

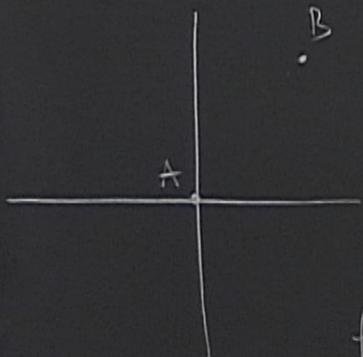
Title: PSI 2017/2018 - Relativistic Quantum Information - Lecture 10

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Abstract:

Communication through a massless quantum field



$$\hat{H}_I = \sum_{\nu \in \{A, B\}} \lambda_\nu \chi_\nu(t) \hat{m}_\nu(t) \int d^3x F(\vec{x} - \vec{x}_\nu) \hat{\phi}(t, \vec{x})$$

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

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

$$P_{dT}^{(2)} = \sum_{\nu, \eta} \lambda_\nu \lambda_\eta \left[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_\nu(t') \chi_\eta(t) \hat{m}_\nu(t') \hat{P}_{A, B, 0} \hat{m}_\eta(t) W(\vec{x}_\nu, t, \vec{x}_\eta, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^t dt' \chi_\nu(t) \chi_\eta(t') (\hat{m}_\nu(t) \hat{m}_\eta(t')) \hat{P}_{A, B, 0} \right]$$

$$\hat{m}_0 = (\hat{\sigma}_0^+ e^{i\Omega_0 t} + \hat{\sigma}_0^- e^{-i\Omega_0 t})$$

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

$$\vec{x}_1(t') - \int_{-a}^a dt \int_{-a}^t dt' \chi_1(t) \chi_2(t') \left(\hat{m}_1(t) \hat{m}_2(t') \hat{p}_{AB,0} \mathcal{W}(\vec{x}_1, t, \vec{x}_2, t') + \hat{p}_{AB,0} \hat{m}_2(t') m_1(t) \mathcal{W}(\vec{x}_1, t', \vec{x}_2, t) \right)$$

$$\hat{m}_0 = (\hat{\sigma}_0^+ e^{i\Omega_0 t} + \hat{\sigma}_0^- e^{-i\Omega_0 t})$$

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

$$\left. \begin{aligned} & \left(\int_{-\infty}^{\infty} dt \int_{-\infty}^t dt' \chi_1(t) \chi_2(t') \left(\hat{m}_1(t) \hat{m}_2(t') \hat{p}_{AB,0} \mathcal{W}(\vec{x}_1, t, \vec{x}_2, t') + \hat{p}_{AB,0} \hat{m}_2(t') \hat{m}_1(t) \mathcal{W}(\vec{x}_2, t', \vec{x}_1, t) \right) \right) \end{aligned} \right\}$$

ough a massless quantum field

$$\lambda_0 \chi_0(t) \hat{m}_0(t) \int d^3x F(\vec{x} - \vec{x}_0) \hat{\phi}(t, \vec{x})$$

$$\hat{m}_0 = (\hat{\sigma}_0^+ e^{i\omega_0 t} + \hat{\sigma}_0^- e^{-i\omega_0 t})$$

$$\hat{p}_0 = \hat{p}_{AB,0} \otimes \hat{p}_{\psi,0} ; \hat{p}_{AB,0}$$

No signalling terms at $\mathcal{O}(\lambda_0)$

expansion. $\hat{p}_T = \hat{p}_0 + \hat{p}_T^{(1)} + \hat{p}_T^{(2)} + \mathcal{O}(\lambda_0^3)$

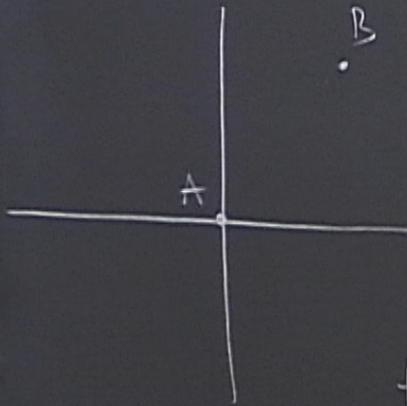
$$\chi_2 \left[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_0(t') \chi_2(t) \hat{m}_0(t') \hat{p}_{AB,0} \hat{m}_2(t) \mathcal{W}(\vec{x}_2, t, \vec{x}_1, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^t dt' \chi_1(t) \chi_2(t') (\hat{m}_1(t) \hat{m}_2(t') \hat{p}_{AB,0} \mathcal{W}(\vec{x}_0, t, \vec{x}_1, t') + \hat{p}_{AB,0} \hat{m}_2(t') \mathcal{W}(\vec{x}_2, t, \vec{x}_1, t')) \right]$$

$$\begin{aligned}
&= \rho_0 + \dots \\
& \chi(t) \hat{m}_1(t) \int_{\vec{x}_0} \hat{m}_2(t) \mathcal{W}(\vec{x}_1, t, \vec{x}_0, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^t dt' \chi_1(t) \chi_2(t') (\hat{m}_1(t) \hat{m}_2(t)) \rho_{\vec{x}_0} \mathcal{W}(\vec{x}_0, t, \vec{x}_1, t') + \rho_{\vec{x}_0} m_2(t) m_1(t) \mathcal{W}(\vec{x}_1, t, \vec{x}_0, t') \\
\mathcal{W}(\vec{x}_0, t, \vec{x}_1, t') &= \int d^{\vec{x}} \int d^{\vec{x}'} F(\vec{x} - \vec{x}_0) F(\vec{x}' - \vec{x}_1) \frac{\mathcal{T}_q(\hat{\phi}(t, \vec{x}) \phi(t', \vec{x}'))}{\mathcal{W}_{\rho_0}(t, \vec{x}, t', \vec{x}')} \hat{\phi}_{i,0}
\end{aligned}$$



