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Relativistic Quantum Information

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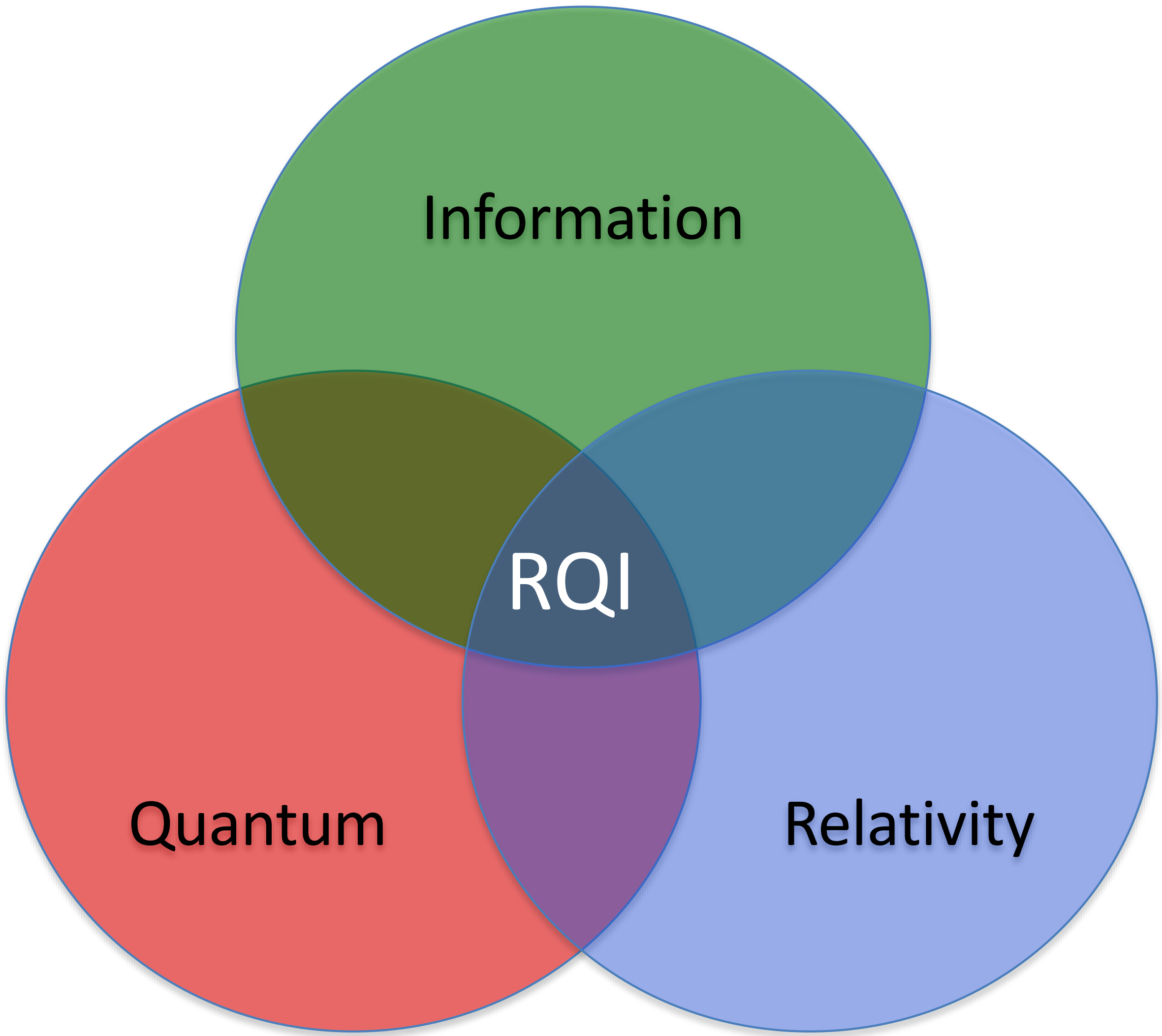


What is RQI?

- How do relativistic effects influence quantum information tasks?
- How do quantum information concepts inform us about the fundamental structure of the universe?

Relativistic Quantum Information

Pre-History

Quantum Field Theory in Curved Spacetime:

- Particles are observer dependent concepts
- Non-inertial detectors experience heat bath
- Black Holes radiate
- de Sitter spacetime is “hot”

Parker and Toms
Davies, Fulling, Unruh
Hawking, Gibbons

Inertial Frames:

- Entanglement is constant between inertially moving observers
- Some degrees of freedom can be transferred to others

Peres,Scudo and Terno
Alsing and Milburn
Gingrich and Adami
Pachos and Solano

Non-Inertial Frames:

- Teleportation fidelity decreases as acceleration increases
- For a bipartite system entanglement degrades as acceleration increases

Alsing/Milburn
PRL **91** 180404 (2003)
Fuentes-Schuller/Mann
PRL **95** 12404 (2005)
Alsing/Fuentes-Schuller/Mann/Tessier PRA **74** 032326 (2006)

