t') \operatorname{Tr}[\hat{m}_A(t) \hat{\rho}_A] \, 2i \operatorname{Im}[W($

Matrix representation for B: $|g\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$; $|e\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ $\Rightarrow$ $m_\nu(\tau) = \begin{pmatrix} 0 & e^{-i\Omega_\nu \tau} \\ e^{i\Omega_\nu \tau} & 0 \end{pmatrix}$; $\hat{\rho}_{AB,0} =$

in this representation: $\operatorname{Tr}[\hat{m}_A(t) \hat{\rho}_A] = 2\operatorname{Re}(b_A e^{i\Omega_A t})$ $[\hat{m}_B(t'), \hat{\rho}_{B,0}] = \begin{pmatrix} -2i \operatorname{Im}(b_B e^{i\Omega_B} \\ (&)^* \end{pmatrix}$

$$\rho^{(2)}_{B,\text{signal}} = 2 \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \, \chi_A(t) \chi_B(t') \operatorname{Re}(b_A e^{i\Omega_A t}) \left([m_B(t'), \hat{\rho}_{B,0}] \right) G(t,t')$$

$$G = i \int d^n x \int d^n x' \, F(\vec{x} - \vec{x}_A) F(\vec{x}' - \vec{x}_B) \left\langle [\hat{\phi}(t, \vec{x}), \phi(t', \vec{x}')] \right\rangle_{\rho_{\phi,0}}$$

$$\ldots(t)\hat{\rho}_A\Big]\, 2i\,\mathrm{Im}\Big[W(\vec{x}_A,t,\vec{x}_B,t')\Big]\Big(\hat{m}_B(t')\hat{\rho}_B - \hat{\rho}_B\hat{m}_B(t')\Big)$$