Separate (local) Noise from signal : $\hat{p}_{\text{EST}}^{(s)} = \lambda_A \lambda_B \hat{p}_{\text{pre-signal}}^{(s)}$

Communication through a massless quantum field



$$\hat{H}_I = \sum_{v \in \{A, B\}} \lambda_v \chi_v(t) \hat{m}_v(t) \int d^n x F(\vec{x} - \vec{x}_v) \hat{\phi}(t, \vec{x})$$

$$\hat{m}_v = (\hat{\sigma}_v^+ e^{i\omega_v t} + \hat{\sigma}_v^-)$$

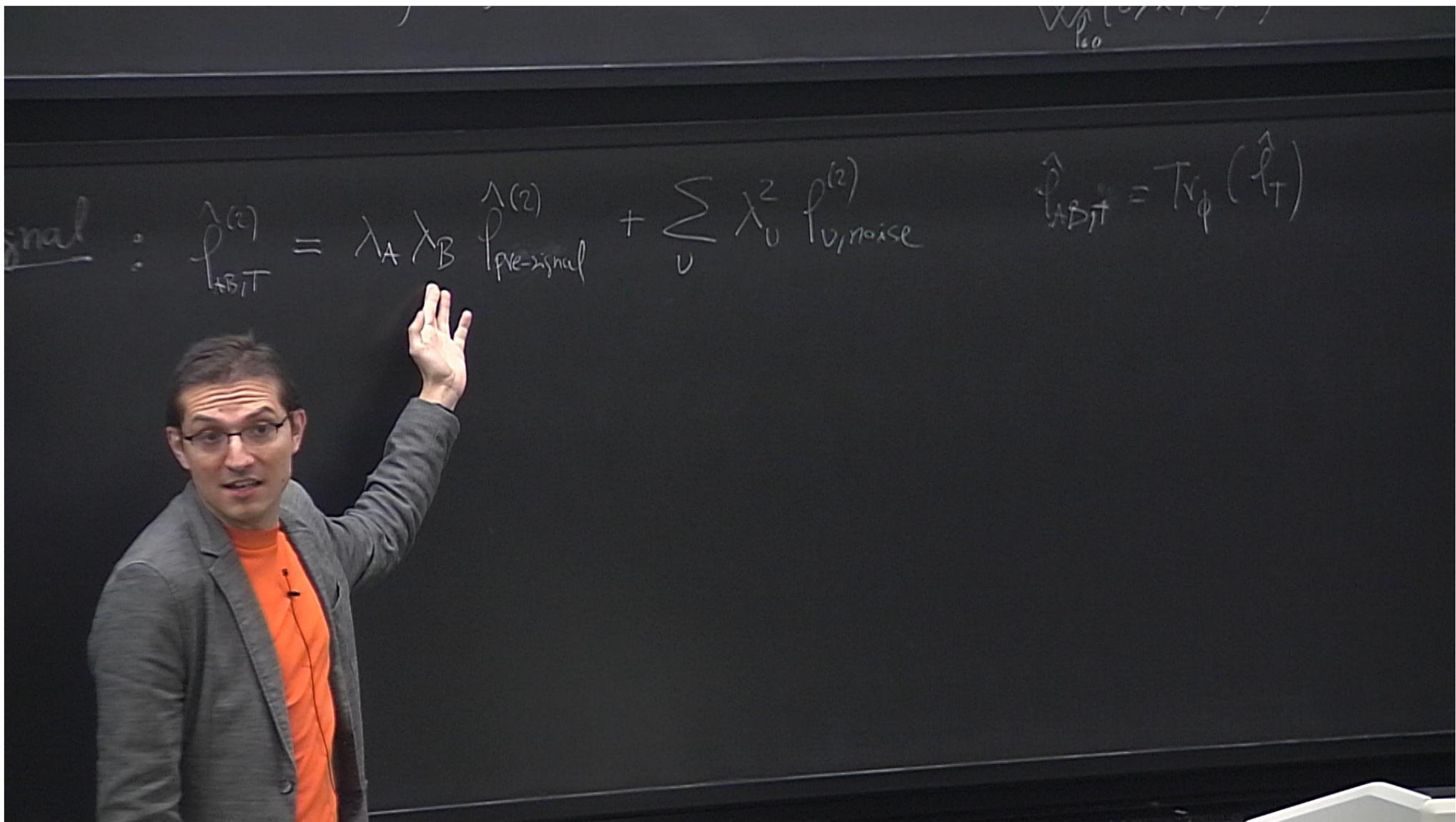
No signalling theorem

Dyson expansion: $\hat{U}_I = \hat{U}_0 + \hat{U}_I^{(1)} + \hat{U}_I^{(2)} + \mathcal{O}(\lambda_v^3)$