QFT in Curved Spacetime

- Gravity is assumed to be classical
- Fields are assumed to be quantum

semiclassical approximation

- Basic idea is to quantize fields in the desired classical spacetime
- Seems straightforward, but
  - Can't relay on flat-space Poincare symmetry
  - Definition of the vacuum is a subtle concept
  - Different observers disagree on the notion of particle
  - Not clear how to deal with time-dependent spacetimes
  - Relationship between local and global effects

Key Assumptions

Mathur 2009

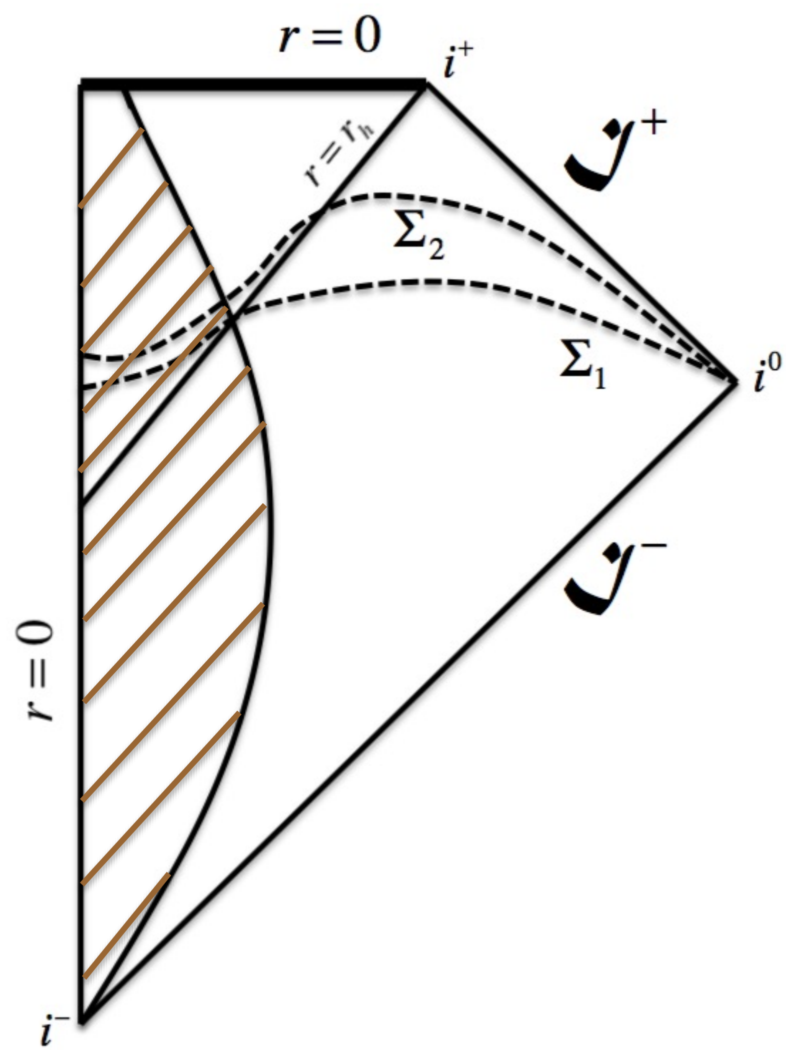
- All quantum states are defined on a spacelike slice Σ

  intrinsic curvature $R^{(3)}_{abcd}$ $\quad |R^{(3)}_{abcd}| << 1/l_p^2$

  extrinsic curvature $K_{\mu\nu}$ $\quad |K_{\mu\nu}| << 1/l_p^2$

- $\exists$ some neighbourhood of Σ where $|R_{\mu\nu\alpha\beta}| << 1/l_p^2$
- $T_{\mu\nu}$ obeys positive energy conditions and $|T_{\mu\nu}| << 1/l_p^2$
- Compton wavelength $\lambda >> l_p$
- Spacelike slice Σ evolves smoothly:

$$|dN/d\tau| << 1/l_p \qquad |dN^a/d\tau| << 1/l_p$$



Niceness Conditions

- Quantum properties of spacetime can be neglected
- Gravitational effects of quantum matter can be neglected
- Assumptions remain valid over a finite time interval

Classical Scalar Fields

Action $$I = -\frac{1}{2}\int d^D x\sqrt{-g}\left(g^{\mu\nu}\nabla_\mu\varphi\nabla_\nu\varphi + m^2\varphi^2\right)$$

Field Eqn $$\nabla^\lambda\nabla_\lambda\varphi - m^2\varphi = 0$$

Stress Energy $$T_{\mu\nu} = \nabla_\mu\varphi\nabla_\nu\varphi - \frac{g_{\mu\nu}}{2}\left[\nabla^\lambda\varphi\nabla_\lambda\varphi + m^2\varphi^2\right]$$

Conjugate Momentum $$\pi(x) = \frac{\partial\mathcal{L}_{\mathrm{KG}}}{\partial\left(u^\mu\partial_\mu\varphi(x)\right)} = \sqrt{-g(x)}u^\mu\nabla_\mu\varphi(x)$$

