No fire walls in quantum gravity

Revisiting the Ashtekar-Bojowald paradigm with an emphasis on discreteness

ILQGS

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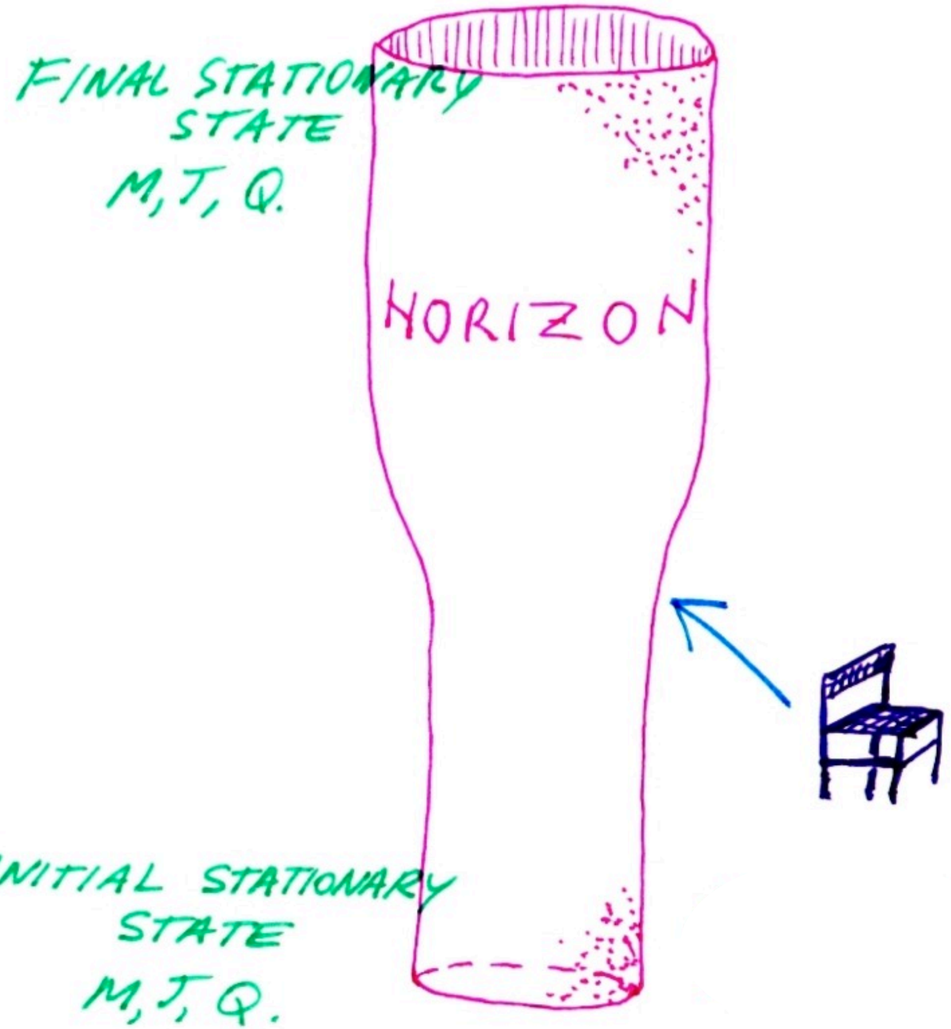
A perpective on the information loss problem

1. No firewalls.(Almeheiri-Marolf-Polchinski-Sully)

2. No large quantum gravity effects at large semiclassical scales.

Black hole mechanics: analogy with thermodynamics



Some definitions

- $\Omega \equiv$ horizon angular velocity
- $\kappa \equiv$surface gravity ('grav. force' at horizon) If $\ell^a =$killing generator, then $\ell^a \nabla_a \ell^b = \kappa \ell^b$.
- $\Phi \equiv$electromagnetic potential.

0th law: the surface gravity κ is constant on the horizon.

1st law:
$\delta M = \frac{\kappa}{8\pi}\delta A + \underbrace{\Omega \delta J + \Phi \delta Q}_{\text{work terms}}$

2nd law:
$\delta A \geq 0$

3rd law: the surface gravity value $\kappa = 0$ (extremal BH) cannot be reached by any physical process.

Black Hole Entropy

Temperature at infinity

$$T_\infty = \frac{\kappa}{2\pi}$$

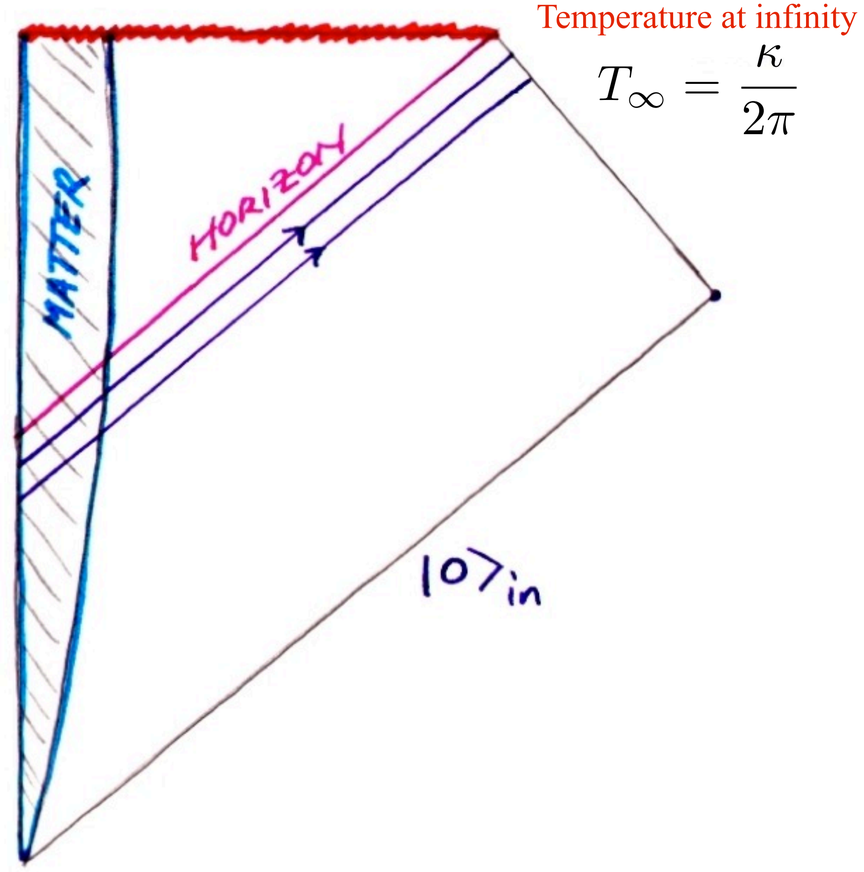
From the first law

$$\delta M = \frac{\kappa}{8\pi}\delta A + \Omega\delta J + \Phi\delta Q$$

One infers the ENTROPY

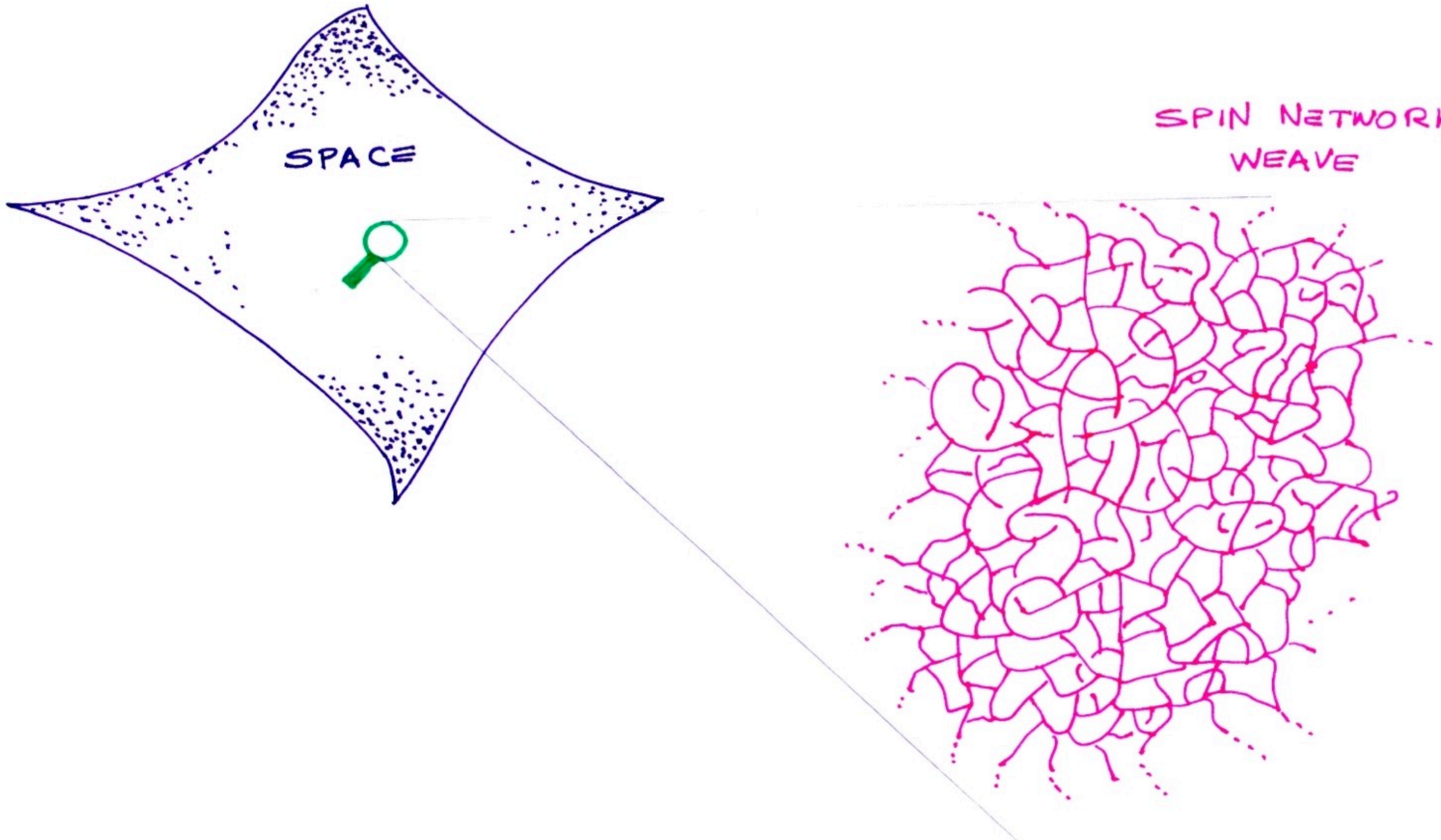
$$S = \frac{A}{4\ell_p^2}$$

Central Question for QG: ***how to get S from statistical mechanics***



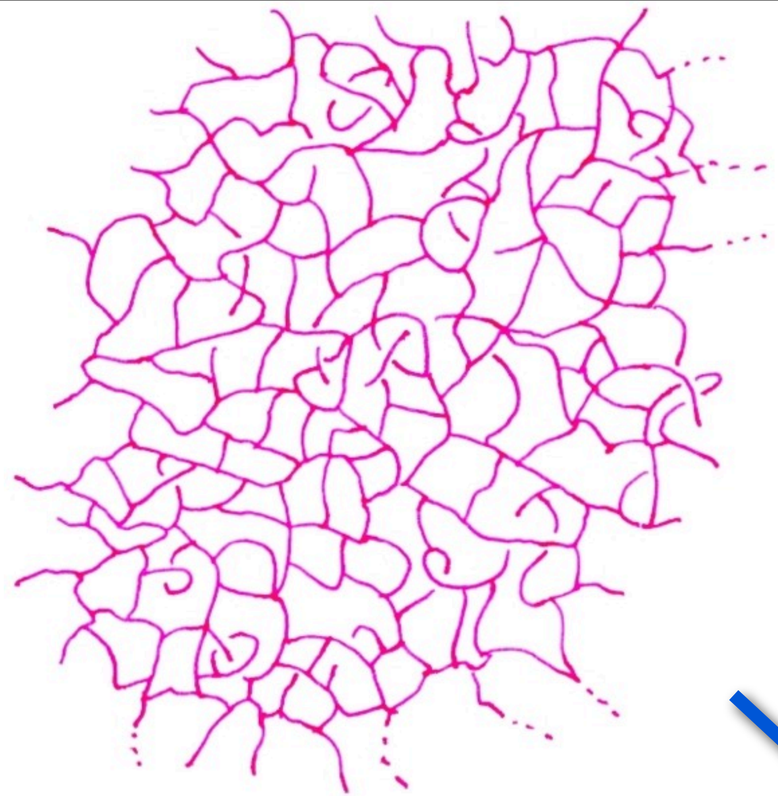
Quantum spacetime is made of discrete weave like excitations