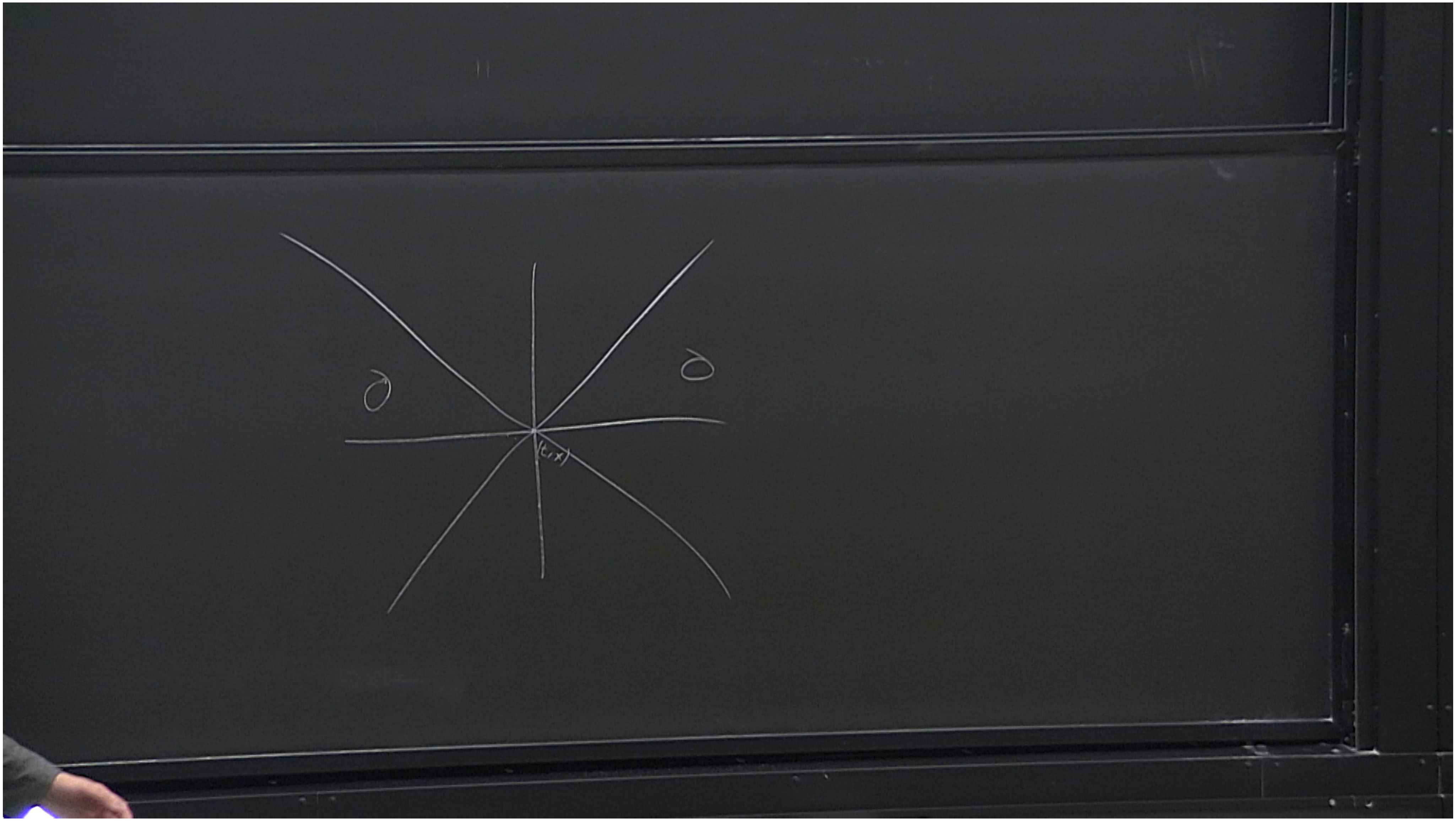
$$W^*(t,x,t',x') = W(t',x',t,x)$$

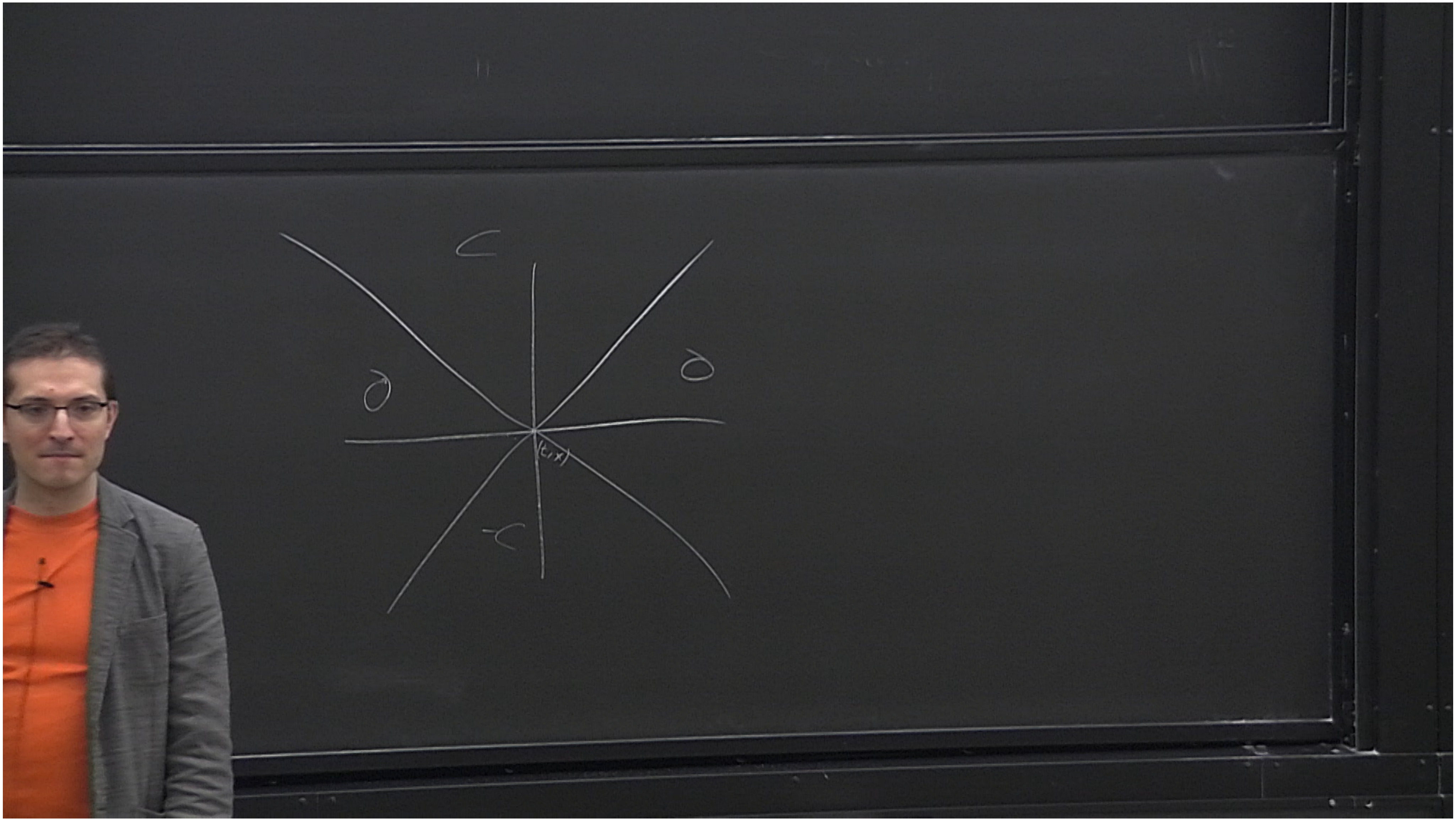
$$= \begin{pmatrix} 0 & e^{-i\Omega_0 z} \\ e^{i\Omega_0 z} & 0 \end{pmatrix};\quad \hat{\rho}_{AB,0} = \hat{\rho}_{A,0}\otimes\hat{\rho}_{B,0} = \begin{pmatrix} a_A & b_A \\ b_A^* & 1-a_A \end{pmatrix}\otimes\begin{pmatrix} a_B & b_B \\ b_B^* & 1-a_B \end{pmatrix}$$

