Title: Quantum Information Theory 3

Date: Jun 09, 2006 03:00 PM

URL: http://pirsa.org/06060028

Abstract:

Entanglement of zero angular momentum mixtures

and black hole entropy

Danny Terno

joint work with

Etera Livine

Nucl. Phys. B **741**, 131 (2006)
Phys. Rev. A **72**, 022307 (2005)

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

Loop quantum gravity

Quantization of GR in 3+1 dimensions

Loop quantum gravity

Quantization of GR in 3+1 dimensions

Action $S = \frac{1}{2k}\int_M d^4x\sqrt{|\det g|}R \quad \rightarrow \quad \Omega = d\omega + \omega\wedge\omega$

$$S(e^I_\mu, \omega^I_{\mu J}) = \frac{1}{4k}\int_M \varepsilon_{IJKL} e^I \wedge e^J \wedge \Omega^{KL} - \frac{1}{2\gamma k}\int_M e^I \wedge e^J \wedge \Omega_{IJ}$$

$$e^I_\mu e_{I\nu} = g_{\mu\nu}$$

Loop quantum gravity

Quantization of GR in 3+1 dimensions

Action $S=\frac{1}{2k}\int_M d^4x\sqrt{|\det g|}R \quad \rightarrow \quad \Omega=d\omega+\omega\wedge\omega$

$$S(e^I_\mu,\omega^I_{\mu J})=\frac{1}{4k}\int_M \varepsilon_{IJKL}e^I\wedge e^J\wedge\Omega^{KL}-\frac{1}{2\gamma k}\int_M e^I\wedge e^J\wedge\Omega_{IJ}$$

$$e^I_\mu e_{I\nu}=g_{\mu\nu}$$

Time function & partial gauge fixing: SO(3)

Loop quantum gravity

Quantization of GR in 3+1 dimensions

Action $S = \frac{1}{2k}\int_M d^4x\sqrt{|\det g|}R \quad \rightarrow \quad \Omega = d\omega + \omega\wedge\omega$

$$S(e^I_\mu, \omega^I_{\mu J}) = \frac{1}{4k}\int_M \varepsilon_{IJKL} e^I \wedge e^J \wedge \Omega^{KL} - \frac{1}{2\gamma k}\int_M e^I \wedge e^J \wedge \Omega_{IJ}$$

$$e^I_\mu e_{I\nu} = g_{\mu\nu}$$

Time function & partial gauge fixing: SO(3)

Γ^i_a so(3)- valued connection on 3D manifold M

K^i_a extrinsic curvature of

Loop quantum gravity

Quantization of GR in 3+1 dimensions

Action $S=\frac{1}{2k}\int_M d^4x\sqrt{|\det g|}R \quad \rightarrow \quad \Omega = d\omega + \omega\wedge\omega$

$$S(e^I_\mu,\omega^I_{\mu J})=\frac{1}{4k}\int_M \varepsilon_{IJKL}e^I\wedge e^J\wedge\Omega^{KL}-\frac{1}{2\gamma k}\int_M e^I\wedge e^J\wedge\Omega_{IJ}$$

$$e^I_\mu e_{I\nu}=g_{\mu\nu}$$

Time function & partial gauge fixing: SO(3)