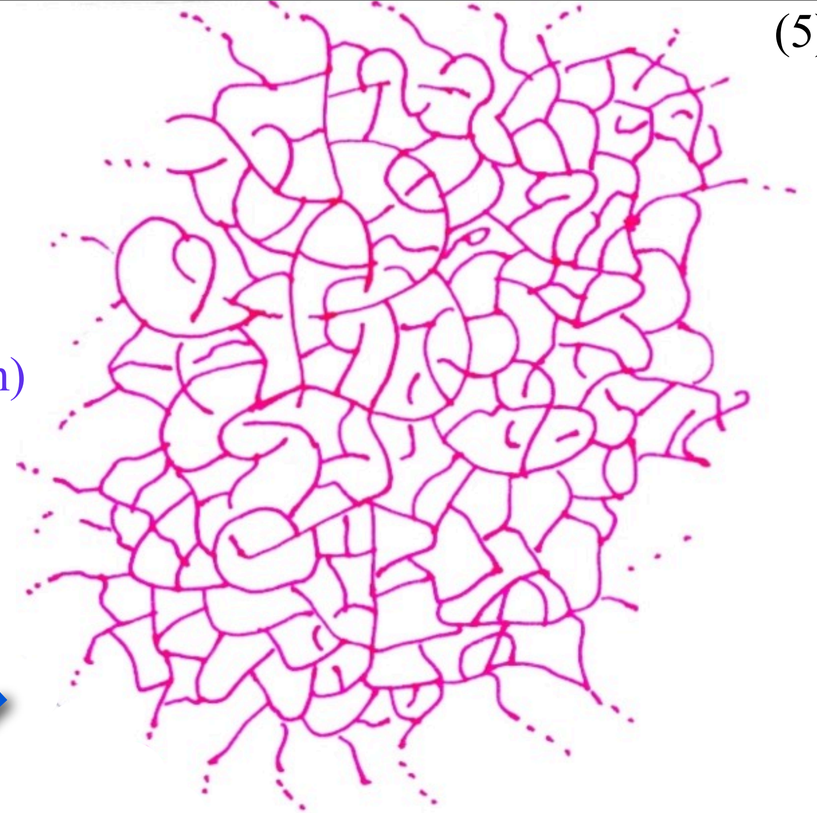
(Ashtekar-Smolin-Rovelli)

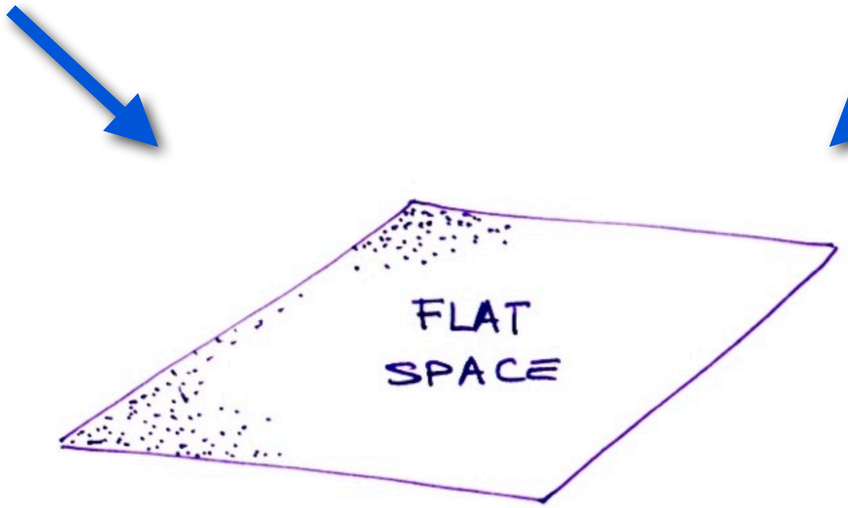


Different weave states define the same spacetime

Smooth geometry is obtained by
coarse graining (Ashtekar et al. Rovelli-Smolin)



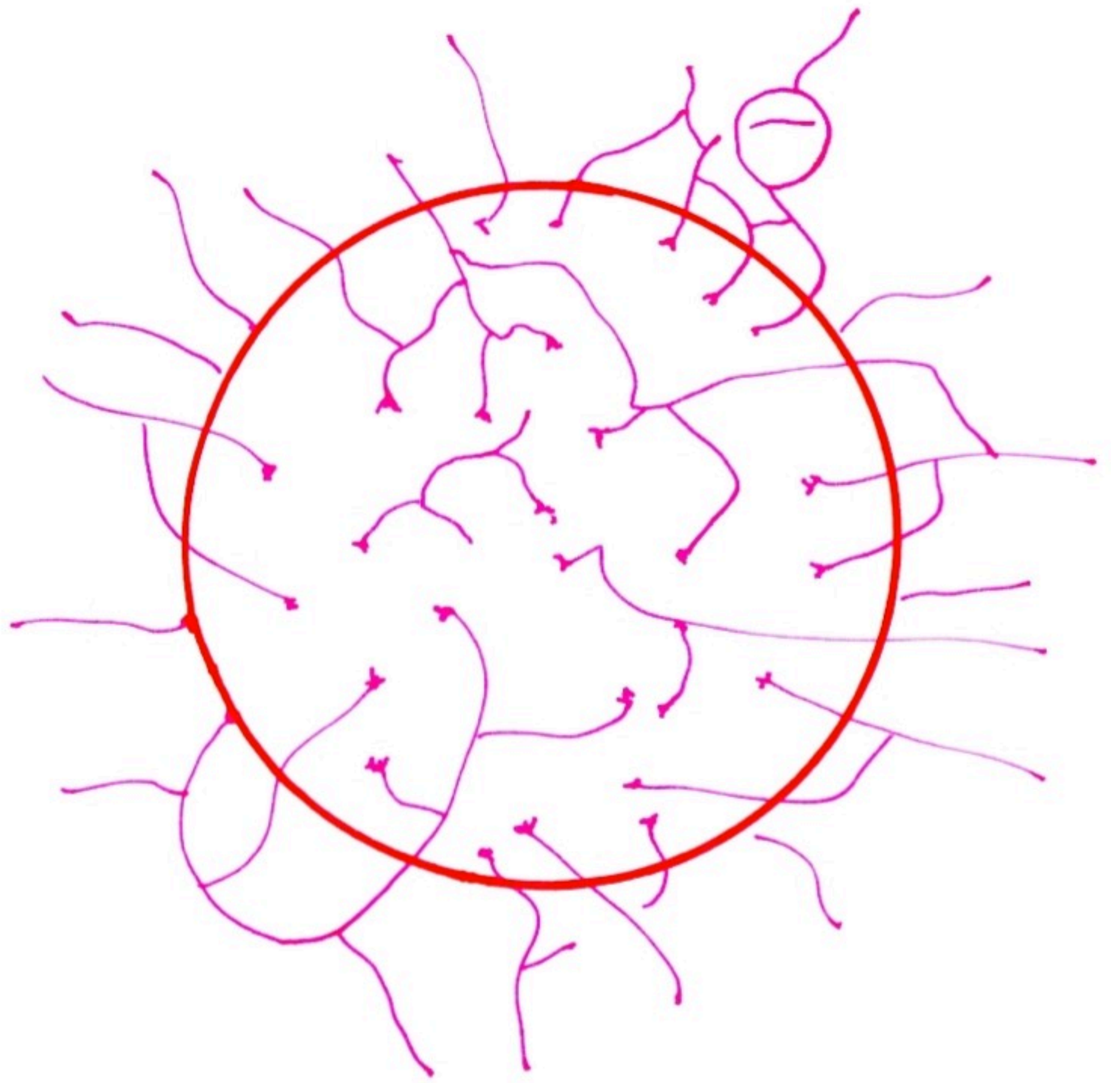




The black hole weave

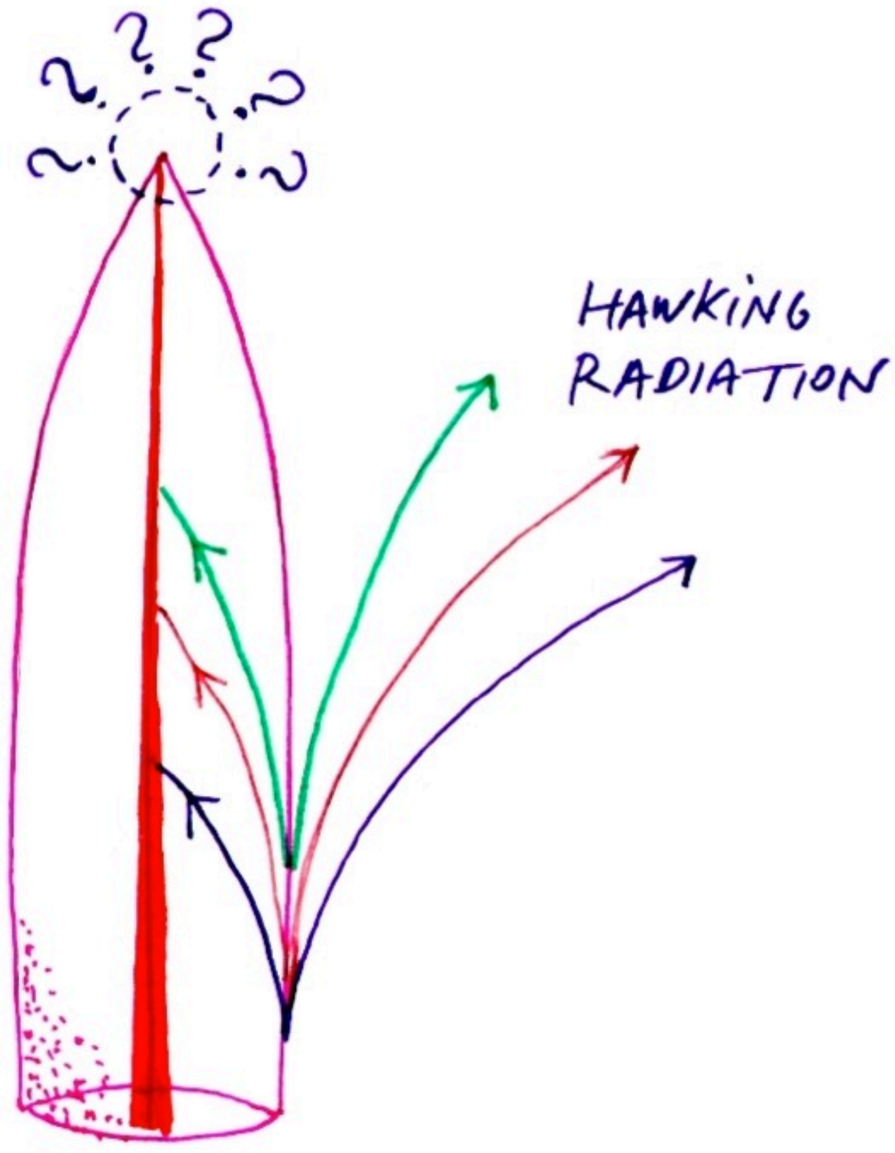
$$S_{stat} = \frac{A}{4G_N\hbar} + \eta\frac{\sqrt{A}}{\sqrt{\gamma G\hbar}}$$