$$\Big[\ldots\hat{\rho}_{B,0}\Big] = \begin{pmatrix} -2i\,\mathrm{Im}\left(b_B e^{i\Omega_B t'}\right) & e^{-i\Omega_B t'}(1-2a_B) \\ (\quad)^* & 2i\,\mathrm{Im}\left(b_B e^{i\Omega_B t'}\right) \end{pmatrix}$$

$$\left\langle\left[\hat{\phi}(t,\vec{x}),\hat{\phi}(t',\vec{x}')\right]\right\rangle_{\rho_{\phi,0}}$$ is independent of $\rho_{\phi,0}$

$$\ldots t',\vec{x}')\Big]\Big\rangle_{\rho_{\phi,0}}$$


(t,x)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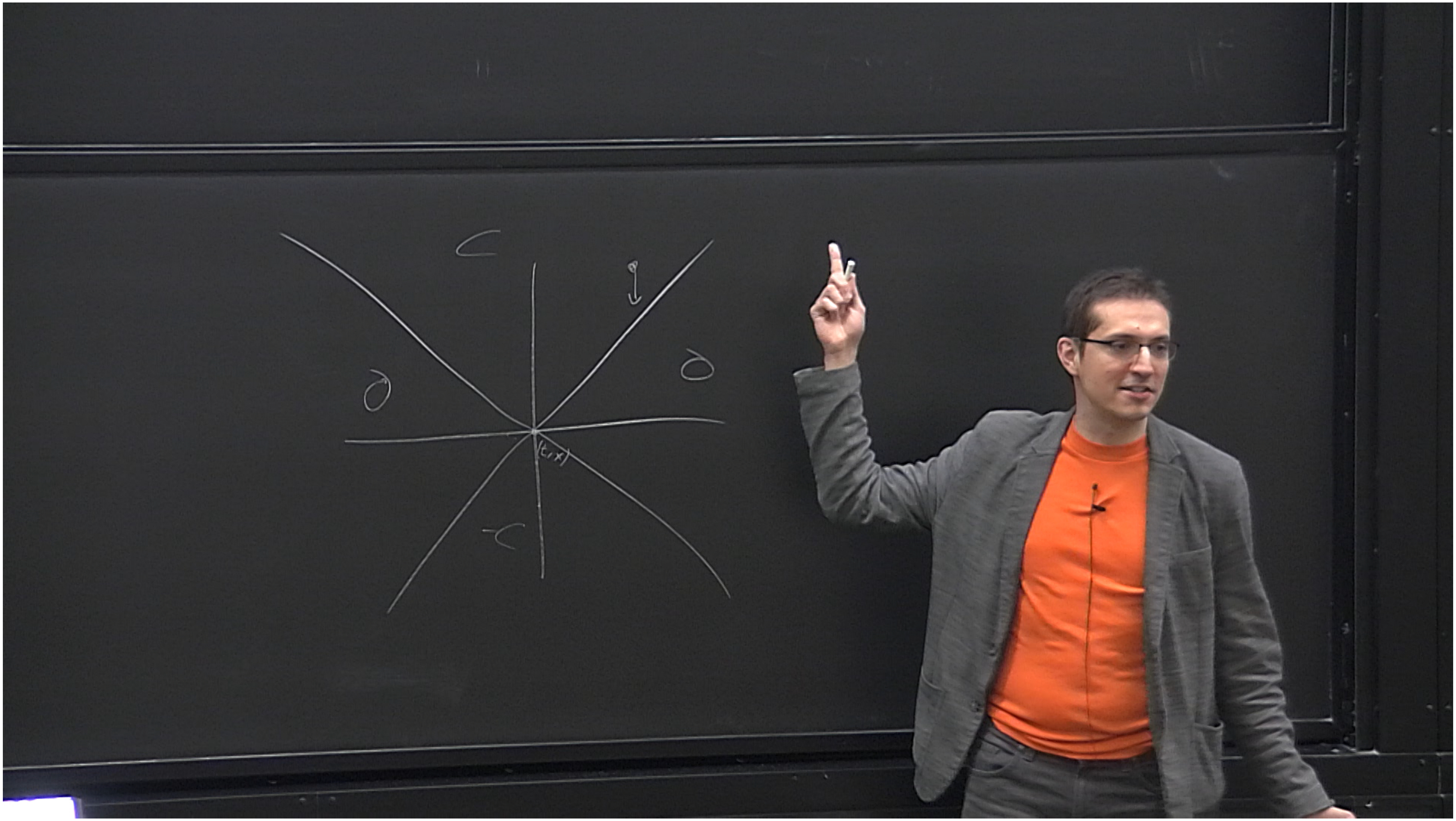
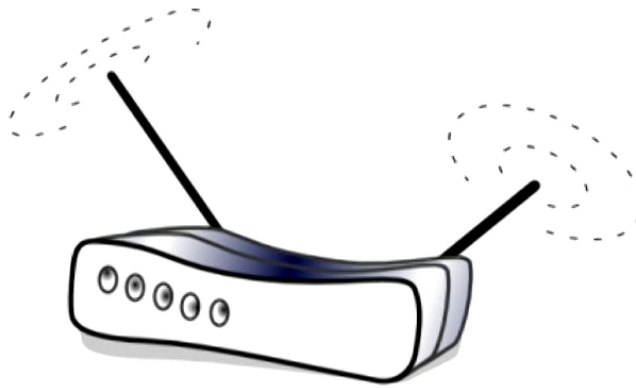

(t,x)

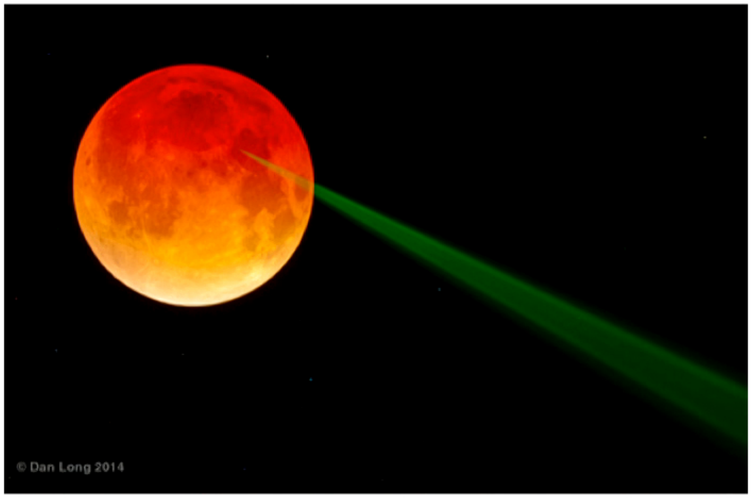
Communication through massless fields



General properties of wireless communication

Communication through the EM field

Communcation mediated by 'real' energy-carrying quanta



An emitter emits photons. A receiver captures photons.