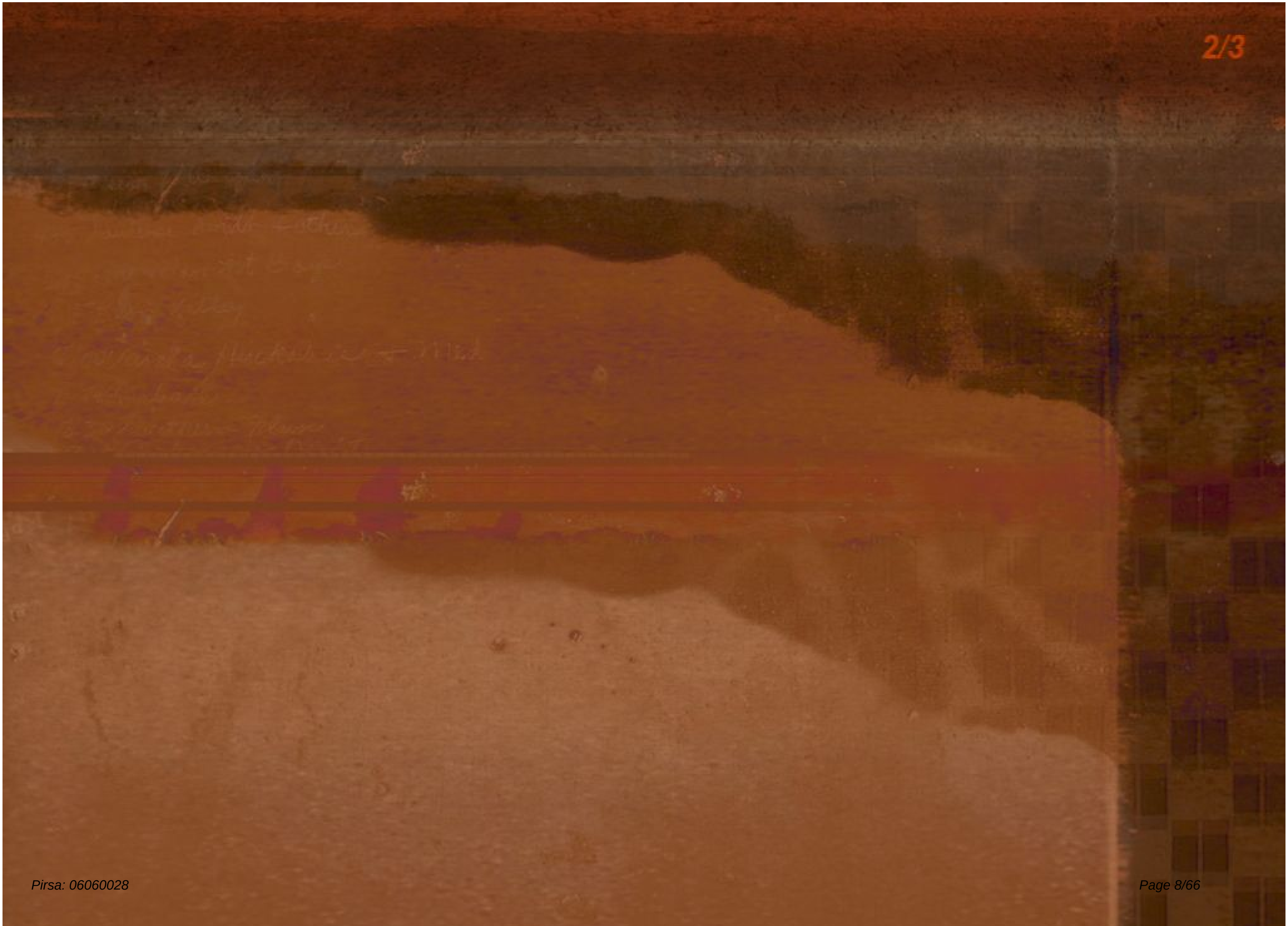
Γ^i_a so(3)- valued connection on 3D manifold M

K^i_a extrinsic curvature of 3D manifold M

Canonical variables

$$A^i_a=\Gamma^i_a-\gamma K^i_a$$

$$P^a_i=E^a_i/k\gamma \qquad E^a_iE^a_j=h_{ij}$$


2/3

Poisson brackets $\left\{A_a^i(\vec{x}), P_j^b(\vec{y})\right\} = \delta_j^i \delta_b^a \delta(\vec{x} - \vec{y})$

Constraints: Gauss/gauge, vector/diffeo, scalar/Hamiltonian

Gauge freedom: su(2)

Poisson brackets $\left\{A_a^i(\vec{x}), P_j^b(\vec{y})\right\} = \delta_j^i \delta_b^a \delta(\vec{x} - \vec{y})$

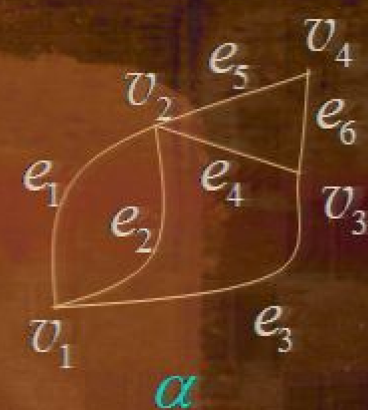
Constraints: Gauss/gauge, vector/diffeo, scalar/Hamiltonian

Gauge freedom: su(2)

Quantization

Configuration space: graphs & holonomies

$$\bar{A}(e_i) = \mathrm{e}^{P\int_{e_i} A dx} \in \mathrm{SU}(2)$$



Poisson brackets $\{A_a^i(\vec{x}), P_j^b(\vec{y})\} = \delta_j^i \delta_b^a \delta(\vec{x} - \vec{y})$

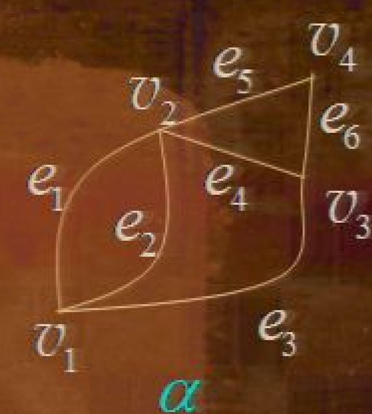
Constraints: Gauss/gauge, vector/diffeo, scalar/Hamiltonian

Gauge freedom: su(2)

Quantization

Configuration space: graphs & holonomies

$$\bar{A}(e_i) = e^{P\int_{e_i} A dx} \in SU(2)$$



Phase space: holonomies & fluxes

Poisson brackets $\left\{A_a^i(\vec{x}), P_j^b(\vec{y})\right\} = \delta_j^i \delta_b^a \delta(\vec{x} - \vec{y})$