Hamiltonian $$H_{\mathrm{KG}} = \int d^{D-1}x\sqrt{-g(x)}T_{00}$$

unit normal to Σ

Scalar Field Quantization

Equal Time Commutation Relation

$$[\varphi(x^0,\vec{x}),\pi(x^0,\vec{y})] = i\hbar\delta(\vec{x},\vec{y})$$

$$\int d^{D-1}x\, F(\vec{x})\delta(\vec{x},\vec{y}) = F(\vec{y})$$

Covariantly

independent of spatial slice
vanishes if *(x,y)* are spacelike separated

$$[\varphi(x),\varphi(y)] \equiv i\Delta(x-y)$$

$$= \int \frac{d^D k}{(2\pi)^{D-1}} \delta(k^2 - m^2) \frac{k^0}{|k^0|} \exp(-ik\cdot(x-y))$$

- Local: system is directly influenced only by its immediate surroundings
- Spacelike separated observables made of (φ,π) have no influence on each other
- Measurements made in one region in space and time cannot affect measurements made anywhere outside the light cone of that region

Consequences of Locality

- Spin-statistics theorem: bosons have integer spin, fermions half-integer spin

- Particle/antiparticle symmetry: mass, lifetime, and magnetic moments are same for both a particle and its antiparticle

Positive and Negative Frequency

Conserved Current

$$j^{\sigma}\left(\chi,\phi\right)=i\sqrt{-g}\,g^{\sigma\nu}(\chi^{*}\nabla_{\nu}\phi-(\nabla_{\nu}\chi^{*})\phi) \qquad \nabla_{\mu}j^{\mu}=0$$

Inner Product

$$\left\langle\left\langle\chi,\phi\right\rangle\right\rangle=\int_{\Sigma}d\Sigma_{\nu}j^{\nu}\left(\chi,\phi\right) \Rightarrow \begin{array}{l}\left\langle\left\langle\chi,\chi^{*}\right\rangle\right\rangle=0\\ \left\langle\left\langle\chi,\phi\right\rangle\right\rangle^{*}=-\left\langle\left\langle\chi^{*},\phi^{*}\right\rangle\right\rangle=\left\langle\left\langle\phi,\chi\right\rangle\right\rangle\end{array}$$

Positive Frequency Solutions

$$\mathcal{Q}_{+}:=\left\{\chi,\phi \middle| \ \left\langle\left\langle\chi,\chi\right\rangle\right\rangle>0 \text{ and } \left\langle\left\langle\chi,\phi^{*}\right\rangle\right\rangle=0\right\}$$

Negative Frequency Solutions

$$\mathcal{Q}_{-}:=\left\{\chi,\phi \middle| \ \left\langle\left\langle\chi,\chi\right\rangle\right\rangle<0 \text{ and } \left\langle\left\langle\chi,\phi^{*}\right\rangle\right\rangle=0\right\}$$

All Solutions

$$\mathcal{Q}=\mathcal{Q}_{+}+\mathcal{Q}_{-}$$

The Vacuum

For a given field φ:

$$\mathbf{a}(\chi) = \langle\langle \chi, \varphi \rangle\rangle \qquad \mathbf{a}^{\dagger}(\chi) = -\mathbf{a}(\chi^{*}) = -\langle\langle \chi^{*}, \varphi \rangle\rangle$$

$$[\mathbf{a}(\chi),\ \mathbf{a}^{\dagger}(\phi)] = \langle\langle \chi, \phi \rangle\rangle$$

$$[\mathbf{a}(\chi),\ \mathbf{a}(\phi)] = [\mathbf{a}^{\dagger}(\chi),\ \mathbf{a}^{\dagger}(\phi)] = 0$$

State of lowest energy $\underbrace{|0\rangle:}_{\text{The vacuum}}$ $\qquad \mathbf{a}(\chi)|0\rangle = 0 \qquad \forall \chi \in \mathcal{Q}_{+}$

Many particle state $|N\rangle$:

$$\prod_{n=1}^{N} \mathbf{a}^{\dagger}(\chi_n)|0\rangle = \mathbf{a}^{\dagger}(\chi_1)\mathbf{a}^{\dagger}(\chi_2)\cdots\mathbf{a}^{\dagger}(\chi_N)|0\rangle$$

Fock space $\mathcal{F}$:
span of all
such states

Mode Decomposition

Decompose the field φ :

$$\varphi(x) = \int d^{D-1}\mathrm{k}\left[\phi_k(x)\mathbf{a}_k + \phi_k^*(x)\mathbf{a}_k^\dagger\right]$$

$$\mathbf{a}_k = \left\langle\left\langle \phi_k, \varphi \right\rangle\right\rangle$$

$$\mathbf{a}_k^\dagger = -\left\langle\left\langle \phi_k^*, \varphi \right\rangle\right\rangle$$