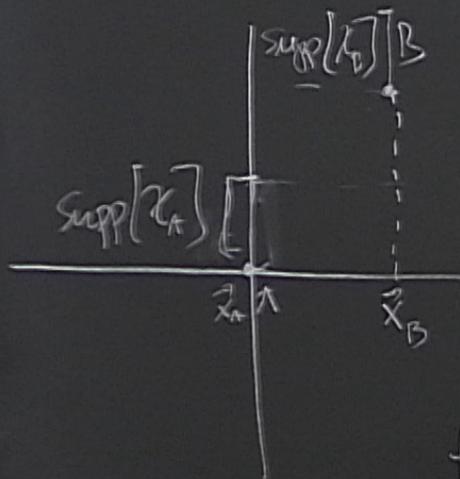
$$P_{AB,T}^{(2)} = \sum_{\nu, \eta} \lambda_\nu \lambda_\eta \left[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_\nu(t') \chi_\eta(t) \hat{m}_\nu(t') \hat{U}_{\nu,0} \hat{m}_\eta(t) \mathcal{W}(\vec{x}_\nu, t, \vec{x}_\eta, t') - \int_{-\infty}^{\infty} dt \int_{-\infty}^t dt' \chi_\nu(t) \chi_\eta(t') \right]$$

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

to (local) noise from signal. $\hat{U}_I^{(2)} = \lambda_\nu \lambda_\eta \hat{U}_{\nu,0}^{(2)} + \sum \lambda_\nu^2$



Communication through a massless quantum field



$$\hat{H}_I = \sum_{\nu \in \{A, B\}} \lambda_\nu \chi_\nu(t) \hat{m}_\nu(t) \int d^3x F(\vec{x} - \vec{x}_\nu) \hat{\phi}(\vec{x}, t)$$

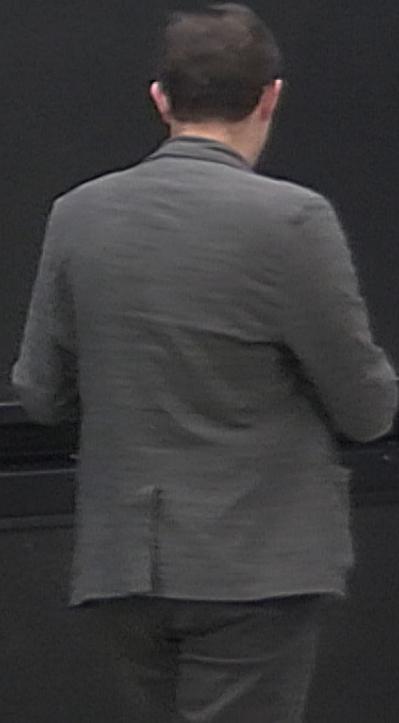
Dyson expansion: $\hat{P}_T = \hat{P}_0 + \hat{P}_T^{(1)} + \hat{P}_T^{(2)} + \mathcal{O}(\lambda^3)$

$$\hat{P}_{ABT}^{(2)} = \sum_{\nu, \eta} \lambda_\nu \lambda_\eta \left[\int_{-\infty}^0 dt \int_{-\infty}^{\infty} dt' \chi_\nu(t') \chi_\eta(t) \hat{m}_\nu(t') \hat{P}_{AB,0} \hat{m}_\eta(t) \mathcal{N}(\vec{x}_\nu, t, \vec{x}_\eta, t) \right]$$

$$W(x_0, t; x_1, t') = \int dx \int dt \dots$$

Separate (local) Noise from signal : $\hat{p}_{ABT}^{(2)} = \lambda_A \lambda_B \hat{p}_{\text{signal}}^{(2)} + \sum_U \lambda_U^2 \hat{p}_{\text{noise}}^{(2)}$

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



$$W(x_0, t_0; x_1, t_1) = \int dx \int dt \dots$$

Separate (local) Noise from signal :
$$p_{\text{SST}}^{(2)} = \lambda_A \lambda_B p_{\text{signal}}^{(2)} + \sum_{\nu} \lambda_{\nu}^2 p_{\nu, \text{noise}}^{(2)}$$

Simplicity assumption: A switches on earlier than B and their switchings do not overlap in time
 w.l.o.g. A switches on first



$$W(\vec{x}_0, t; \vec{x}_1, t') = \int d\vec{x} \int d\vec{x}' F(\vec{x} - \vec{x}_0) F(\vec{x}' - \vec{x}_1) \frac{T_q(\vec{q}(t, \vec{x}) \vec{q}(t', \vec{x}'))}{W_{q,0}(t, \vec{x}, t', \vec{x}')} P_{q,0}$$

Separate (local) Noise from signal: $\hat{p}_{\text{FBIT}}^{(2)} = \lambda_A \lambda_B \hat{p}_{\text{signal}}^{(2)} + \sum_U \lambda_U^2 \hat{p}_{U, \text{noise}}^{(2)}$ $\hat{p}_{\text{FBIT}}^{(1)} = T_q(\hat{f}_T)$