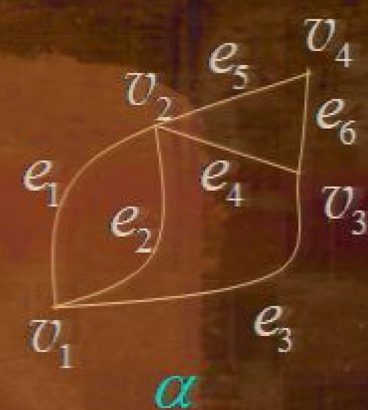
Constraints: Gauss/gauge, vector/diffeo, scalar/Hamiltonian

Gauge freedom: su(2)

Quantization

Configuration space: graphs & holonomies

$$\bar{A}(e_i) = \mathrm{e}^{P\int_{e_i} A dx} \in \mathrm{SU}(2)$$



Phase space: holonomies & fluxes

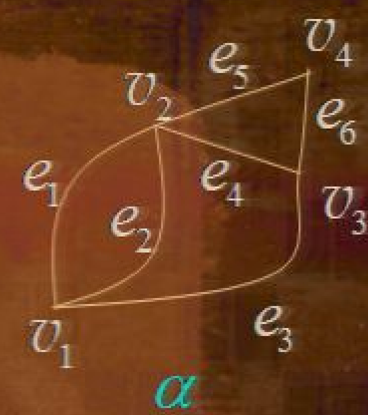
Hilbert space: functions of holonomies, basic operators

Poisson brackets $\left\{A_a^i(\vec{x}), P_j^b(\vec{y})\right\} = \delta_j^i \delta_b^a \delta(\vec{x} - \vec{y})$

Constraints: Gauss/gauge, vector/diffeo, scalar/Hamiltonian

Gauge freedom: su(2)

Quantization



Configuration space: graphs & holonomies

$$\bar{A}(e_i) = \mathrm{e}^{P\int_{e_i} A dx} \in \mathrm{SU}(2)$$

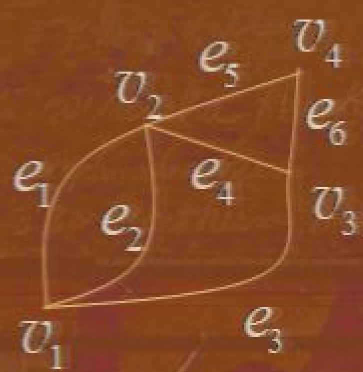
Phase space: holonomies & fluxes

More math

Hilbert space: functions of holonomies, basic operators

Decomposition: example *Peter- Weyl*

$$L^2(G, d\mu_H) = \oplus_j V_j \otimes V_j^* \equiv \oplus_j H_j$$

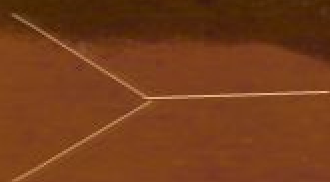


v_4
e_5
v_2
e_6
e_1
e_4
v_3
e_2
v_1
e_3

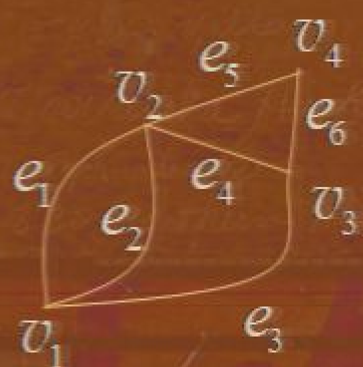
Decomposition $H = \oplus_\alpha H_\alpha = \oplus_\alpha H_{\alpha jl}$

Gauge & diffeomorphism constraints: $I = 0$

Intertwiners:



Coupling theory

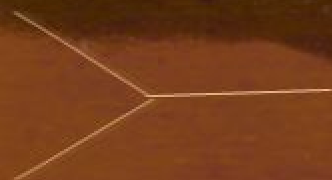


spin networks

Decomposition $H = \oplus_\alpha H_\alpha = \oplus_\alpha H_{\alpha \mathrm{jl}}$

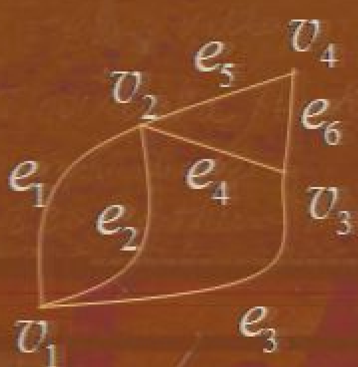
Gauge & diffeomorphism constraints: $\mathrm{I} = 0$

Intertwiners:



Coupling theory

spin networks



Fixed graph:

$L^2\left(SU(2)^E / SU(2)^V\right) \langle x | n \rangle \; I_1 I_2 \ldots I_V$

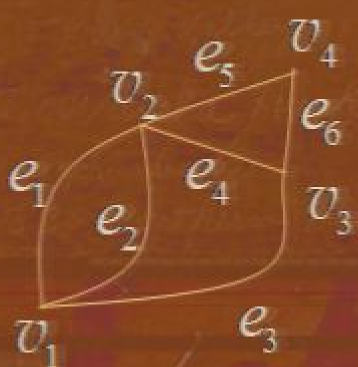
contraction

Decomposition $H = \oplus_{\alpha} H_{\alpha} = \oplus_{\alpha} H_{\alpha \mathrm{jl}}$