For a (timelike) Killing vector ξ :

$$i\xi^\mu \partial_\mu \phi_k = \omega_k \phi_k$$

positive frequency modes

$$i\frac{\partial\psi}{\partial t} = E\psi \Rightarrow \psi \sim \exp\left(-iEt\right)$$

$$i\xi^\mu \partial_\mu \phi_k^* = -\omega_k \phi_k^*$$

negative frequency modes

$$i\frac{\partial\psi^*}{\partial t} = -E\psi^* \Rightarrow \psi^* \sim \exp\left(+iEt\right)$$

$$\xi^\mu \partial_\mu = \frac{\partial}{\partial t}$$

$$\vec{\nabla}\phi_k\left(x\right) = \vec{k}\phi_k\left(x\right)$$

$$\nabla^\lambda \nabla_\lambda \varphi - m^2 \varphi = 0$$

$$\left|\vec{k}\right|^2 + m^2 = \omega_k^2$$

Orthonormal Basis

$$\langle\langle \phi_k, \phi_{k'} \rangle\rangle = -\langle\langle \phi_k^*, \phi_{k'}^* \rangle\rangle = \delta^{(D-1)}\left(\vec{k} - \vec{k}'\right) \qquad \langle\langle \phi_k, \phi_{k'}^* \rangle\rangle = 0$$

$$\Rightarrow \quad \left[\mathbf{a}_k, \mathbf{a}_{k'}^\dagger\right] = \delta^{(D-1)}\left(\vec{k} - \vec{k}'\right)$$

Minkowski Space

$$\phi_k(x) = \frac{e^{-i\omega_k t + i\vec{k}\cdot\vec{x}}}{\sqrt{2\omega_k (2\pi)^{(D-1)}}}$$

Energy and Momentum

eliminate
zero point
contribution

Energy $$H = \int \frac{d^{D-1}\mathrm{k}}{(2\pi)^{(D-1)}} \omega_k \left(\mathbf{a}_k^\dagger \mathbf{a}_k + \cancel{\frac{1}{2}\left[\mathbf{a}_k, \mathbf{a}_k^\dagger\right]} \right)$$

$$H = \int \frac{d^{D-1}\mathrm{k}}{(2\pi)^{(D-1)}} \omega_k \mathbf{N}_k \qquad \mathbf{N}_k = \mathbf{a}_k^\dagger \mathbf{a}_k$$

Momentum $$\vec{P} = \int \frac{d^{D-1}\mathrm{k}}{(2\pi)^{(D-1)}} \vec{k} \; \mathbf{a}_k^\dagger \mathbf{a}_k$$

Multiparticle state

$$\left| n_{k_1}, n_{k_2}, \ldots \right\rangle = \prod_{m=1}^{N} (\mathbf{a}_{n_k}^\dagger)^{n_k} \left| 0 \right\rangle$$

Energy eigenvalue eqn

$$H \left| n_{k_1}, n_{k_2}, \ldots \right\rangle = \sum_i n_{k_i} \omega_{k_i} \left| n_{k_1}, n_{k_2}, \ldots \right\rangle$$

Bogoliubov Transformations

$$\mathcal{Q} = \mathcal{Q}_+ + \mathcal{Q}_- = \tilde{\mathcal{Q}}_+ + \tilde{\mathcal{Q}}_-$$

$$\mathcal{Q}_+ \Rightarrow |0\rangle \quad \mathcal{F} = \{|n_k\rangle\}$$

$$\tilde{\mathcal{Q}}_+ \Rightarrow |\tilde{0}\rangle \quad \tilde{\mathcal{F}} = \{|\tilde{n}_k\rangle\}$$

$$|0\rangle \notin \tilde{\mathcal{F}}$$

$$|\tilde{0}\rangle \notin \mathcal{F}$$

space of positive frequency solutions is not unique

But if $\tilde{\phi} \in \tilde{\mathcal{Q}}_+$ then $\tilde{\phi} = \phi + \chi^*$ for some $(\chi, \phi) \in \mathcal{Q}_+$.

$$\tilde{\chi}_k(x) = \int d^{(D-1)}k' \left[\alpha_{kk'} \chi_{k'}(x) + \beta_{kk'} \chi^*_{k'}(x) \right]$$

$\{\tilde{\chi}_k(x)\}$ $\tilde{\mathcal{Q}}_+$ basis

$\{\chi_k(x)\}$ $\mathcal{Q}_+$ basis

Bogoliubov Transformation

$$\alpha_{kk'} = \langle\langle \tilde{\chi}_k(x), \chi_{k'}(x) \rangle\rangle$$

$$\beta_{kk'} = -\langle\langle \tilde{\chi}_k(x), \chi^*_{k'}(x) \rangle\rangle$$

Two different particle interpretations of field excitations!

Particle Production

$$\tilde{\mathbf{a}}_k = \int d^{(D-1)}k' \left[\alpha^*_{kk'}\mathbf{a}_k - \beta_{kk}\mathbf{a}^\dagger_k\right] \qquad \mathbf{a}_k = \int d^{(D-1)}k' \left[\alpha_{kk'}\tilde{\mathbf{a}}_k + \beta^*_{kk}\tilde{\mathbf{a}}^\dagger_k\right]$$

Commutation Relations

$$\begin{pmatrix} \alpha & \beta \\ \beta^* & \alpha^* \end{pmatrix}\begin{pmatrix} \alpha^\dagger & -\beta^T \\ -\beta^\dagger & \alpha^T \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Number of particles in the $|\tilde{0}\rangle$ vacuum:

$$\langle\tilde{0}|N_k|\tilde{0}\rangle = \langle\tilde{0}|\mathbf{a}^\dagger_k\mathbf{a}_k|\tilde{0}\rangle = \int \frac{d^{(D-1)}k'}{(2\pi)^{(D-1)}} |\beta_{kk'}|^2$$

Nonzero if $\beta \neq 0$!