(Ghosh-Noui-AP 2014)



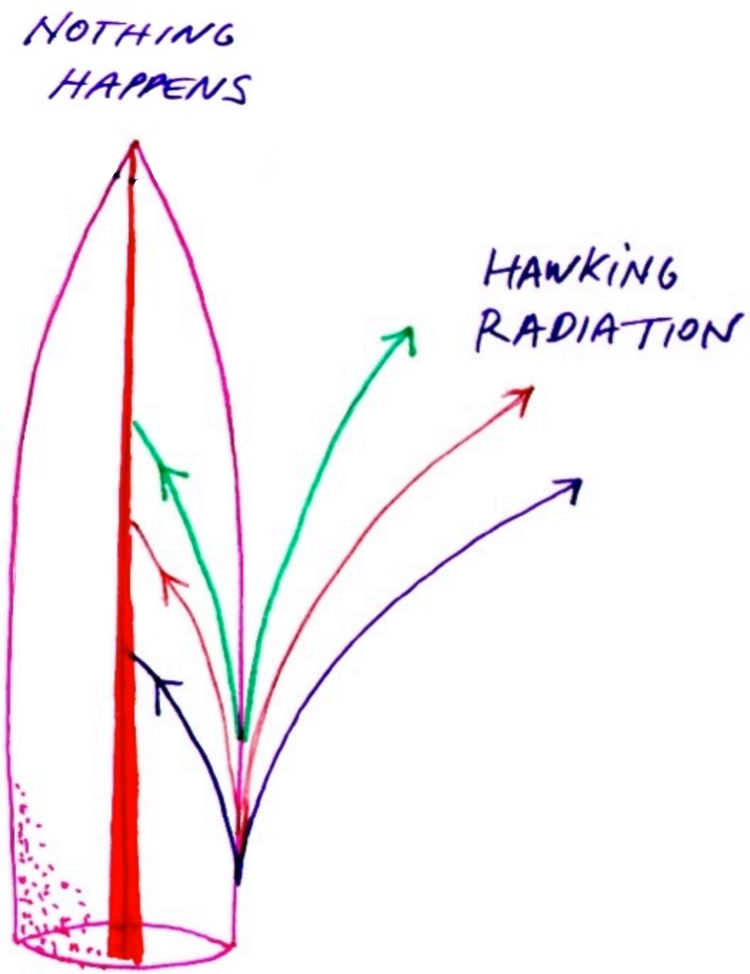
(Alesci, Ashtekar, Baez, Barbero, Bianchi, Borja, Corichi, Diaz-Polo, Engle, Frodden, Ghosh, Krasnov, Livine, Lewandowski, Majumdar, Mitra, Noui, AP, Pranzetti, Rovelli, Sahlmann, Terno, Thiemann, Villasenor, etc.)

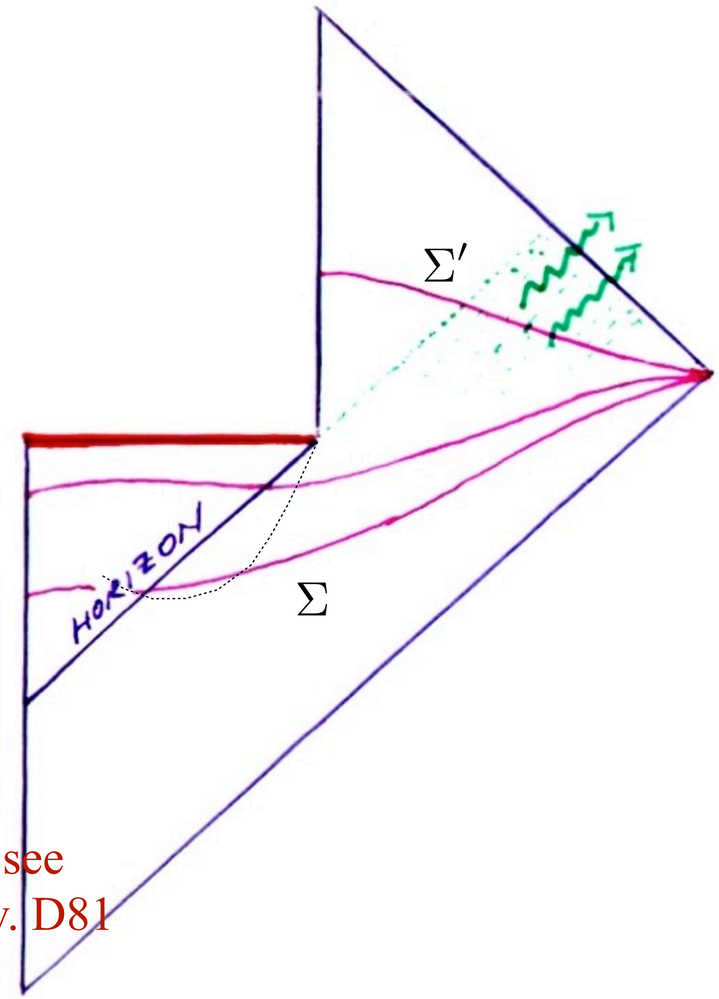
The hard problem



The hard problem: information loss paradox

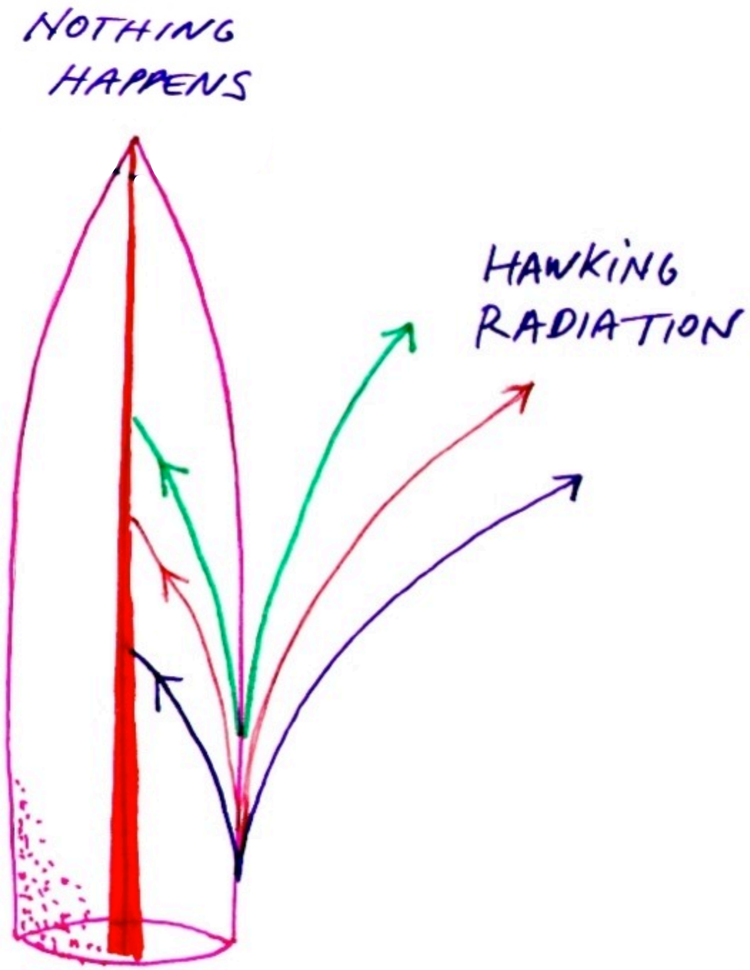
(Hawking 1976)

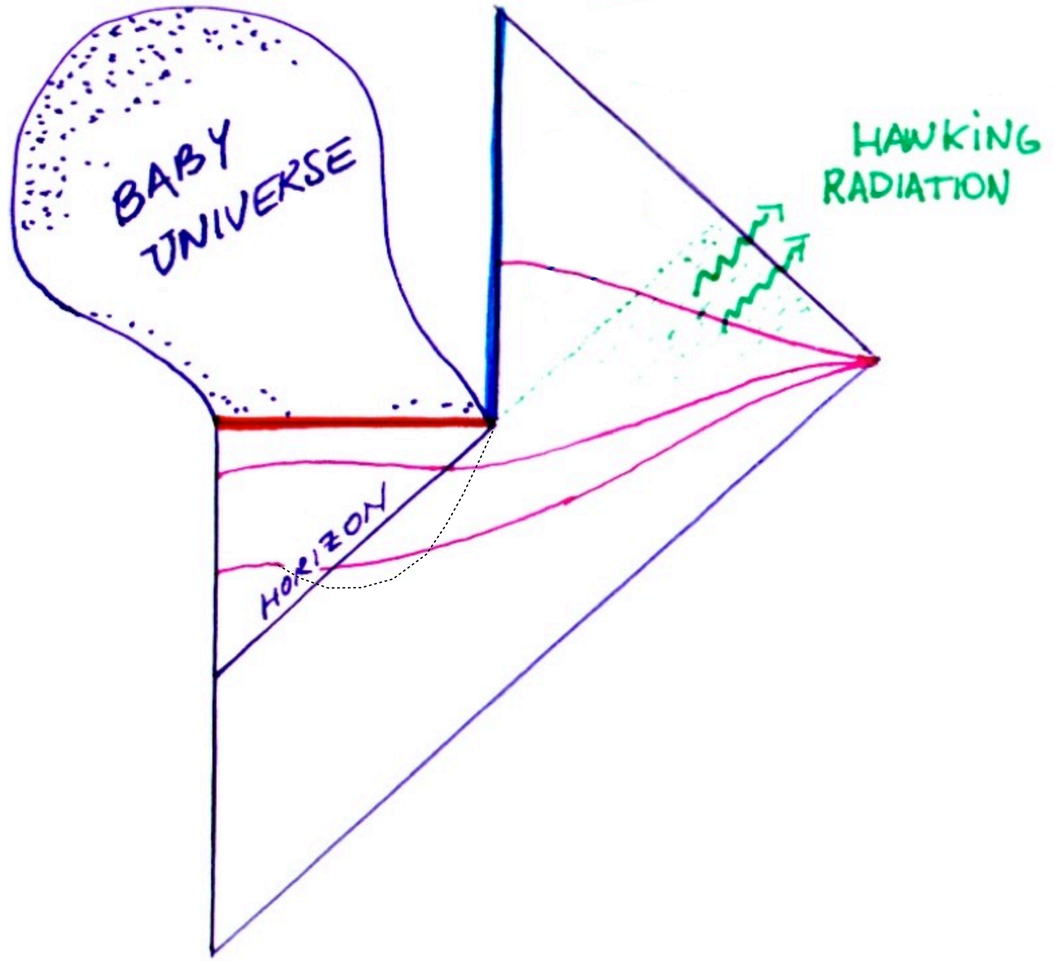




For a review on possibilities see Hossenfelder-Smolin, Phys.Rev. D81 (2010) 064009