Gauge & diffeomorphism constraints: $\mathrm{I} = 0$

Intertwiners:

Coupling theory



spin networks

Fixed graph:

$$L^2\left(SU(2)^E / SU(2)^V\right) \quad \langle x|n\rangle \quad I_1 I_2 \ldots I_V$$

contraction

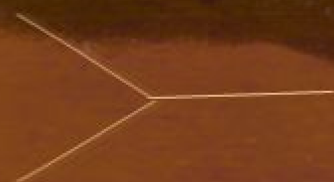
Area operator — Cutting edges

Volume operator — Counting vertices

Decomposition $H = \oplus_\alpha H_\alpha = \oplus_\alpha H_{\alpha jl}$

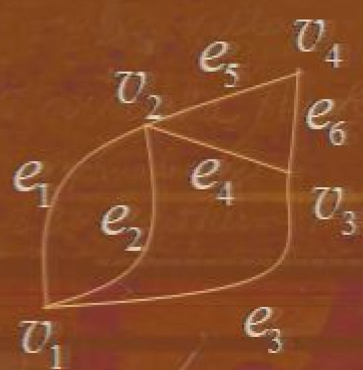
Gauge & diffeomorphism constraints: $I = 0$

Intertwiners:



Coupling theory

spin networks



Fixed graph:

$$L^2\left(SU(2)^E / SU(2)^V\right) \quad \langle x | n \rangle \quad I_1 I_2 \ldots I_V$$

contraction

Area operator — Cutting edges

Volume operator — Counting vertices

Problems…

Black holes

PHILOSOPHICAL

TRANSACTIONS,

OF THE

ROYAL SOCIETY

OF

LONDON.

VOL. LXXIV. For the Year 1784.

PART I.

LONDON,

SOLD BY LOCKYER DAVIS, AND PETER ELMSLY,
PRINTERS TO THE ROYAL SOCIETY.
MDCCLXXXIV.

16. Hence, according to article 10, if the semi-diameter of a sphære of the same density with the sun were to exceed that of the sun in the proportion of 500 to 1, a body falling from an infinite height towards it, would have acquired at its surface a greater velocity than that of light, and consequently, supposing light to be attracted by the same force in proportion to its vis inertiæ, with other bodies, all light emitted from such a body would be made to return towards it, by its own proper gravity.

17. But if the semi
sity with the sun, wa
that of the sun, thou
such a body, would
always suffer some dim
magnitude of the said f
tion may be easily foun
to represent the semi-d
the semi-diameter of t
from what has been sh
ference between the sq
be always proportiona
after it has suffered all
from this cause; and
whole velocity of ligh
above, will be the dim
diminution of the velo
account of it's gravitat
what less than a 494
would have had if no
the square of 497 being
the diminution of the

VII. *On the Means of discovering the Distance, Magnitude, &c. of the Fixed Stars, in consequence of the Diminution of the Velocity of their Light, in case such a Diminution should be found to take place in any of them, and such other Data should be procured from Observations, as would be farther necessary for that Purpose. By the Rev.* John Michell, *B. D. F. R. S. In a Letter to* Henry Cavendish, *Esq. F. R. S. and A. S.*

Read November 27, 1783.

DEAR SIR, Thornhill, May 26, 1783.

THE method, which I mentioned to you when I was last in London, by which it might perhaps be possible to find the distance, magnitude, and weight of some of the fixed stars, by means of the diminution of the velocity of their light, occurred to me soon after I wrote what is mentioned by Dr. PRIESTLEY in his History of Optics, concerning the diminution of the velocity of light in consequence of the attraction of the sun; but the extreme difficulty, and perhaps impossibility, of procuring the other data necessary for this purpose appeared to me to be such objections against the scheme, when I first thought of it, that I gave it then no farther consideration. As some late observations, however, begin to give us a little more chance of procuring some at least of these data, I thought it would not be amiss, that astronomers should be apprized of the method, I propose (which, as far as I know, has

Black hole
in LQG


Black hole
in LQG
Object: static black hole
Comment 1: no dynamics
Comment 2: closed 2-surface

Black hole
in LQG

Object: static black hole

Comment 1: no dynamics

Comment 2: closed 2-surface

States: spin network that crosses the horizon

Black hole
in LQG

Object: static black hole

- Comment 1: no dynamics
- Comment 2: closed 2-surface

States: spin network that crosses the horizon

Definition of a "black hole":
complete coarse-graining of the spin network inside

Black hole
in LQG

Object: static black hole

Comment 1: no dynamics

Comment 2: closed 2-surface

States: spin network that crosses the horizon

Definition of a “black hole”:
complete coarse-graining of the spin network inside

Gauge invariance: SU(2) invariance at each vertex becomes SU(2) invariance for the horizon states

Black hole
in LQG

Object: static black hole

Comment 1: no dynamics

Comment 2: closed 2-surface

States: spin network that crosses the horizon

Definition of a "black hole":
complete coarse-graining of the spin network inside