Particle Creation and Observer-Dependent Radiation

- Flat space vacuum: state of no particles
  - Minkowski vacuum

$$\mathbf{a}_k |0\rangle = 0$$

- Accelerating Observers: Minkowski vacuum is detected as a thermal bath of particles
- How is this possible since there is no spacetime curvature?
- What is the meaning of a thermal system?

Thermality in Field Theory

Operator O in canonical ensemble

$$\langle \mathrm{O} \rangle_\beta \equiv \langle e^{-\beta H} \mathrm{O} \rangle = \frac{\mathrm{Tr}\left[e^{-\beta H} \ \mathrm{O} \right]}{Z}$$

$\beta = 1/T$

Temperature

$Z = \mathrm{Tr}\left[e^{-\beta H} \right]$

trace over mircrostates of the system

Finite # of degrees of freedom

Time Evolution of operators: $\langle \mathrm{A}(t)\mathrm{B} \rangle = \langle e^{itH} \ \mathrm{A}(0) e^{-itH} \mathrm{B} \rangle$

Thermality Condition

$$\langle \mathrm{A}(-i\beta)\mathrm{B} \rangle_\beta = \langle \mathrm{BA} \rangle_\beta$$

Kubo-Martin-Schwinger (KMS) Condition

- Thermal state in curved space-time
- Same as above for finite systems
- If KMS holds:
  - free energy is locally minimized
  - any finite system coupled to an infinite system will come into thermal equilibrium with that system

Green's Functions

Thermality Condition $\Rightarrow \left\langle \mathrm{A}(-i\beta)\mathrm{B} \right\rangle_\beta = \left\langle \mathrm{BA} \right\rangle_\beta$

$$\mathrm{LHS} = \left\langle \mathrm{A}(-i\beta)\mathrm{B} \right\rangle_\beta = \left\langle e^{-\beta H} e^{\beta H}\ \mathrm{A} e^{-\beta H} \mathrm{B} \right\rangle = \left\langle \mathrm{A} e^{-\beta H} \mathrm{B} \right\rangle$$

$$\mathrm{RHS} = \left\langle \mathrm{BA} \right\rangle_\beta = \left\langle e^{-\beta H} \mathrm{BA} \right\rangle \longrightarrow \left\langle e^{-\beta H} \mathrm{BA} \right\rangle = \left\langle \mathrm{A} e^{-\beta H} \mathrm{B} \right\rangle \quad \text{KMS}$$

Time Ordered Green's Function for Scalars

complex t-plane

$$G_T(x,y) = \Theta(t_x - t_y)\langle \phi(x)\phi(y) \rangle + \Theta(t_y - t_x)\langle \phi(y)\phi(x) \rangle$$
$$\equiv \Theta(t_x - t_y) G_+(x,y) + \Theta(t_y - t_x) G_-(x,y)$$

$$G_+^\beta(x,y) = \langle \phi(x)\phi(y) \rangle_\beta$$
$$G_-^\beta(x,y) = \langle \phi(y)\phi(x) \rangle_\beta$$

KMS Condition

$$G_+^\beta(z - i\beta, \vec{x}, \vec{y}) = G_-^\beta(z, \vec{y}, \vec{x})$$

More generally: Any free scalar field whose

Wightman function obeys $\mathcal{G}^{\beta}(\tau,\vec{x},\vec{y})=\mathcal{G}^{\beta}(\tau+in\beta,\vec{x},\vec{y})$

on a stationary curved space-time is defined to be in a thermal state

$\mathcal{G}^{\beta}(z,\vec{x},\vec{y})$ is holomorphic in complex z plane

except for branch cuts along $\left(|\Re(z)|>|\vec{x}-\vec{y}|,\Im(z)=n\beta\right)$

ending in poles at $\Re(z)=|\vec{x}-\vec{y}|$

If space-time is static $\Rightarrow G^{\beta}\left(\tau\right)=G^{\beta}\left(\tau+\beta\right)$

$\rightarrow$ related to thermal states on original (Lorentzian)

spacetime by analytic continuation $t\rightarrow i\tau$

Hot Flat Space

Flat Minkowski Spacetime

$$ds^2 = -dt^2 + dr^2 + r^2 d\Omega^2_{D-2} = -dt^2 + dx^2 + \sum_{i=2}^{D} dw^i\, dw^i$$

KG equation $\nabla^\lambda \nabla_\lambda \varphi - m^2 \varphi = 0$ Quantum Vacuum $\mathbf{a}_k \left|0\right\rangle = 0$