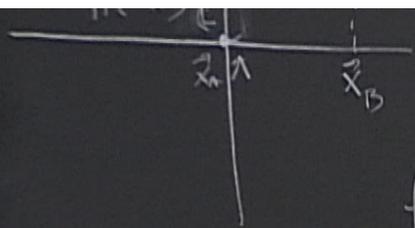
Simplcity assumption: A switches on earlier than B and their switchings do not overlap in time
 w.l.o.g A switches on first, we can then write

$$\hat{p}_{\text{FBIT}}^{(2)} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_A(t) \chi_B(t') \left[W(\vec{x}_B, t', \vec{x}_A, t) \left(\hat{m}_A(t) \hat{p}_{A,0} \hat{m}_B(t') - \hat{m}_B(t') \hat{m}_A(t) \hat{p}_{A,0} \right) + W(\vec{x}_A, t, \vec{x}_B, t') \left(\hat{m}_B(t') \hat{p}_{B,0} \hat{m}_A(t) - \hat{p}_{B,0} \hat{m}_A(t) \hat{m}_B(t') \right) \right]$$

Separate (local) Noise from signal : $\hat{p}_{\text{ABIT}}^{(2)} = \lambda_A \lambda_B \hat{p}_{\text{pre-signal}}^{(2)} + \sum_U \lambda_U^2$

Simplcity assumption: A switches on earlier than B and their switchings do not overlap
 w.l.o.g. A switches on first, we can then write

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



Dyson expansion: $\hat{P}_H = \hat{P}_0 + \hat{I}T$

$$\hat{P}_{AB}^{(2)} = \sum_{\nu, \eta} \chi_\nu \chi_\eta \left[\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_\nu(t') \chi_\eta(t) \hat{m}_\nu(t') \hat{P}_{AB,0} \hat{m}_\eta(t) \mathcal{W}(\vec{x}_\nu, t, \vec{x}_\eta, t') \right] - \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_\nu(t) \chi_\eta(t')$$

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

... by A and B ...

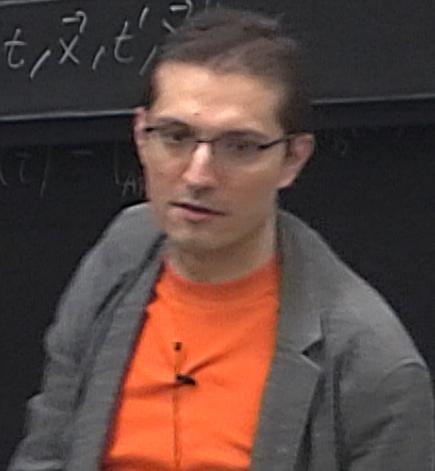
$$\hat{P}_{pre-sym}^{(2)} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_A(t) \chi_B(t') \left[\mathcal{W}(\vec{x}_B, t', \vec{x}_A, t) (\hat{m}_A(t) \hat{P}_{AB,0} \hat{m}_B(t') - \hat{m}_B(t') \hat{m}_A(t) \hat{P}_{AB,0}) + \mathcal{W}(\vec{x}_A, t, \vec{x}_B, t') (\hat{m}_B(t) \hat{P}_{AB,0}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

$$\hat{m}_0 = (\hat{\sigma}_0^+ e^{i\lambda_0 t} + \hat{\sigma}_0^- e^{-i\lambda_0 t}) \quad \hat{\rho}_0 = \hat{\rho}_{AB,0} \otimes \hat{\rho}_{\Phi,0} \quad ; \quad \hat{\rho}_{AB,0} = \hat{\rho}_{A,0} \otimes \hat{\rho}_{B,0}$$

No signaling terms at $\mathcal{O}(\lambda_0)$

$$\left. \left(\vec{x}_0, t \right) - \left[\int_{-\infty}^{\infty} dt' \int_{-\infty}^t dt \chi_1(t) \chi_2(t') \left(\hat{m}_1(t) \hat{m}_2(t') \hat{\rho}_{AB,0} \mathcal{W}(\vec{x}_0, t, \vec{x}_1, t') + \hat{\rho}_{AB,0} \hat{m}_2(t) m_1(t) \mathcal{W}(\vec{x}_1, t', \vec{x}_0, t) \right) \right] \right\}$$

$$\int d\vec{x} \int d\vec{x}' F(\vec{x} - \vec{x}_0) F(\vec{x}' - \vec{x}_1) \left[\mathcal{T}_{\chi} \left(\hat{\phi}(t, \vec{x}) \hat{\phi}(t', \vec{x}') \hat{\rho}_{\Phi,0} \right) \right]$$



$$\hat{p}_{AB}^{(2)} + \sum_U \lambda_U^2 p_{U, \text{noise}}^{(2)} \quad \hat{p}_{ABIT} = \text{Tr}_\phi(\hat{p}_T)$$