Gauge invariance: SU(2) invariance at each vertex becomes SU(2) invariance for the horizon states

Microscopic states: intertwiners $J=0$

Features & assumptions

Features & assumptions

Area spectrum

The probing scale

$j = \frac{1}{2}, 1, \frac{3}{2}, \ldots$

$$a_j \propto \begin{cases} \sqrt{j(j+1)} \\ j + \frac{1}{2} \end{cases}$$

Features & assumptions

The probing scale

$j = \frac{1}{2}, 1, \frac{3}{2}, \ldots$

We work at fixed j

Area spectrum

$$a_j \propto \begin{cases} \sqrt{j(j+1)} \\ j + \frac{1}{2} \end{cases}$$

The flow: scaling and invariance of physical quantities

Features & assumptions

Area spectrum

$$a_j \propto \begin{cases} \sqrt{j(j+1)} \\ j+\frac{1}{2} \end{cases}$$

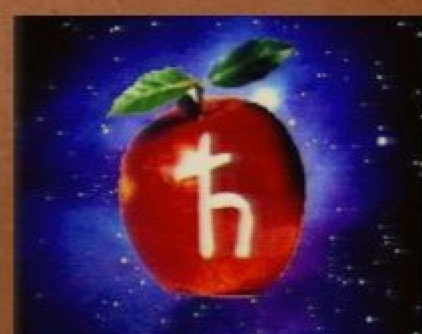
The probing scale

$j = \frac{1}{2}, 1, \frac{3}{2}, \ldots$

We work at fixed j

The flow: scaling and invariance of physical quantities

For starters: a qubit black hole



Standard counting story

$2n$ spins

Standard counting story

$2n$ spins

area $A = a_{1/2} 2n$

constraint $\mathbf{J}^2 |\Psi_k\rangle = 0$

Standard counting story

$2n$ spins

area $A = a_{1/2} 2n$

constraint $\mathbf{J}^2 |\Psi_k\rangle = 0$

number of states $N = \frac{C_n^{2n}}{n+1} : \frac{2^{2n}}{\sqrt{\pi n^3}}$

entropy $S = \log N : 2n \log 2 - \frac{3}{2} \log n$

Standard counting story

$2n$ spins

area $A = a_{1/2} 2n$

constraint $\mathbf{J}^2 |\Psi_k\rangle = 0$

number of states $N = \frac{C_n^{2n}}{n+1} : \frac{2^{2n}}{\sqrt{\pi n^3}}$

entropy $S = \log N : 2n \log 2 - \frac{3}{2} \log n$

Fancy counting story

density matrix $\rho = \frac{1}{N} \sum_{k=1}^{N} |\Psi_k\rangle\langle\Psi_k|$

entropy $S = -\mathrm{tr}\rho \log \rho = \log N$

Combinatorics

Schur's duality $\bigotimes^{2n} C^2 \cong \bigoplus_{j=0}^{n} H_j \equiv \bigoplus_{j=0}^{n} V^j \otimes \sigma_{n,j}$

$\sigma_{n,j}$ is the irrep $[n+j, n-j]$ of the permutation group

Combinatorics

Schur's duality $\bigotimes^{2n} \mathbb{C}^2 \cong \bigoplus_{j=0}^{n} \mathrm{H}_j \equiv \bigoplus_{j=0}^{n} V^j \otimes \sigma_{n,j}$

$\sigma_{n,j}$ is the irrep $[n+j, n-j]$ of the permutation group

Example: $\left(V^{1/2}\right)^{\otimes 4} = 2V^0 \oplus 3V^1 \oplus V^2$

$d_j^{(2n)} = \dim \sigma_{n,j}$ =# irreps in the universal rep

=#standard tableaux

Combinatorics

Schur's duality $\bigotimes^{2n} \mathbf{C}^2 \cong \bigoplus_{j=0}^{n} \mathrm{H}_j \equiv \bigoplus_{j=0}^{n} V^j \otimes \sigma_{n,j}$

$\sigma_{n,j}$ is the irrep $[n+j, n-j]$ of the permutation group

Example: $\left(V^{1/2}\right)^{\otimes 4} = 2V^0 \oplus 3V^1 \oplus V^2$

$d_j^{(2n)} = \dim \sigma_{n,j}$ =# irreps in the universal rep

=#standard tableaux

Combinatorics

Schur's duality $\bigotimes^{2n} \mathbb{C}^2 \cong \bigoplus_{j=0}^{n} \mathrm{H}_j \equiv \bigoplus_{j=0}^{n} V^j \otimes \sigma_{n,j}$

$\sigma_{n,j}$ is the irrep $[n+j, n-j]$ of the permutation group

Example: $\left(V^{1/2}\right)^{\otimes 4} = 2V^0 \oplus 3V^1 \oplus V^2$

$d_j^{(2n)} = \dim \sigma_{n,j}$ =# irreps in the universal rep

=#standard tableaux

1	2
3	4

Combinatorics

Schur's duality $\bigotimes^{2n} \mathbb{C}^2 \cong \bigoplus_{j=0}^{n} \mathrm{H}_j \equiv \bigoplus_{j=0}^{n} V^j \otimes \sigma_{n,j}$