Green's function: $\left(\nabla_x^2 - m^2\right) G_{\mathcal{M}}(x,y) = \delta^D(x-y)$

$$G_{\mathcal{M}}(x,y) = G_{\mathcal{M}}(\Delta t, \vec{x}, \vec{y}) = {}_{\mathcal{M}}\left\langle 0 \middle| \phi(x)\phi(y) \middle| 0 \right\rangle$$

$\Delta t = x^0 - y^0 = t_x - t_y$

Euclidean Green's function:

$$G_{\mathcal{M}}(i\Delta\tau, \vec{x}, \vec{y}) = G_E(\Delta\tau, \vec{x}, \vec{y}) = G_E(x,y)$$

$$G^\beta(\tau) = G^\beta(\tau + \beta)$$

arbitrary

KG Green's function in Minkowski Spacetime can be periodic in imaginary time with any desired period

→ Can have fields at any desired finite temperature

Flat Space in Multiple Guises

Flat Minkowski Spacetime

$$ds^2 = -dt^2 + dr^2 + r^2 d\Omega_{D-2}^2 = -dt^2 + dx^2 + \sum_{i=2}^{D} dw^i dw^i$$

Coordinate Transformations

$$t = \mathrm{X}\sinh(\kappa \mathrm{T}) = \frac{1}{\kappa} e^{\kappa\xi} \sinh(\kappa\varsigma) = \frac{1}{2\kappa}\left(e^{\kappa U} - e^{-\kappa V}\right)$$

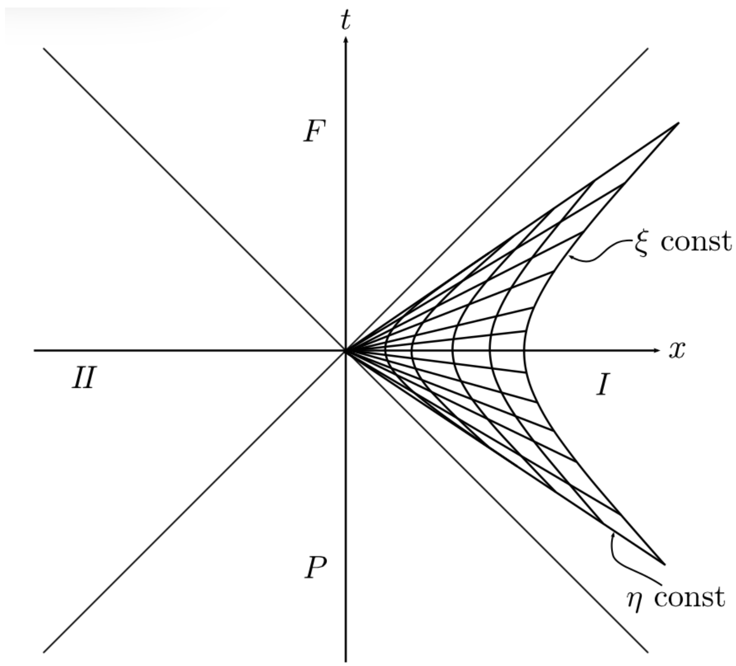
$$x = \mathrm{X}\cosh(\kappa \mathrm{T}) = \frac{1}{\kappa} e^{\kappa\xi} \cosh(\kappa\varsigma) = \frac{1}{2\kappa}\left(e^{\kappa U} + e^{-\kappa V}\right)$$

$$\vec{w} = \vec{W}$$

$$ds^2 = -\kappa^2 \mathrm{X}^2 d\mathrm{T}^2 + d\mathrm{X}^2 + \sum_{i=2}^{d} dW^i dW^i$$