switchings do not overlap in time

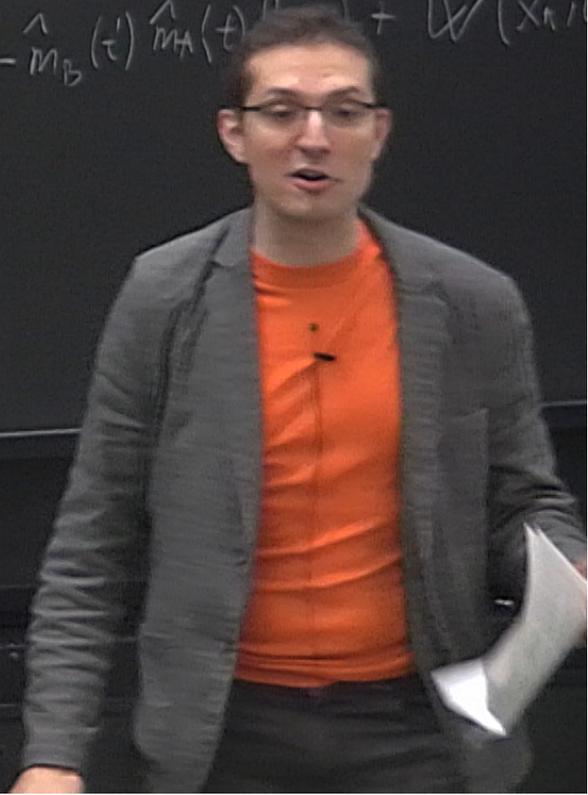
$$\left. \begin{aligned} & \hat{m}_A(t) p_{AB,0} \right) + \mathcal{W}(\vec{x}_{A,1}(t), \vec{x}_{B,1}(t')) \left(\hat{m}_B(t') p_{AB,0} m(t) - p_{AB,0} \hat{m}_A(t) \hat{m}_B(t') \right) \end{aligned} \right]$$

Separate (local) Noise from signal : $\hat{p}_{\text{ABIT}}^{(2)} = \lambda_A \lambda_B \hat{p}_{\text{pre-signal}}^{(2)} + \sum_u \chi_u^2$

Simplcity assumption: A switches on earlier than B and their switchings do not overlap
 w.l.o.g. A switches on first, we can then write

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

$$\hat{p}_{\text{B,signal}}^{(2)}$$



Separate (local) Noise from signal : $\hat{p}_{B|T}^{(2)} = \lambda_A \lambda_B \hat{p}_{\text{pre-signal}}^{(2)} + \sum_U \chi_U^2$

Simplcity assumption: A switches on earlier than B and their switchings do not overlap
 w.l.o.g. A switches on first, we can then write

$$\hat{p}_{\text{pre-signal}}^{(2)} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_A(t) \chi_B(t') \left[\mathcal{W}(\vec{x}_{B|T} t', \vec{x}_{A|T} t) (\hat{m}_A(t) \hat{p}_{A,B,U} \hat{m}_B(t') - \hat{m}_B(t') \hat{m}_A(t) p_{A,B,U}) + \mathcal{W}(\vec{x}_{A|T} t, \vec{x}_{B|T} t') (\hat{m}_B(t) \hat{p}_{A,B,U} \hat{m}_A(t') - \hat{m}_A(t) \hat{m}_B(t') p_{A,B,U}) \right]$$

$$p_{B|\text{signal}}^{(2)} = \text{Tr}_A(\hat{p}_{\text{pre-signal}}^{(2)})$$

the (local) noise from signal : $p_{B/T}^{(2)} = \lambda_A \lambda_B p_{\text{pre-signal}}^{(2)} + \sum_u \lambda_u^2 p_{\text{noise}}^{(2)}$ $p_{B/T}^{(2)} = T_{\text{eff}}(p_T)$

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

A switches on first, we can then write

$$\int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_A(t) \chi_B(t') \left[\mathcal{W}(\vec{x}_{B,t'}, \vec{x}_{A,t}) \left(\hat{m}_A(t) \hat{p}_{A \rightarrow B} \hat{m}_B(t') - \hat{m}_B(t') \hat{m}_A(t) p_{A \rightarrow B} \right) + \mathcal{W}(\vec{x}_{A,t}, \vec{x}_{B,t'}) \left(\hat{m}_B(t) \hat{p}_{B \rightarrow A} \hat{m}_A(t') - \hat{m}_A(t') \hat{m}_B(t) p_{B \rightarrow A} \right) \right]$$

Contains information about A AND is locally accessible to B

$$p_{B \text{ signal}}^{(2)} = T_{V_A}(p_{\text{pre-signal}}^{(2)})$$

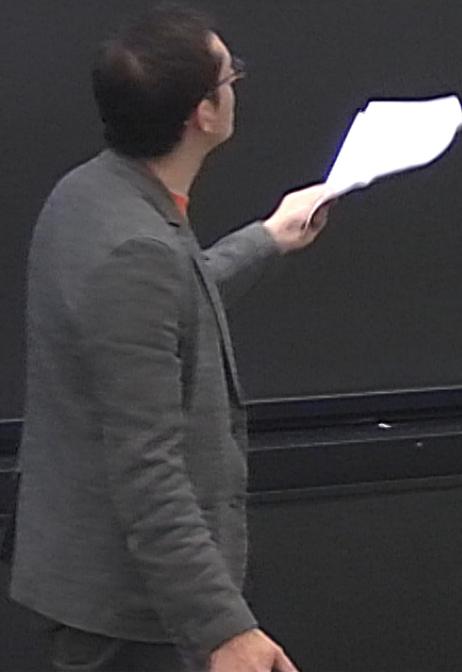
$$T_{\text{pre-signal}} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \dots$$