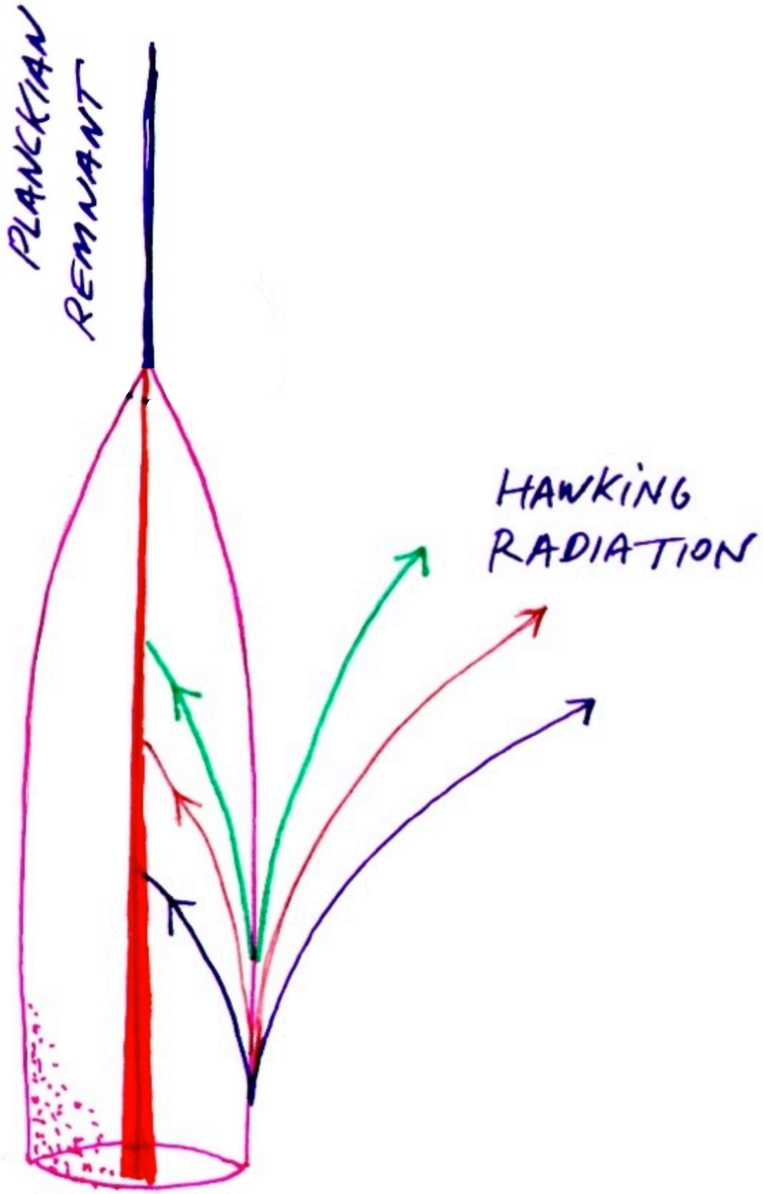
Proposal 1:
baby universe

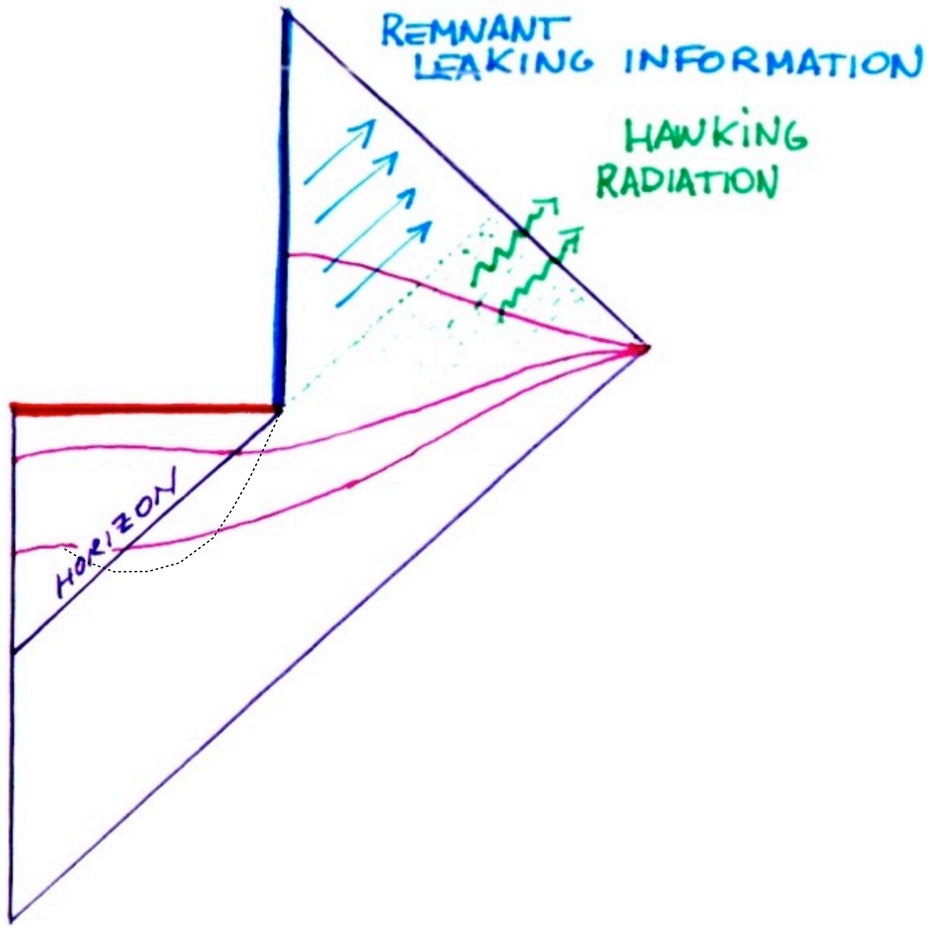




Proposal 2:
Remnants

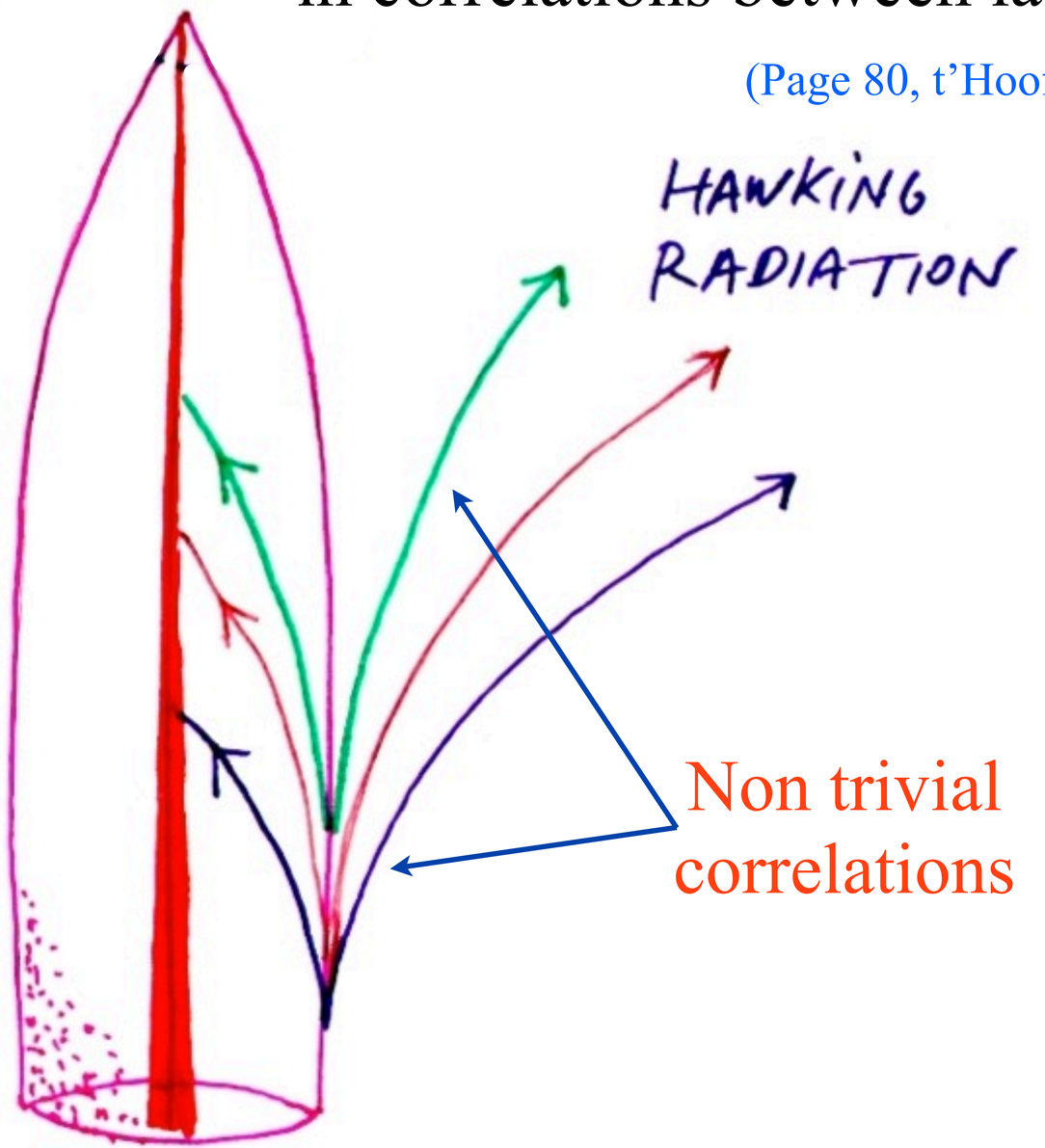
(Giddings 94, Banks 95)

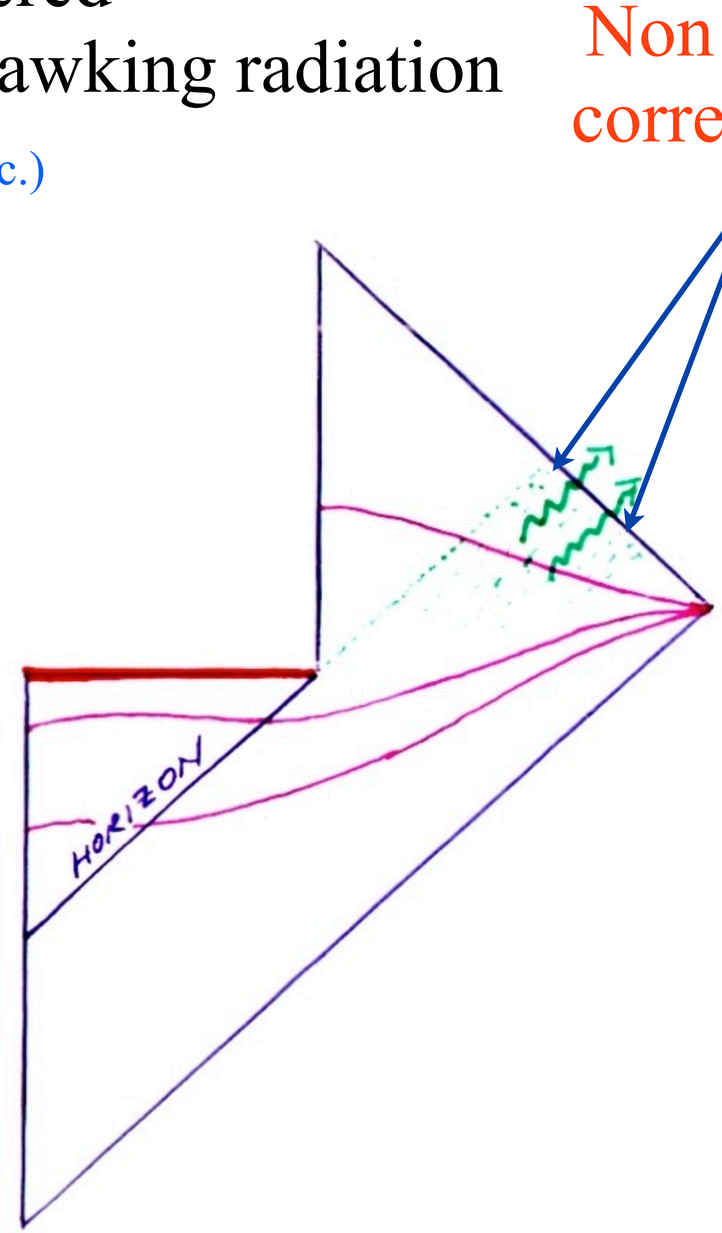




Proposal 3:
information is to be recovered
in correlations between late and early hawking radiation