$$= e^{2\kappa\xi}(-d\varsigma^2 + d\xi^2) + \sum_{i=2}^{d} dW^i dW^i$$

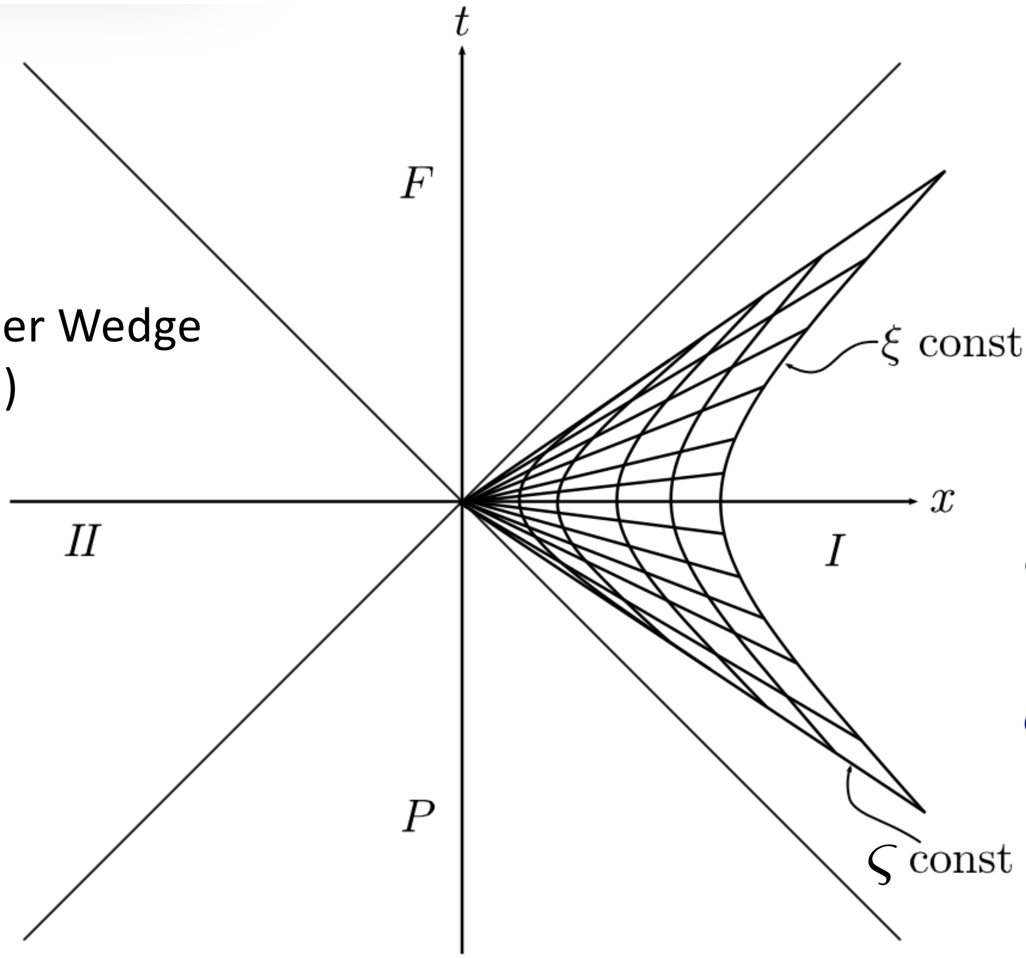
$$= -e^{\kappa(U-V)} dU\, dV + \sum_{i=2}^{d} dW^i dW^i$$



Rindler Space

Future Rindler Wedge (region F)

Left Rindler Wedge (region II)



Past Rindler Wedge (region P)

$$ds^2 = -\kappa^2 \mathrm{X}^2 d\mathrm{T}^2 + d\mathrm{X}^2 + \sum_{i=2}^{d} dW^i\, dW^i$$

$$= e^{2\kappa\xi}(-d\varsigma^2 + d\xi^2) + \sum_{i=2}^{d} dW^i\, dW^i$$

$$= -e^{\kappa(U-V)} dU\, dV + \sum_{i=2}^{d} dW^i\, dW^i$$

Right Rindler Wedge (region I)

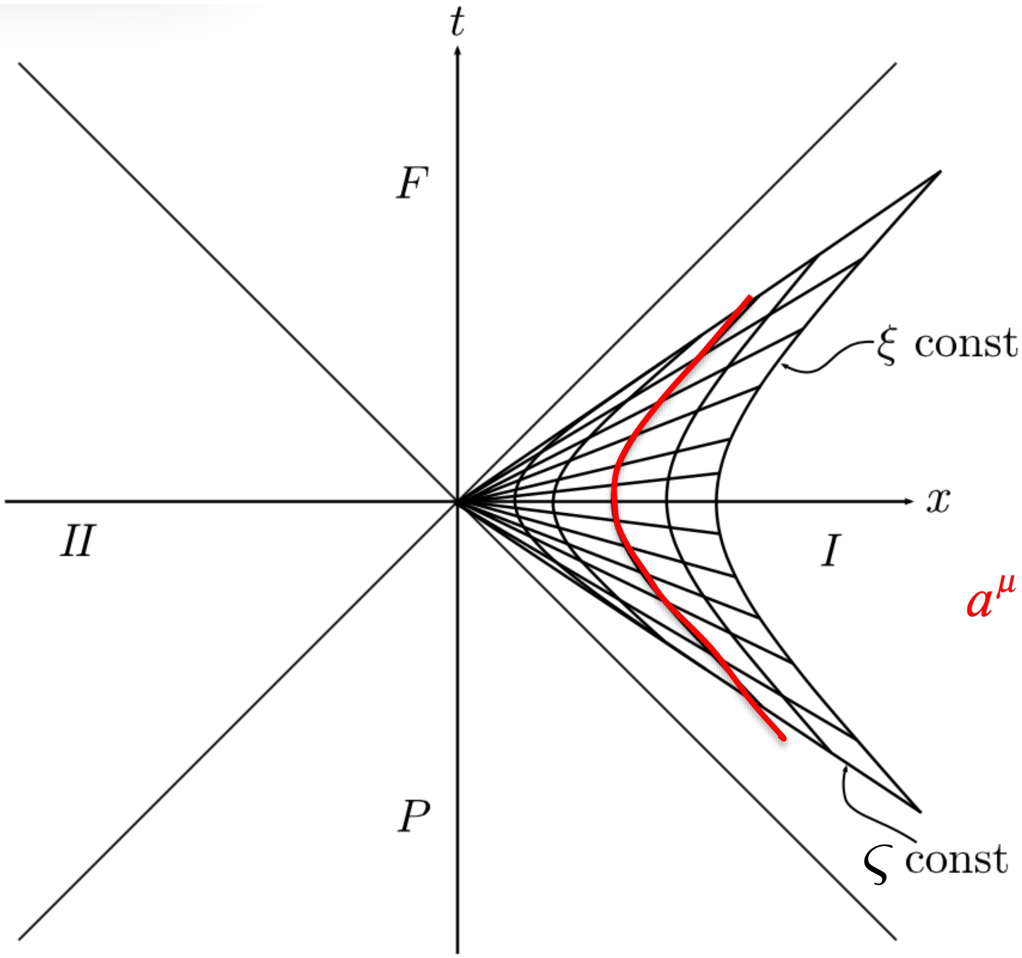
$$\xi = \frac{1}{\kappa}\ln\left(\kappa \mathrm{X}\right) = \frac{1}{2\kappa}\ln[\kappa^2(x^2 - t^2)]$$