$$P_{B, \text{signal}}^{(2)} = \text{Tr}_A(P_{\text{pre-signal}}^{(2)})$$

Contains information about A AND is locally accessible to B

Assuming: $\hat{P}_{A, B, 0} = \hat{P}_{A, 0} \otimes \hat{P}_{B, 0}$

$$\hat{P}_{B, \text{signal}}^{(2)} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_A(t) \chi_B(t') \text{Tr}_A[\hat{m}_A(t) \hat{P}_A] 2i \text{Im}[\mathcal{W}(\vec{x}_A, t, \vec{x}_B, t')] (\hat{m}_B(t) \hat{P}_B - \hat{P}_B \hat{m}_B(t))$$



$$\psi(\vec{x}, t) \hat{p}_A] 2i \operatorname{Im} \left[\mathcal{W}(\vec{x}_A, t, \vec{x}_B, t') \right] \left(\hat{m}_B(t') \hat{p}_R - \hat{p}_B \hat{m}_B(t') \right) \quad \mathcal{W}^*(t, x, t', x') = \mathcal{W}(t', x', t, x)$$

$$\psi(t) \hat{p}_A] 2i \operatorname{Im} \left[\mathcal{W}(\vec{x}_A, t, \vec{x}_B, t') \right] \left(\hat{m}_B(t') \hat{p}_B - \hat{p}_B \hat{m}_B(t') \right) \leftarrow \begin{matrix} \mathcal{W}^*(t, x, t', x') = \\ \mathcal{W}(t', x', t, x) \end{matrix}$$

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

Assuming $\hat{P}_{B,0} = \hat{P}_{A,0} \otimes \hat{P}_{B,0}$ $\hat{J}_{B, \text{signal}}^{(2)} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_A(t) \chi_B(t') T_V[\hat{m}_A(t) \hat{P}_A] z; \text{Im}[W]$

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

$$\begin{aligned}
 & \chi_A(t) \chi_B(t') T_V [\hat{m}_A(t) \hat{p}_A] z; \text{Im} [\mathcal{W}(\vec{x}_A, t, \vec{x}_B, t')] (\hat{m}_B(t') \hat{p}_B - \hat{p}_B \hat{m}_B(t')) \leftarrow \mathcal{W}^*(t, x, t', x') = \mathcal{W}(t', x', t, x) \\
 & \Rightarrow \begin{pmatrix} 0 \\ 1 \end{pmatrix} \Rightarrow m_V(z) = \begin{pmatrix} 0 & e^{-i\Omega_V z} \\ e^{i\Omega_V z} & 0 \end{pmatrix}; \hat{p}_{A,0} = \hat{p}_{A,0} \otimes \hat{p}_{B,0} = \begin{pmatrix} a_A & b_A \\ b_A^* & 1-a_A \end{pmatrix} \otimes \begin{pmatrix} a_B & b_B \\ b_B^* & 1-a_B \end{pmatrix}
 \end{aligned}$$

$|B, \text{signal}\rangle$

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

Matrix representation for B: $|g\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$; $|e\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \Rightarrow m_B(z) = \begin{pmatrix} 0 & e^{-i\Omega_B z} \\ e^{i\Omega_B z} & 0 \end{pmatrix}$; $\hat{\rho}_{KB,0} =$
in this representation: $\text{Tr}[\hat{m}_A(t) \hat{\rho}_A] = 2 \text{Re}(b_A e^{i\Omega_A t})$ $[\hat{m}_B(t), \hat{\rho}_{B,0}] = \begin{pmatrix} -2i \text{Im}(b_B e^{i\Omega_B t}) & \\ & \end{pmatrix}$

$$\begin{aligned}
 & \hat{p}_A] 2i \operatorname{Im} [W(\vec{x}_A, t, \vec{x}_B, t')] (\hat{m}_B(t') \hat{p}_B - \hat{p}_B \hat{m}_B(t')) \leftarrow W^*(t, x, t', x') = W(t', x', t, x) \\
 & = \begin{pmatrix} 0 & e^{-i\omega_0 z} \\ i\omega_0 z & 0 \\ e & 0 \end{pmatrix}; \hat{p}_{A,0} = \hat{p}_{A,0} \otimes \hat{p}_{B,0} = \begin{pmatrix} a_A & b_A \\ b_A^* & 1-a_A \end{pmatrix} \otimes \begin{pmatrix} a_B & b_B \\ b_B^* & 1-a_B \end{pmatrix} \\
 & \hat{p}_{B,0} = \begin{pmatrix} -2i \operatorname{Im}(b_B e^{i\omega_B t'}) & e^{-i\omega_B t'} (1-2a_B) \\ ()^* & 2i \operatorname{Im}(b_B e^{i\omega_B t'}) \end{pmatrix}
 \end{aligned}$$

1B, signal

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

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

in this representation: $\text{Tr}[\hat{m}_A(t) \hat{P}_A] = 2 \text{Re}(b_A e^{i\nu_A t})$ $[\hat{m}_B(t), \hat{P}_{B,0}] = \begin{pmatrix} -2i \text{Im}(b_B e^{i\nu_B t}) \\ \end{pmatrix}$