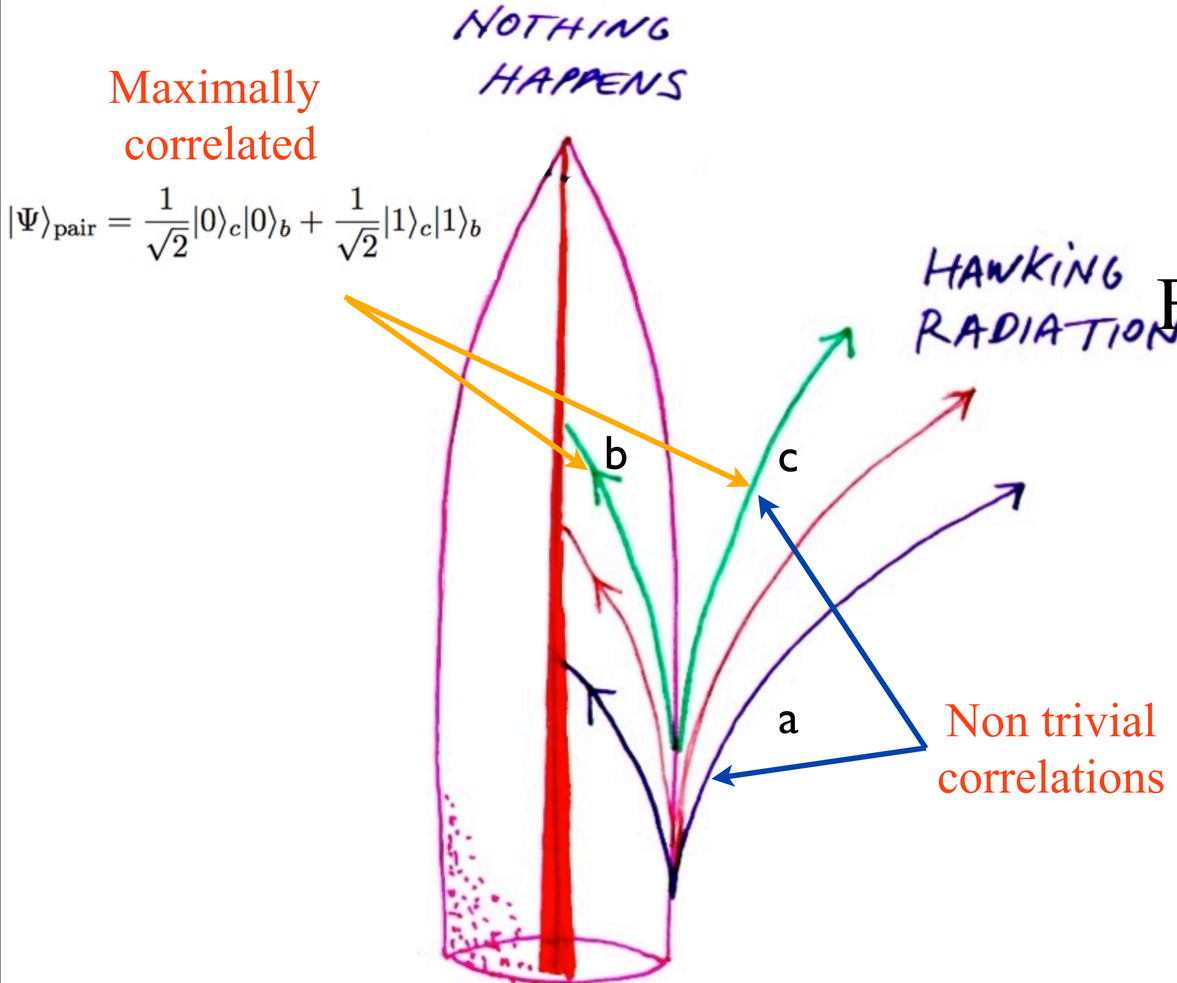
(Page 80, t'Hooft 90, Susskind 93, etc.)



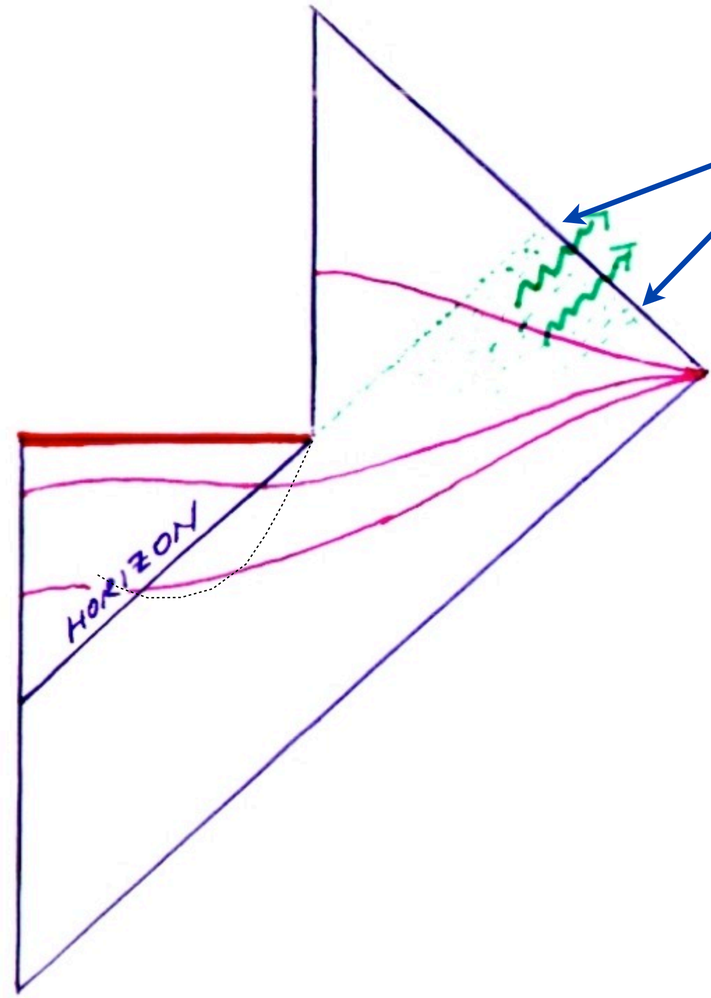


Proposal 3: information is to be recovered in correlations between late and early hawking radiation

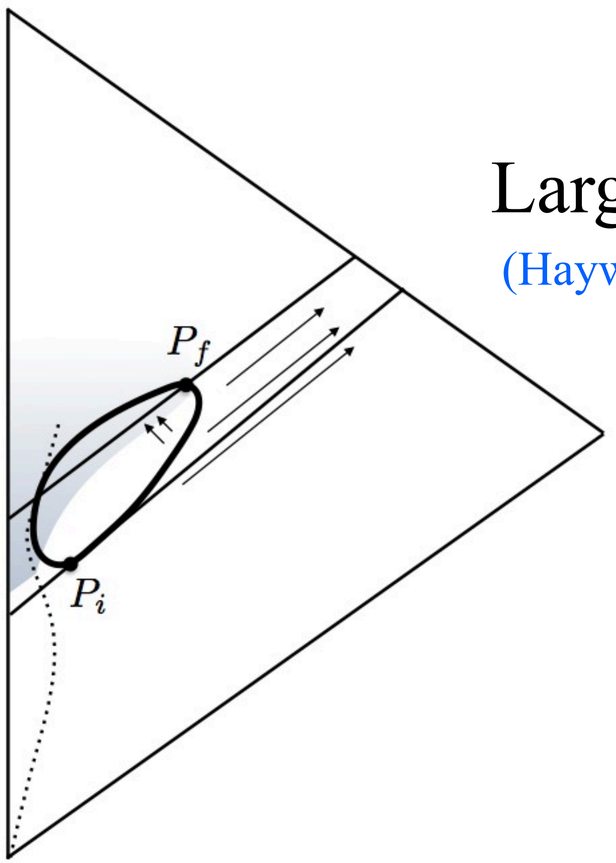
(Almeheiri-Marolf-Polchinski-Sully 2013; S. L. Braunstein, S. Pirandola, and Kyczkowski, 2013)



Firewalls



Proposal 4:
Planck Stars

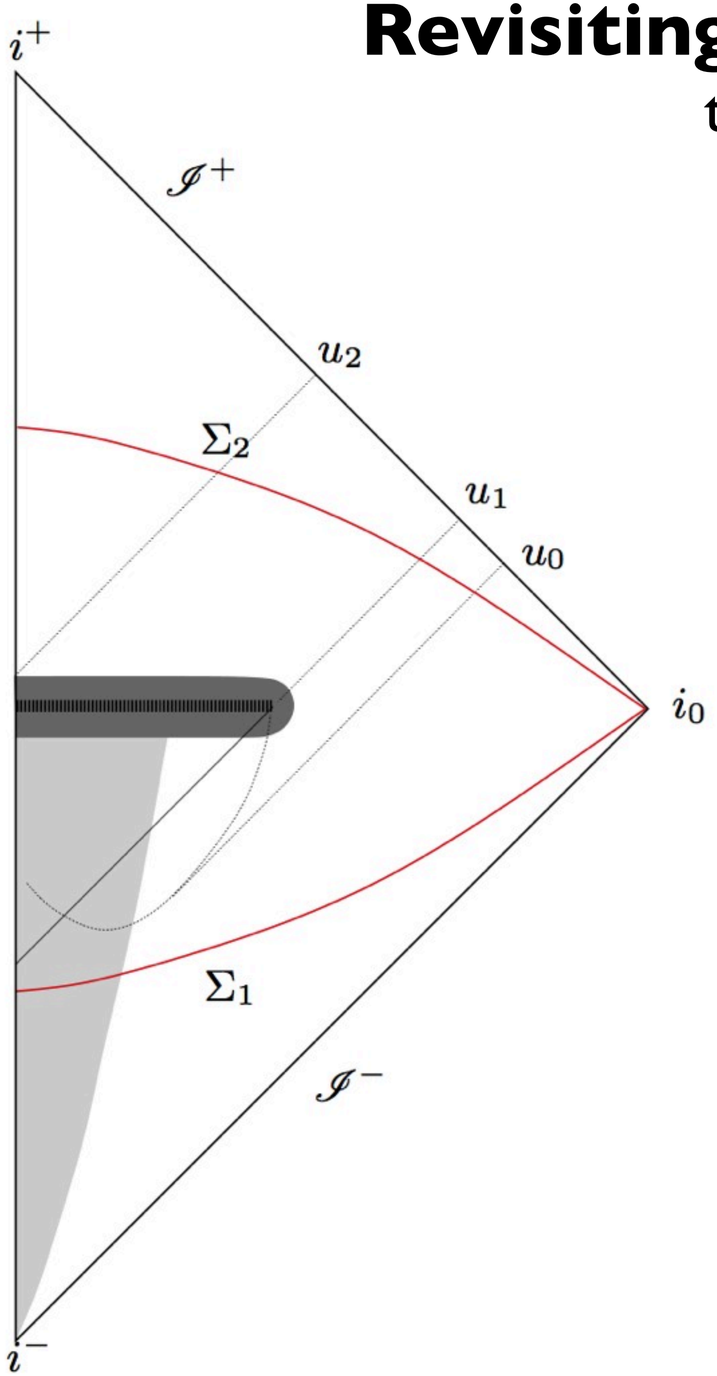


Large QG effects at low curvature

(Hayward, Rovelli-Vidotto, Rovelli-Haggard, etc...)