$\sigma_{n,j}$ is the irrep $[n+j, n-j]$ of the permutation group

Example: $\left(V^{1/2}\right)^{\otimes 4} = 2V^0 \oplus 3V^1 \oplus V^2$

$d_j^{(2n)} = \dim \sigma_{n,j}$ =# irreps in the universal rep

=#standard tableaux

1	2
3	4

1	3
2	4

Combinatorics

Schur's duality $\bigotimes^{2n} \mathbb{C}^2 \cong \bigoplus_{j=0}^{n} \mathrm{H}_j \equiv \bigoplus_{j=0}^{n} V^j \otimes \sigma_{n,j}$

$\sigma_{n,j}$ is the irrep $[n+j, n-j]$ of the permutation group

Example: $\left(V^{1/2}\right)^{\otimes 4} = 2V^0 \oplus 3V^1 \oplus V^2$

$d_j^{(2n)} = \dim \sigma_{n,j}$ =# irreps in the universal rep

=#standard tableaux

1	2
3	4

1	3
2	4

$N = d_j^{(2n)}$

$\mathrm{H}_0 \equiv V^0 \otimes \sigma_{n,0}$

Entanglement calculation

Entanglement calculation

$$\rho = \sum_i w_i |\Psi_i\rangle\langle\Psi_i|$$

$$S(\{\Psi\}) = \sum_i w_i S(tr_\bullet |\Psi_i\rangle\langle\Psi_i|)$$

$$E_F(\rho) = \inf_{\{\Psi\}} S(\{\Psi\})$$

Entanglement calculation

$$\rho = \sum_i w_i |\Psi_i\rangle\langle\Psi_i|$$

$$E_F(\rho) = \inf_{\{\Psi\}} S(\{\Psi\})$$

$$S(\{\Psi\}) = \sum_i w_i S(tr_\bullet |\Psi_i\rangle\langle\Psi_i|)$$

$$\bigotimes^{2n} C^2 \cong \bigotimes^{2k} C^2 \otimes \bigotimes^{2n-2k} C^2 = \bigoplus_{j_A, j_B} (V^{j_A} \otimes V^{j_B}) \otimes (\sigma_{n,j_A} \otimes \sigma_{n-k,j_B})$$

$$\mathrm{H}_0 \equiv \bigoplus_{j=0}^{k} V^0_{(j)} \otimes (\sigma_{n,j_A} \otimes \sigma_{n-k,j_B})$$

Entanglement calculation

$$\rho = \sum_i w_i |\Psi_i\rangle\langle\Psi_i|$$

$$S(\{\Psi\}) = \sum_i w_i S(tr_{\bullet} |\Psi_i\rangle\langle\Psi_i|)$$

$$E_F(\rho) = \inf_{\{\Psi\}} S(\{\Psi\})$$

$$\bigotimes^{2n} C^2 \cong \bigotimes^{2k} C^2 \otimes \bigotimes^{2n-2k} C^2 = \bigoplus_{j_A, j_B} (V^{j_A} \otimes V^{j_B}) \otimes (\sigma_{n,j_A} \otimes \sigma_{n-k,j_B})$$

$$\mathrm{H}_0 \equiv \bigoplus_{j=0}^{k} V^0_{(j)} \otimes (\sigma_{n,j_A} \otimes \sigma_{n-k,j_B})$$

Clever notation $|\Psi_{ja_jb_j}\rangle \to |j\rangle_{AB} \otimes |a_j\rangle_{\sigma_A^j} \otimes |b_j\rangle_{\sigma_B^j}$

Entanglement calculation

$$\rho = \sum_i w_i |\Psi_i\rangle\langle\Psi_i|$$

$$E_F(\rho) = \inf_{\{\Psi\}} S(\{\Psi\})$$

$$S(\{\Psi\}) = \sum_i w_i S(tr_{\bullet} |\Psi_i\rangle\langle\Psi_i|)$$

$$\bigotimes^{2n} C^2 \cong \bigotimes^{2k} C^2 \otimes \bigotimes^{2n-2k} C^2 = \bigoplus_{j_A, j_B} (V^{j_A} \otimes V^{j_B}) \otimes (\sigma_{n, j_A} \otimes \sigma_{n-k, j_B})$$

$$\mathrm{H}_0 \equiv \bigoplus_{j=0}^{k} V^0_{(j)} \otimes (\sigma_{n, j_A} \otimes \sigma_{n-k, j_B})$$