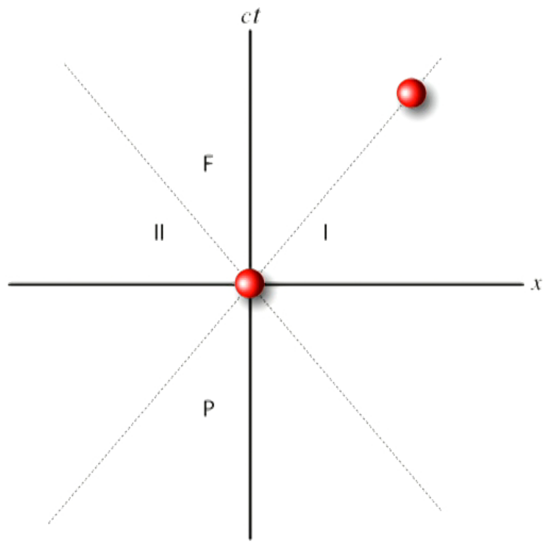
Communication through the EM field

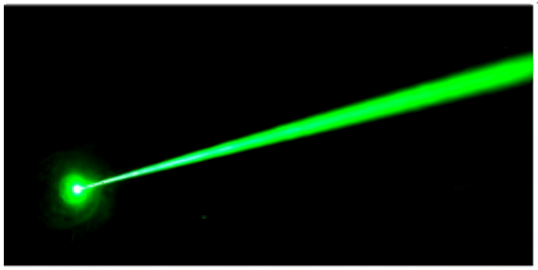
Information flow carried by (an average) energy flow

Information reaches you when energy reaches you

Communication through the EM field

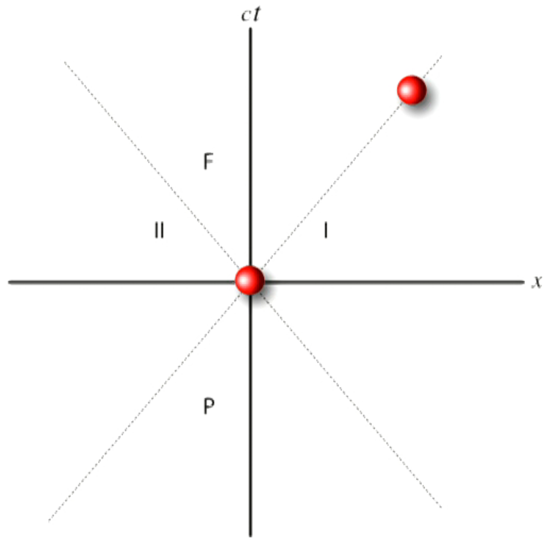
Communication is only possible at the speed of light (in vacuum)

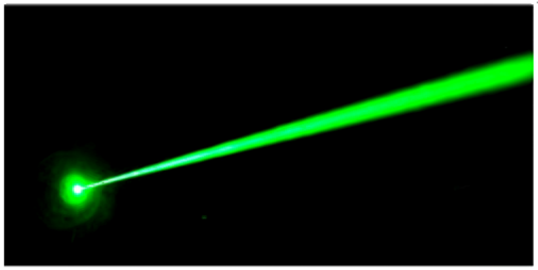




Communication through the EM field

Communication is only possible at the speed of light (in vacuum)





If you miss the beam, you miss the message

Communication through massless fields

Communication through a masses fields in the vacuum

-Only At the speed of light.

-Through the exchange of real quanta

-Information flow carried by energy flow.

-Miss the beam, miss the message

Communication through massless fields

Communication through a masses fields in the vacuum

- -Only At the speed of light.
- -Through the exchange of real quanta
- -Information flow carried by energy flow.
- -Miss the beam, miss the message