Revisiting the Ashtekar-Bojowald paradigm

two ways of presenting the spacetime



The story told from the perspective of observers at future null infinity is a **semiclassical one**

The local version of the story must be told by **quantum gravity**

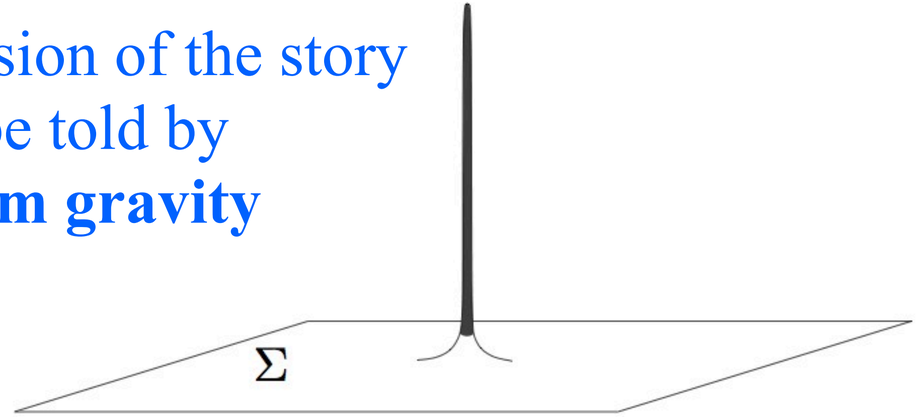
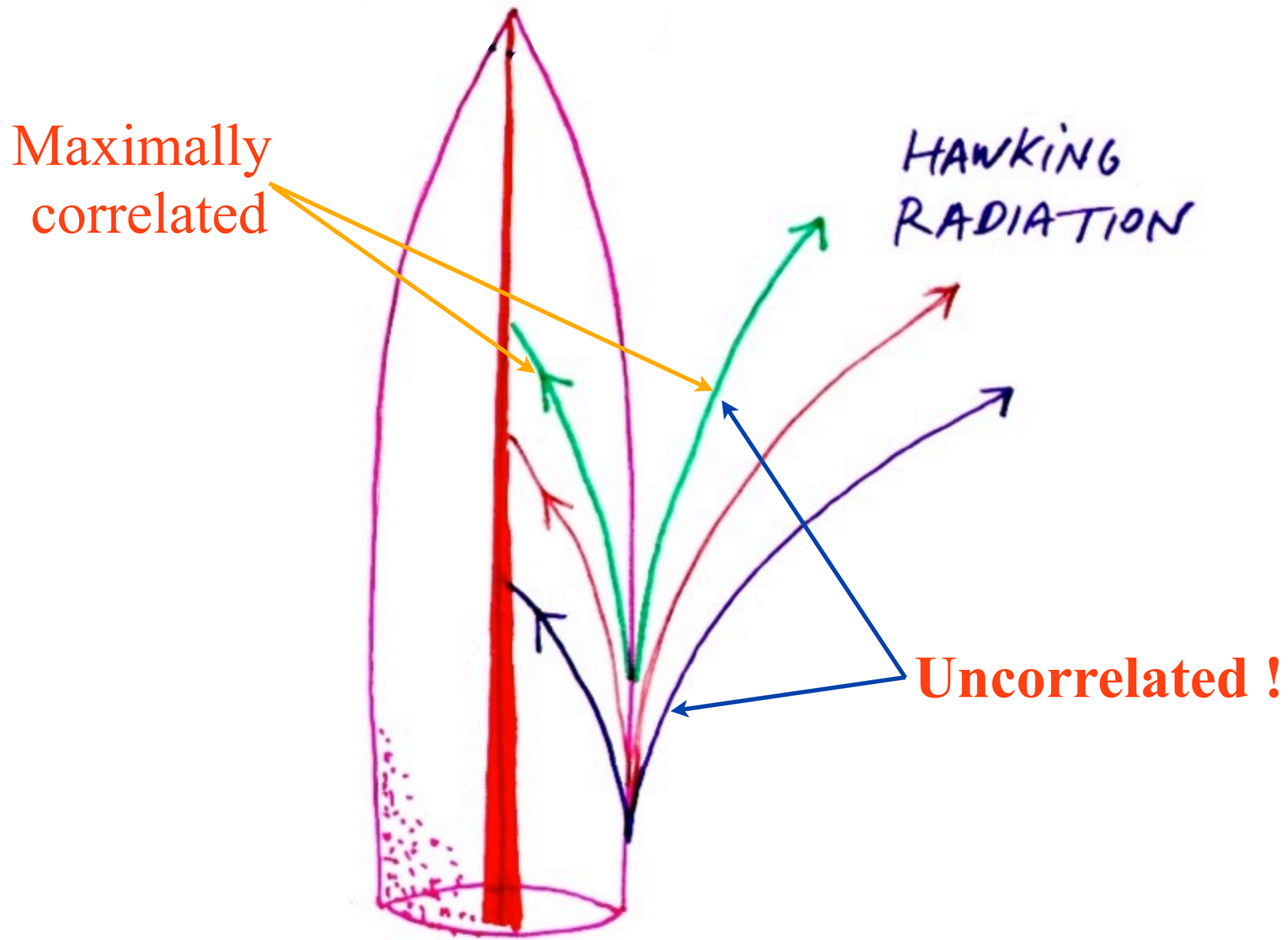


FIG. 8: A qualitative representation of the Riemannian geometry of Σ and Σ' of Fig 5. The shaded regions are those 'touching' the quantum region.

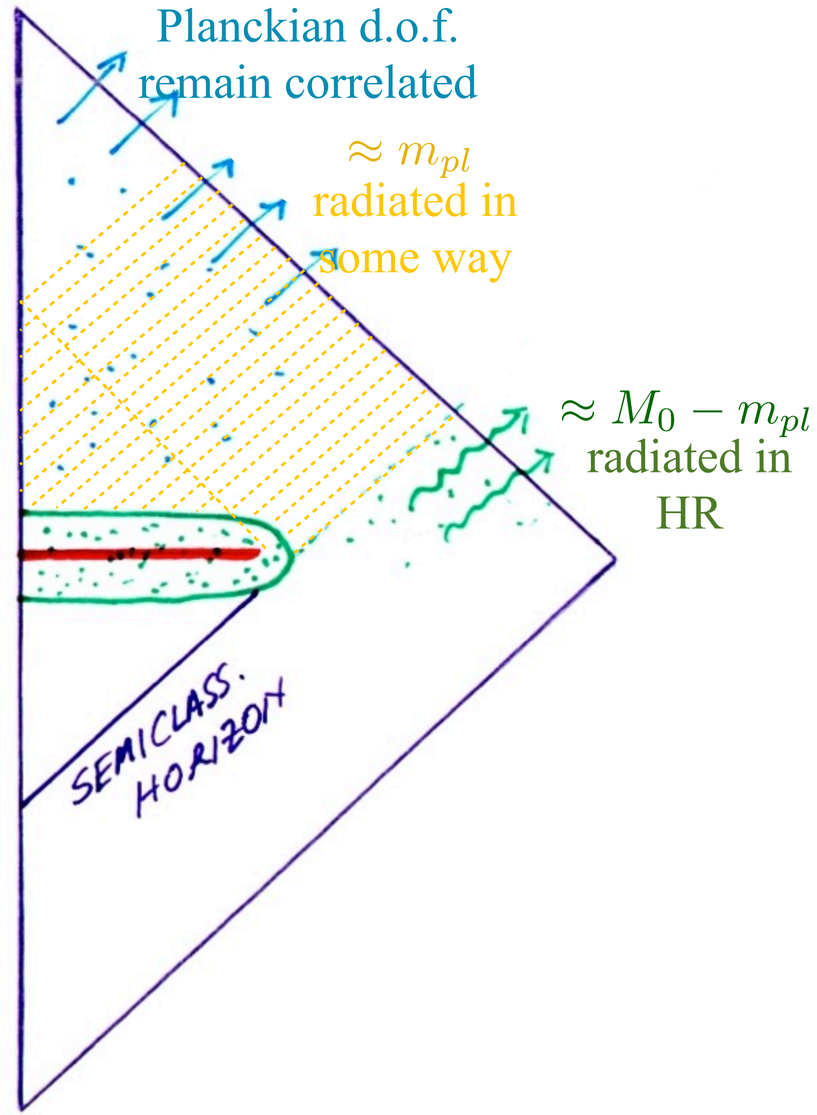
The Ashtekar-Bojowald paradigm:
Uncorrelated Hawking radiation



The Ashtekar-Bojowald paradigm:
Uncorrelated Hawking radiation

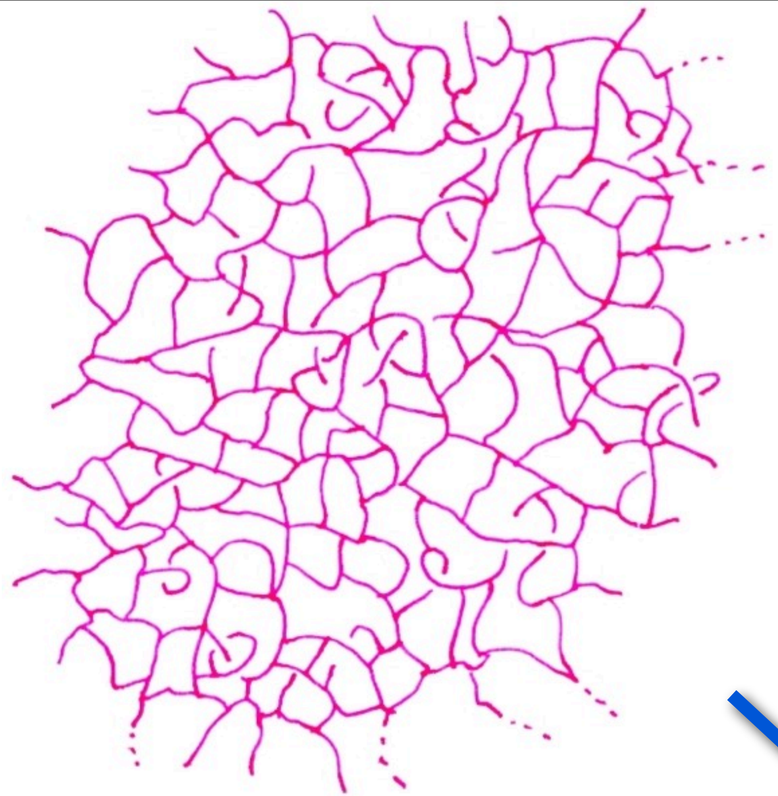
The constraint that a small (Planckian) amount of mass is radiated while the naked *would-be-singularity* is visible suggests **the lack of unitarity** of the EQFT degrees of freedom (**arXiv:1409.0144** Bianchi-De Lorenzo-Smerlak).