Clever notation $|\Psi_{j a_j b_j}\rangle \to |j\rangle_{AB} \otimes |a_j\rangle_{\sigma^j_A} \otimes |b_j\rangle_{\sigma^j_B}$

$$E(\rho) = \tfrac{1}{N} \sum_j d^B_j d^A_j \log(2j+1)$$

Entanglement calculation

$$\rho = \sum_i w_i |\Psi_i\rangle\langle\Psi_i|$$

$$E_F(\rho) = \inf_{\{\Psi\}} S(\{\Psi\})$$

$$S(\{\Psi\}) = \sum_i w_i S(tr_\bullet |\Psi_i\rangle\langle\Psi_i|)$$

$$\bigotimes^{2n} C^2 \cong \bigotimes^{2k} C^2 \otimes \bigotimes^{2n-2k} C^2 = \bigoplus_{j_A, j_B} (V^{j_A} \otimes V^{j_B}) \otimes (\sigma_{n, j_A} \otimes \sigma_{n-k, j_B})$$

$$\mathrm{H}_0 \equiv \bigoplus_{j=0}^{k} V^0_{(j)} \otimes (\sigma_{n, j_A} \otimes \sigma_{n-k, j_B})$$

Clever notation $|\Psi_{j a_j b_j}\rangle \rightarrow |j\rangle_{AB} \otimes |a_j\rangle_{\sigma_A^j} \otimes |b_j\rangle_{\sigma_B^j}$

$$E(\rho) = \tfrac{1}{N} \sum_j d_j^B d_j^A \log(2j+1)$$

Entanglement calculation

$$\rho = \sum_i w_i |\Psi_i\rangle\langle\Psi_i|$$

$$S(\{\Psi\}) = \sum_i w_i S(tr_{\bullet} |\Psi_i\rangle\langle\Psi_i|)$$

$$E_F(\rho) = \inf_{\{\Psi\}} S(\{\Psi\})$$

$$\bigotimes^{2n} C^2 \cong \bigotimes^{2k} C^2 \otimes \bigotimes^{2n-2k} C^2 = \bigoplus_{j_A, j_B} (V^{j_A} \otimes V^{j_B}) \otimes (\sigma_{n,j_A} \otimes \sigma_{n-k,j_B})$$

$$\mathrm{H}_0 \equiv \bigoplus_{j=0}^{k} V^0_{(j)} \otimes (\sigma_{n,j_A} \otimes \sigma_{n-k,j_B})$$

Clever notation $|\Psi_{j a_j b_j}\rangle \rightarrow |j\rangle_{AB} \otimes |a_j\rangle_{\sigma_A^j} \otimes |b_j\rangle_{\sigma_B^j}$

$$E(\rho) = \frac{1}{N} \sum_j d_j^B d_j^A \log(2j+1)$$

Entanglement
calculation

- Alternative decomposition: linear combinations
- Its reduced density matrices: mixtures
- Entropy: concavity

$$\rho = \sum_{\alpha} w_{\alpha} |\Psi_{\alpha}\rangle\langle\Psi_{\alpha}|$$

$$|\Psi_{\alpha}\rangle = \sum_{ja_jb_j} c_{\alpha,ja_jb_j} |j\rangle_{AB} \otimes |a_j\rangle_{D^{A_j}} \otimes |b_j\rangle_{D^{B_j}}$$

Clever notation (2): $\lambda_{\alpha j a_j a'_j} = \sum_{b_j} c_{\alpha j a_j b_j} c^{*}_{\alpha j a'_j b_j} \quad \pi_{\alpha j} = \sum_{a_j} \lambda_{\alpha j a_j a_j}$

Clever notation (3): $\rho_A(\alpha) = \sum_{\alpha j} \pi_{\alpha j} \rho_j \otimes \Lambda_j(\alpha)$

Coup de grâce: $\sum_{\alpha} w_{\alpha} S(\rho_A(\alpha)) \geq \sum_{\alpha j} w_{\alpha} \pi_{\alpha j} [S(\rho_j) + S(\Lambda_j(\alpha))] \geq$

$$\sum_{\alpha j} w_{\alpha} \pi_{\alpha j} S(\rho_j) = \tfrac{1}{N} \sum_{j} c_j^A c_j^B S(\rho_j)$$

Entanglement

calculation:: *distillation*

$$\rho = \frac{1}{N} \sum_{j,a_j,b_j} |j\rangle_{AB} \langle j| \otimes |a_j\rangle_{\sigma_A^j} \langle a_j| \otimes |b_j\rangle_{\sigma_B^j} \langle b_j|$$

⇑

Bi-local non-destructive identification

Entanglement

calculation:: *distillation*

$$\rho = \frac{1}{N}\sum_{j,a_j,b_j} |j\rangle_{AB}\langle j| \otimes |a_j\rangle_{\sigma_A^j}\langle a_j| \otimes |b_j\rangle_{\sigma_B^j}\langle b_j|$$

Bi-local non-destructive identification

spin *j* singlet: $P(j) = \frac{d_A^j d_B^j}{N}$ $E(j) = \log(2j+1)$

Entanglement

calculation:: *distillation*

$$\rho = \frac{1}{N}\sum_{j,a_j,b_j} |j\rangle_{AB}\langle j| \otimes |a_j\rangle_{\sigma_A^j}\langle a_j| \otimes |b_j\rangle_{\sigma_B^j}\langle b_j|$$