$f^{(2)} = 2 \int_{-\infty}^{\infty} dt \int_{-\infty}^{\infty} dt' \chi_A(t) \chi_B(t') \text{Re}(b_A e^{i\nu_A t}) \left([\hat{m}_B(t), \hat{P}_{B,0}] \right) G(t, t')$

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

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

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

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

in this representation: $\text{Tr}[\hat{m}_A(t) \hat{P}_A] = 2 \text{Re}(b_A e^{i\nu_A t})$ $[\hat{m}_B(t), \hat{P}_{B,0}] = \begin{pmatrix} -2i \text{Im}(b_B e^{i\nu_B t}) \\ \end{pmatrix}$

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

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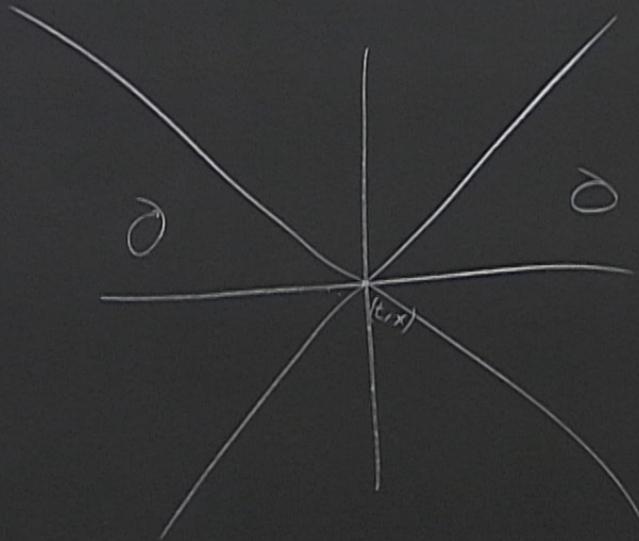
$$i \hat{p}_A] 2i \operatorname{Im} [W(\vec{x}_A, t, \vec{x}_B, t')] (\hat{m}_B(t') \hat{p}_B - \hat{p}_B \hat{m}_B(t')) \leftarrow W^*(t, x, t', x') = W(t', x', t, x)$$

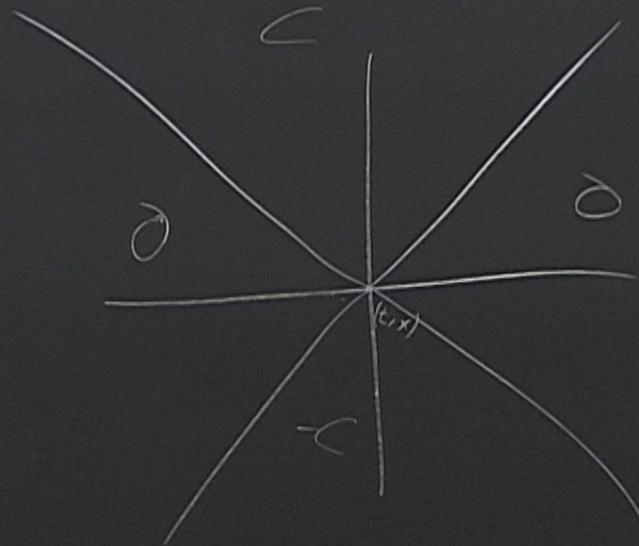
$$= \begin{pmatrix} 0 & e^{-i\Omega_B z} \\ i\Omega_B z & 0 \\ e & 0 \end{pmatrix}; \hat{p}_{AB,0} = \hat{p}_{A,0} \otimes \hat{p}_{B,0} = \begin{pmatrix} a_A & b_A \\ b_A^* & 1-a_A \end{pmatrix} \otimes \begin{pmatrix} a_B & b_B \\ b_B^* & 1-a_B \end{pmatrix}$$

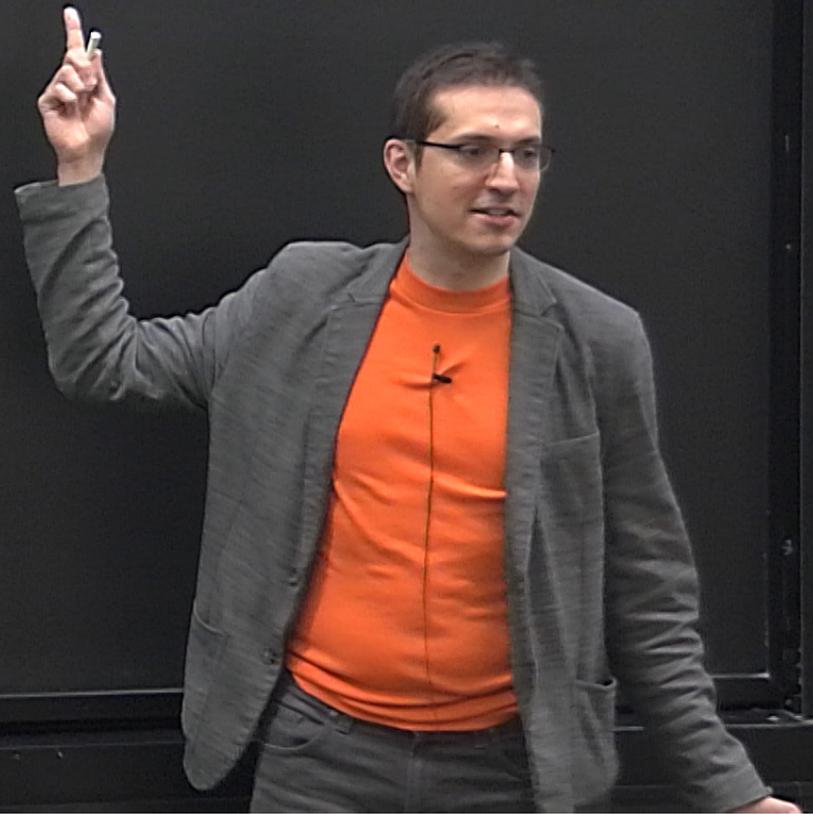
$$= \begin{pmatrix} -2i \operatorname{Im}(b_B e^{i\Omega_B t'}) & e^{-i\Omega_B t'} (1-2a_B) \\ ()^* & 2i \operatorname{Im}(b_B e^{i\Omega_B t}) \end{pmatrix}$$