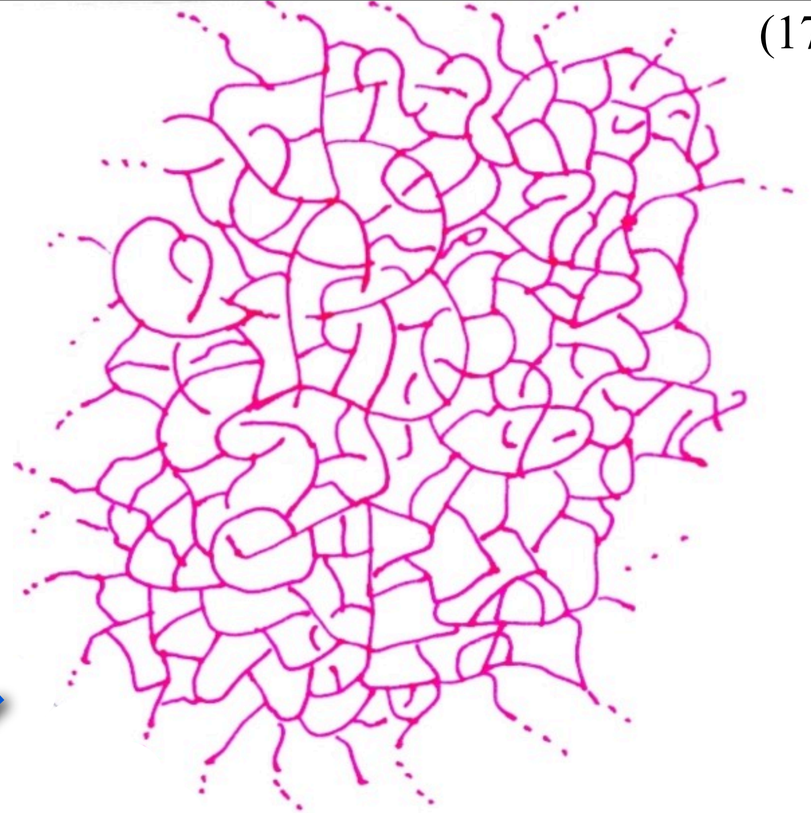
Solution: EQFT unitarity is broken while fundamental quantum gravity unitarity holds. Information is retrieved in correlations of **Planckian quantum geometry degrees of freedom** (after would-be-singularity becomes visible) that are **entangled with radiation in Hawking era.**

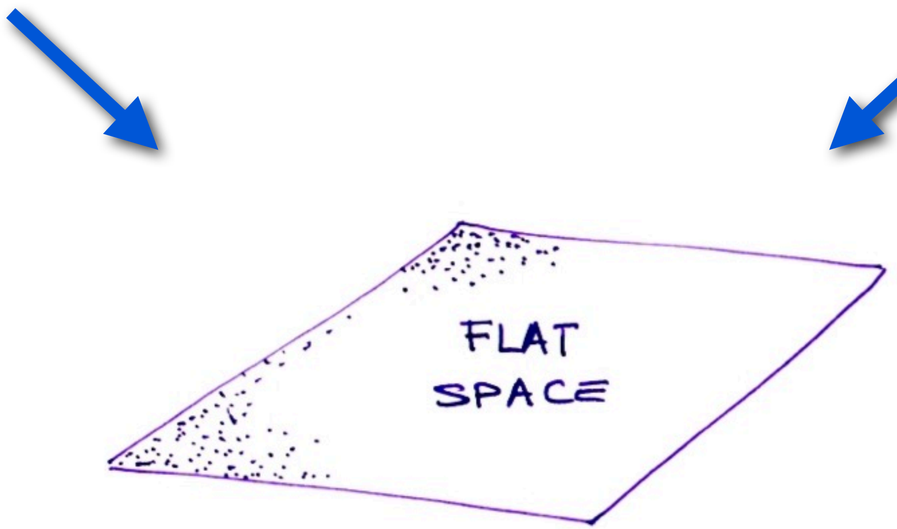


Different weave states define the same spacetime

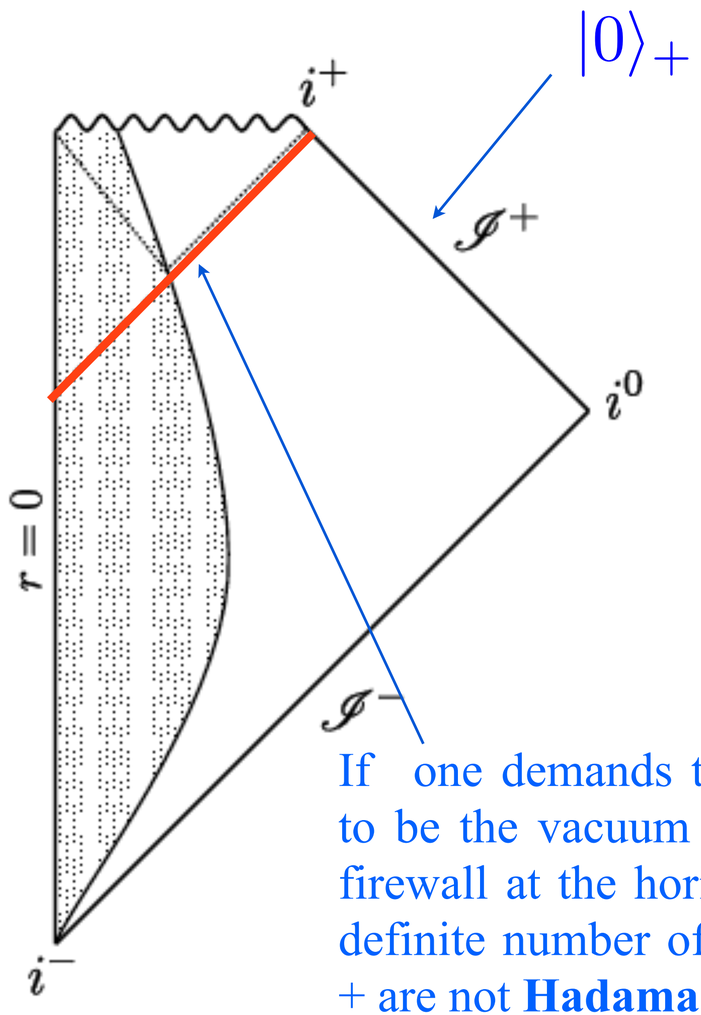
Smooth geometry is obtained by coarse graining (Ashtekar et al.)





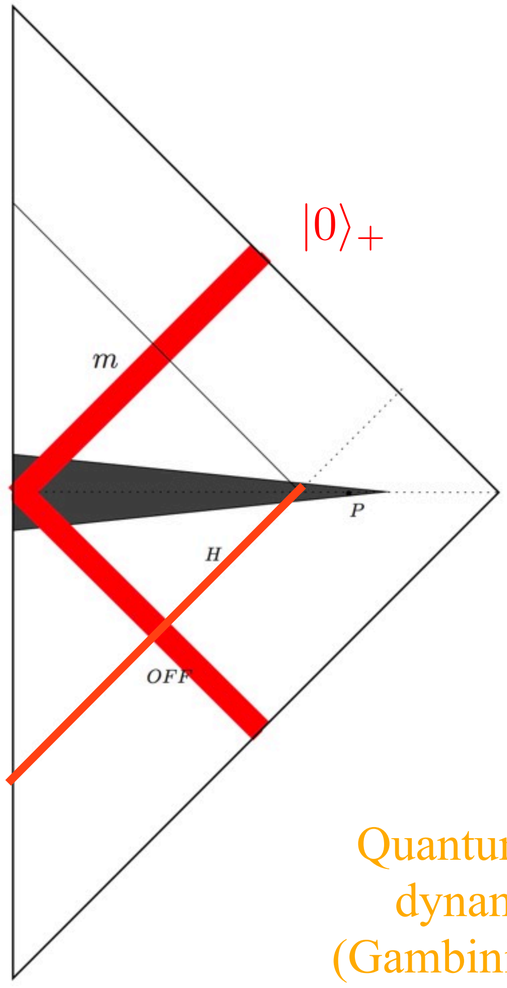


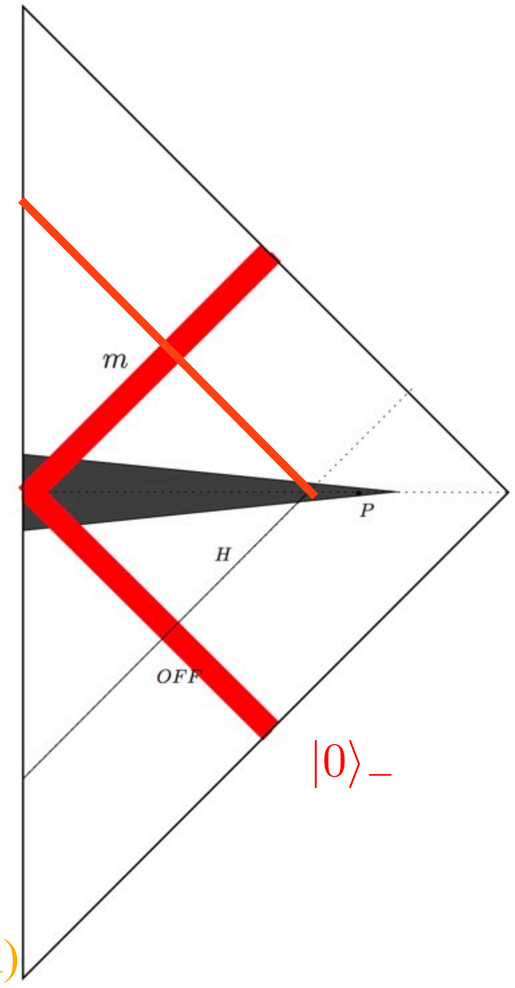
Time symmetric pictures seem problematic



If one demands the state at scri+ to be the vacuum then there is a firewall at the horizon (states with definite number of particles at scri + are not **Hadamard** states).

Quantum effects break time symmetry of the Haggard-Rovelli's **Fireworks** framework.