↑

Bi-local non-destructive identification

spin *j* singlet: $P(j) = \frac{d_A^j d_B^j}{N}$ $E(j) = \log(2j+1)$

and since $\langle S\rangle \geq E_F \geq E_D$

we are done

Entanglement

2 vs 2n-2

Entanglement

2 vs 2n-2

States

$$|0,0,a_0\rangle \otimes |0,0,b_0\rangle$$

degeneracy indices

$$\frac{1}{\sqrt{3}}\left(|1,-1,a_1\rangle \otimes |1,1,b_1\rangle - |1,0,a_1\rangle \otimes |1,0,b_1\rangle + |1,1,a_1\rangle \otimes |1,-1,b_1\rangle\right)$$

Entanglement

2 vs 2n-2

States

$$|0,0,a_0\rangle \otimes |0,0,b_0\rangle$$

degeneracy indices

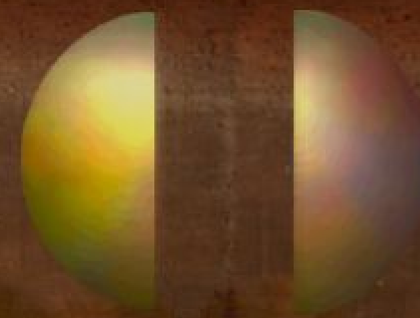
$$\tfrac{1}{\sqrt{3}}\left(|1,-1,a_1\rangle \otimes |1,1,b_1\rangle - |1,0,a_1\rangle \otimes |1,0,b_1\rangle + |1,1,a_1\rangle \otimes |1,-1,b_1\rangle\right)$$

Unentangled fraction $\quad f_0 : \tfrac{1}{4}$

Entanglement $\quad E(\rho\,|\,2) : \tfrac{3}{4}\log 3$

n vs n

n vs n $E(\rho):\ \frac{1}{2}\log n$



n vs n $\quad E(\rho): \frac{1}{2}\log n$

Entropy of the whole vs. sum of its parts

$$S(\rho) \le S(\rho_A) + S(\rho_B)$$

n vs n $E(\rho) : \frac{1}{2}\log n$

Entropy of the whole vs. sum of its parts

$$S(\rho) \leq S(\rho_A) + S(\rho_B)$$

n vs n $\quad E(\rho) : \frac{1}{2}\log n$

Entropy of the whole vs. sum of its parts

$$S(\rho) \le S(\rho_A) + S(\rho_B)$$

Reduced density matrices

$$S(\rho_A) = S(\rho_B) : \ n\log 2$$

$$\boxed{S(\rho) : \ 2S(\rho_{\text{half}}) - 3E(\rho)}$$

n vs n $E(\rho) : \frac{1}{2}\log n$

Entropy of the whole vs. sum of its parts

$$S(\rho) \leq S(\rho_A) + S(\rho_B)$$

Reduced density matrices

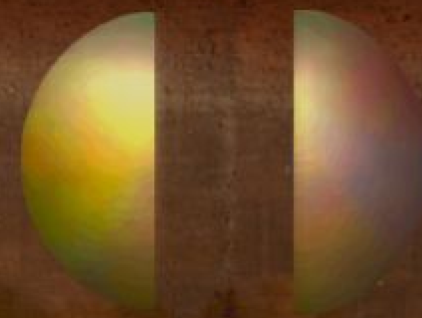
$$S(\rho_A) = S(\rho_B) : n\log 2$$

$$\boxed{S(\rho) : 2S(\rho_{\text{half}}) - 3E(\rho)}$$

Logarithmic correction equals quantum mutual information

$$I_\rho(A:B) = S(\rho_A) + S(\rho_B) - S(\rho) \approx 3E_{A:B}(\rho)$$

n vs n $\quad E(\rho):\ \frac{1}{2}\log n$



Entropy of the whole vs. sum of its parts

$$S(\rho)\leq S(\rho_A)+S(\rho_B)$$

Reduced density matrices

$$S(\rho_A)=S(\rho_B):\ n\log 2$$

$$\boxed{S(\rho):\ 2S(\rho_{\text{half}})-3E(\rho)}$$

BH is not made
from independent qubits,
but…

Logarithmic correction equals quantum mutual information

$$I_\rho(A:B)=S(\rho_A)+S(\rho_B)-S(\rho)\approx 3E_{A:B}(\rho)$$

Universality

and the random walks

Universality
and the random walks

Entropy

$$S(\rho) : \; 2n_j \log(2j+1) - \tfrac{3}{2}\log n_j$$

$$\frac{3}{2}\log$$

Explanation: a random walk with a mirror

Open questions

Open questions

Dynamics: evolution of entanglement
dynamical evolution of evaporation
"*H*=0" section & the number of states

Open questions

Dynamics: evolution of entanglement
dynamical evolution of evaporation
"*H*=0" section & the number of states

Semi-classicality: requiring states to represent
semi-classical BH
rotating BH

Open questions

Dynamics: evolution of entanglement
dynamical evolution of evaporation
"H=0" section & the number of states

Semi-classicality: requiring states to represent
semi-classical BH
rotating BH

Quantum info: is there anything beyond
local distinguishability?