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

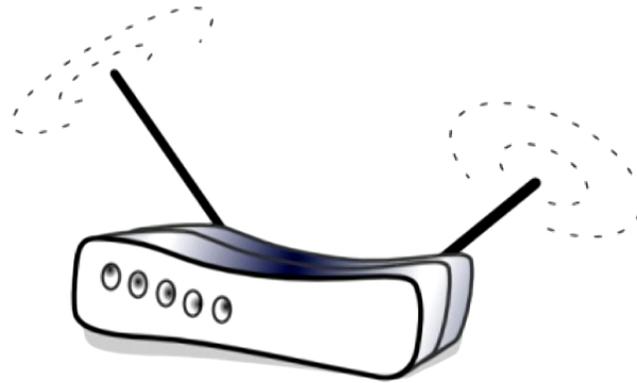
$$\langle \hat{\phi}(t, \vec{x}) \rangle_{\rho_{B,0}}$$







Communication through massless fields



General properties of wireless communication

Communication through the EM field

Communication mediated by 'real' energy-carrying quanta



An emitter emits photons. A receiver captures photons.

Communication through the EM field

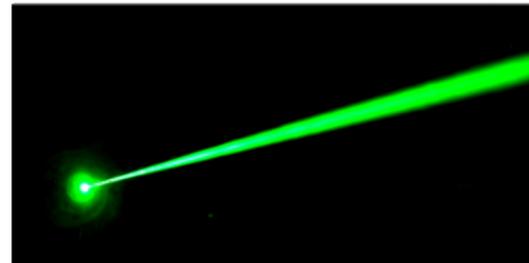
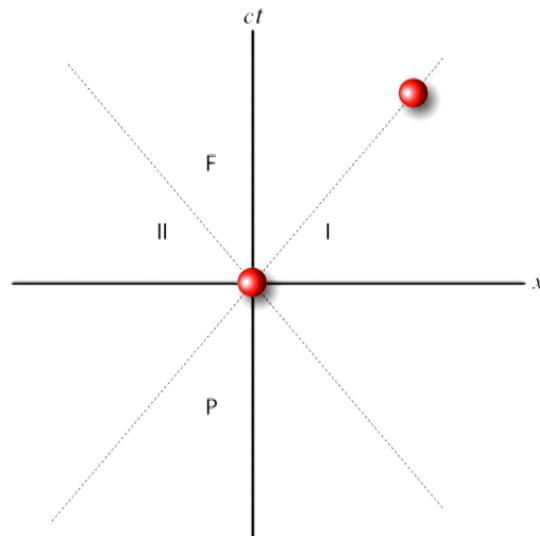
Information flow carried by (an average) energy flow



Information reaches you when energy reaches you

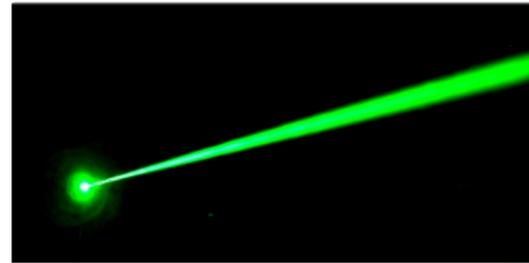
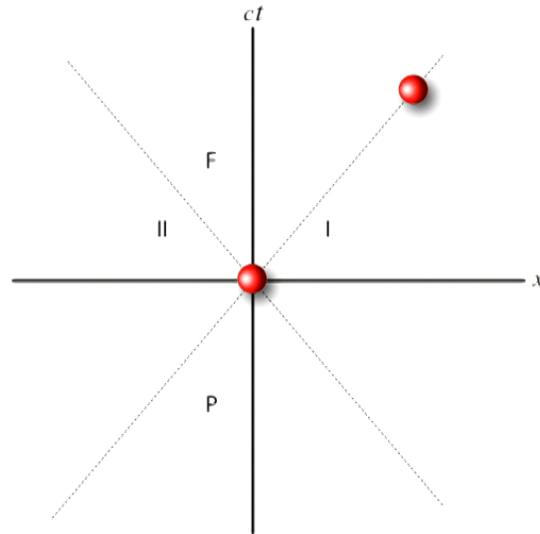
Communication through the EM field

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 massless 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