$$\varsigma = \mathrm{T} = \frac{1}{\kappa}\mathrm{arctanh}(t/x)$$

Rindler Observers

$$ds^2 = e^{2\kappa\xi}(-d\varsigma^2 + d\xi^2) + \sum_{i=2}^{d} dW^i\, dW^i$$

$$z^\mu(\varsigma) = \frac{1}{\kappa} e^{\kappa\xi_0}\left[\sinh(\kappa\varsigma), \cosh(\kappa\varsigma), \vec{w}_0\right]$$



$$v^\mu(\varsigma) = e^{-\kappa\xi_0}\frac{\partial z^\mu}{\partial\varsigma}$$ Proper velocity

$$= \left[\cosh(\kappa\varsigma), \sinh(\kappa\varsigma), \vec{0}\right]$$

$$a^\mu(\varsigma) = e^{-\kappa\xi_0}\frac{\partial v^\mu}{\partial\varsigma}$$ Proper acceleration

$$= \kappa e^{-\kappa\xi_0}\left[\sinh(\kappa\varsigma), \cosh(\kappa\varsigma), \vec{0}\right]$$

$$a_\nu a^\nu = \kappa^2$$

Uniform acceleration for all time!

Acceleration Radiation

Minkowski Spacetime

$$ds^2 = -dt^2 + dx^2 + \sum_{i=2}^{D} dw^i\, dw^i \xrightarrow{t \to i\tau} d\tau^2 + dx^2 + \sum_{i=2}^{D} dw^i\, dw^i$$

Green's function: $\left(\nabla_x^2 - m^2\right) G_{\mathcal{M}}(x,y) = \delta^D(x-y) \xrightarrow{t \to i\tau} G_E(\Delta\tau, \vec{x}, \vec{y}) = G_{\mathcal{M}}(i\Delta\tau, \vec{x}, \vec{y})$

$$\text{KMS} \Rightarrow G_E^{\beta}(\tau) = G_E^{\beta}(\tau + \beta)$$

Temperature

$$T = {}^{1}\!/_{\beta}$$

Minkowski Observer ⟶ value of β is arbitary

$$d\tau^2 + dx^2 + \sum_{i=2}^{D} dw^i\, dw^i \xrightarrow{(\tau, x, \vec{w}) = \left(\mathrm{X}\sin\left(\frac{2\pi\Im}{\beta}\right), \mathrm{X}\cos\left(\frac{2\pi\Im}{\beta}\right), \vec{W}\right)} \left(\frac{2\pi}{\beta}\right)^2 \mathrm{X}^2 d\Im^2 + d\mathrm{X}^2 + \sum_{i=2}^{d} dW^i\, dW^i$$

Rindler Observer ⟶ value of β is set by the state of motion

$$-\kappa^2 \mathrm{X}^2 d\mathrm{T}^2 + d\mathrm{X}^2 + \sum_{i=2}^{d} dW^i\, dW^i \xrightarrow{\mathrm{T} = i\Im} \kappa^2 \mathrm{X}^2 d\Im^2 + d\mathrm{X}^2 + \sum_{i=2}^{d} dW^i\, dW^i \Rightarrow \boxed{\beta = \frac{2\pi}{\kappa}}$$

and $G_E(\Delta\tau, \vec{x}, \vec{y}) = G_R(\Delta\Im, \vec{\mathrm{X}}, \vec{\mathrm{Y}}) = G_R\left(\Delta\Im + \frac{2\pi}{\kappa}, \vec{\mathrm{X}}, \vec{\mathrm{Y}}\right) = G_R^{2\pi/\kappa}(\Delta\Im, \vec{\mathrm{X}}, \vec{\mathrm{Y}})$

Acceleration Radiation

$$\beta = \frac{2\pi}{\kappa} \Rightarrow T = \frac{\kappa}{2\pi}$$

- A uniformly accelerated detector of scalar particles experiences a thermal bath of scalars (Unruh effect)
- A uniformly accelerated detector/observer in right Rindler wedge is causally disconnected from the left wedge ➔any state (such as the vacuum state) detected by this observer is obtained by tracing over the degrees of freedom in the left wedge
- Yields a mixed state from the perspective of the accelerated observer ➔ entropy coming from entanglement between modes from left and right wedges