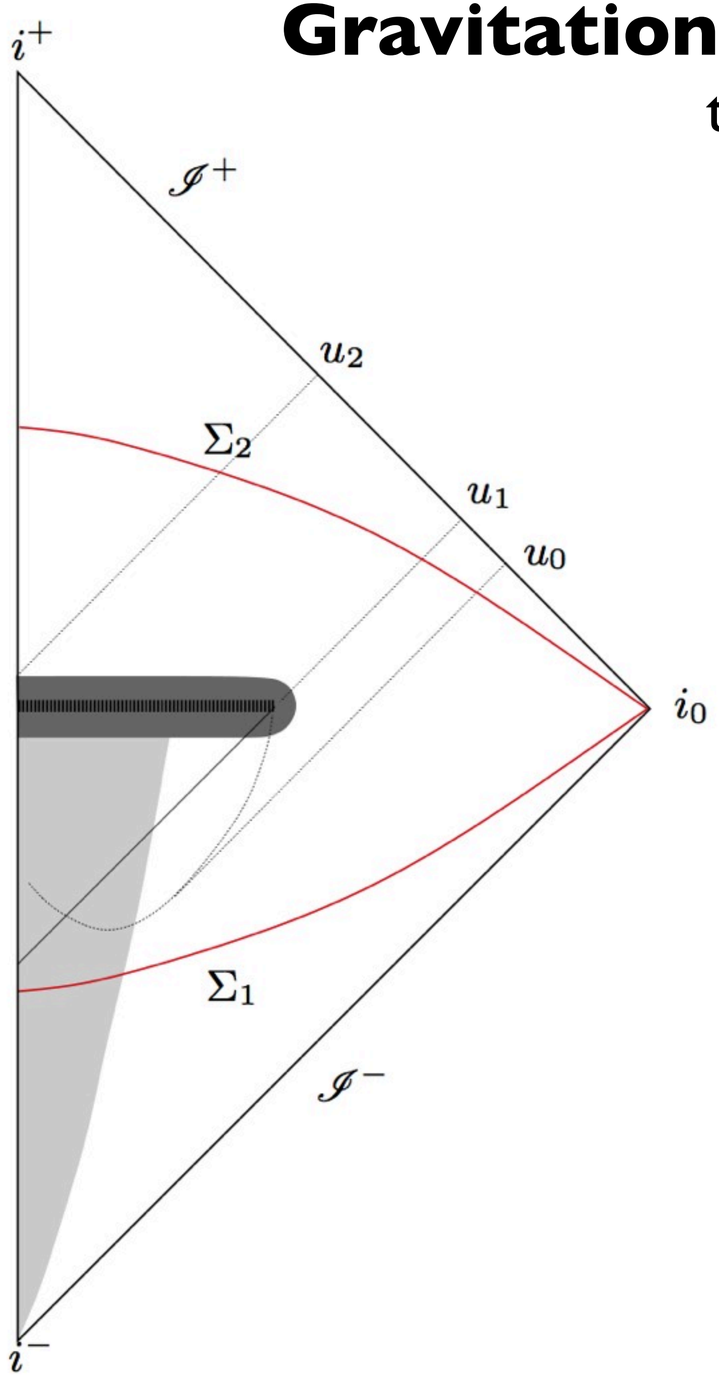




Quantum shell dynamics? (Gambini-Pullin)

Gravitational collapse is highly time asymmetric

two ways of presenting the spacetime



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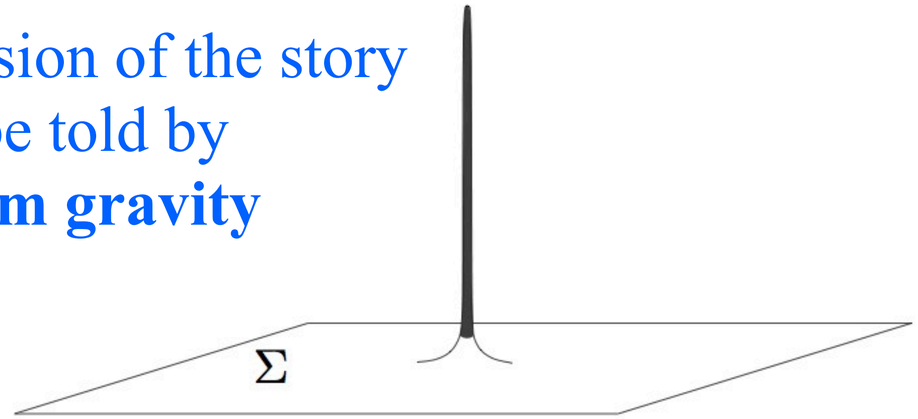
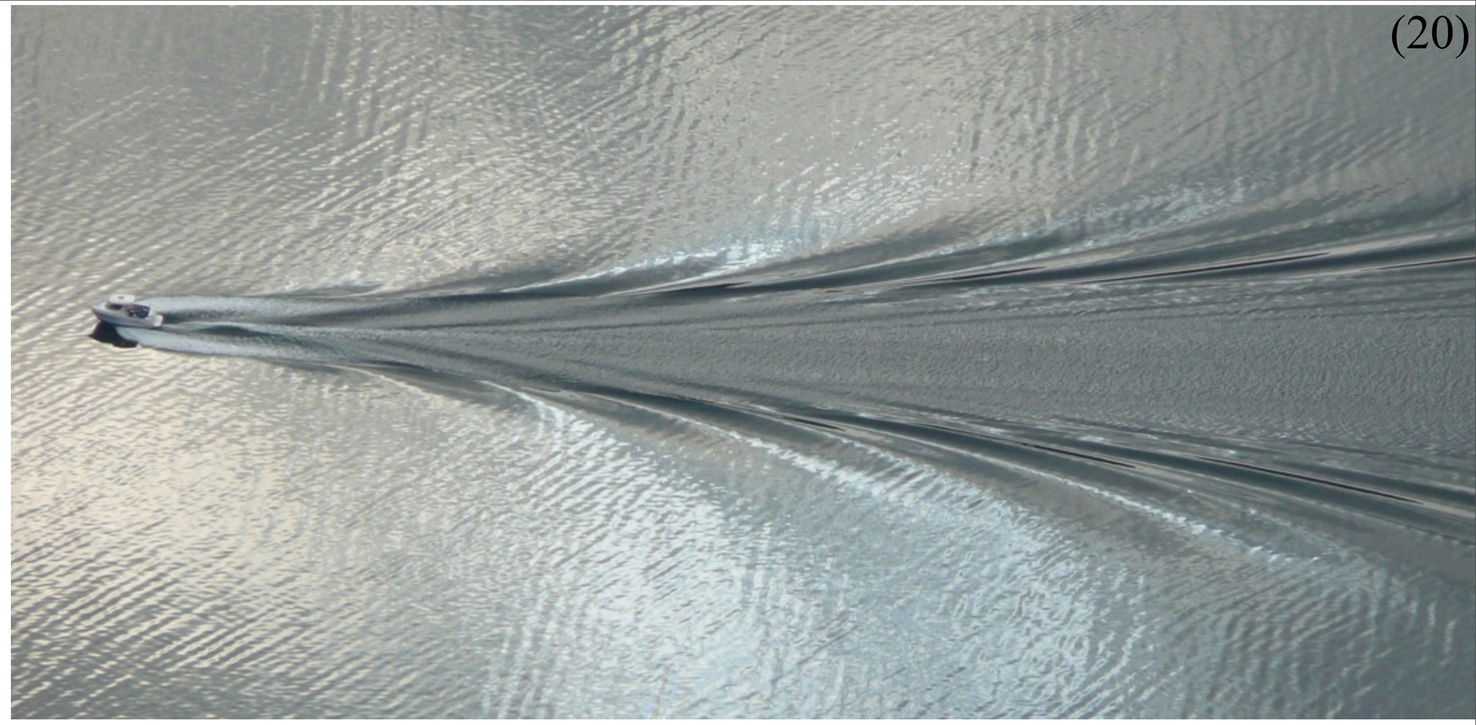
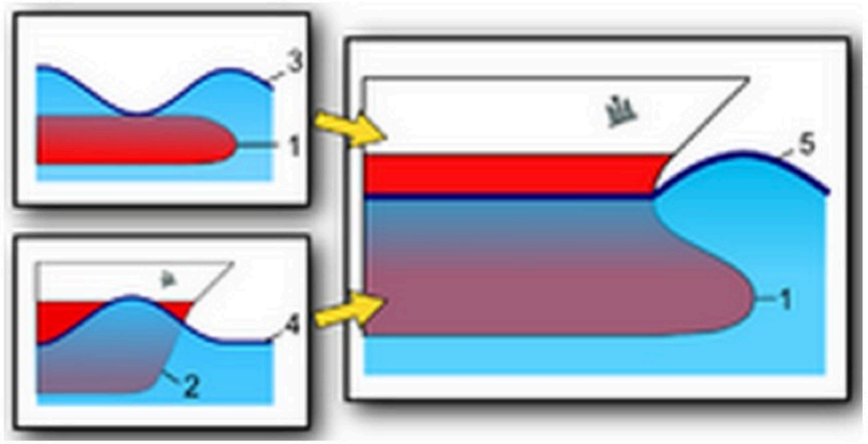


FIG. 8: A qualitative representation of the Riemannian geometry of Σ and Σ' of Fig 5. The shaded regions are those 'touching' the quantum region.


GREEN DOLPHIN 575




3
1
4
2
5
1

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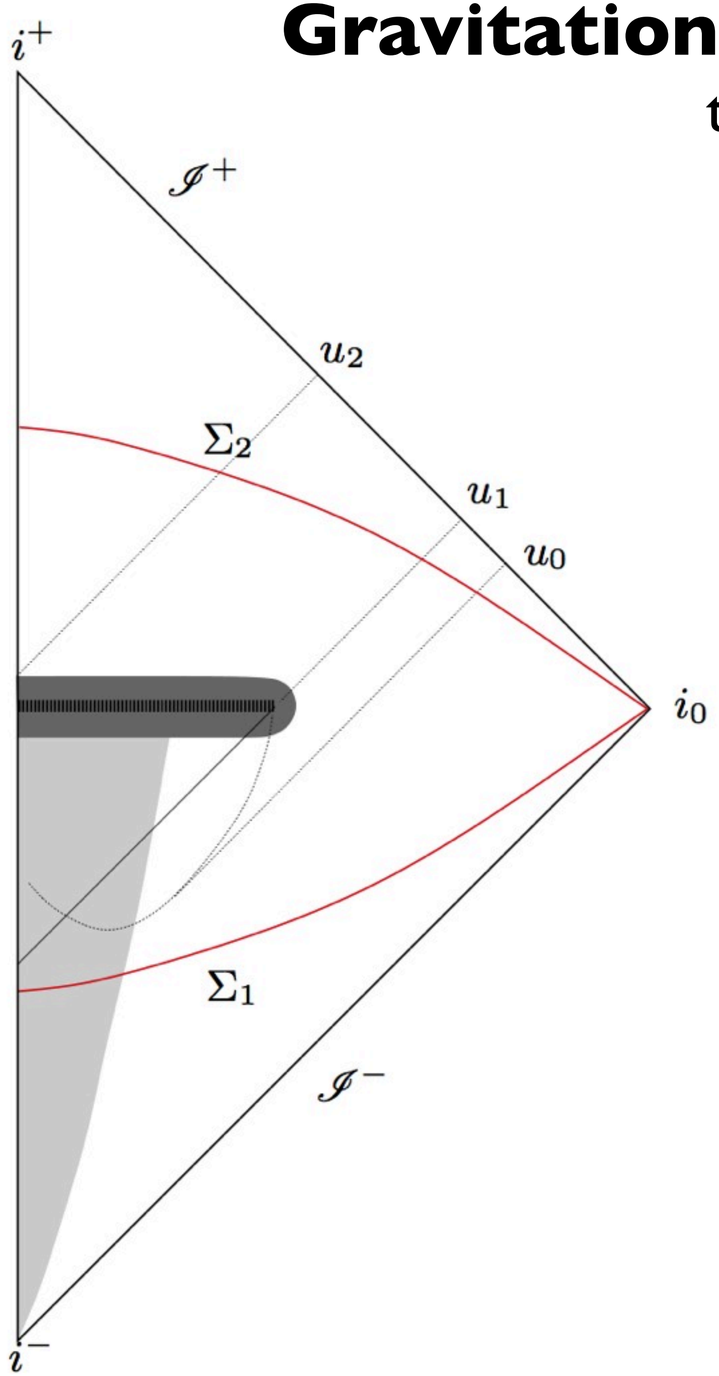

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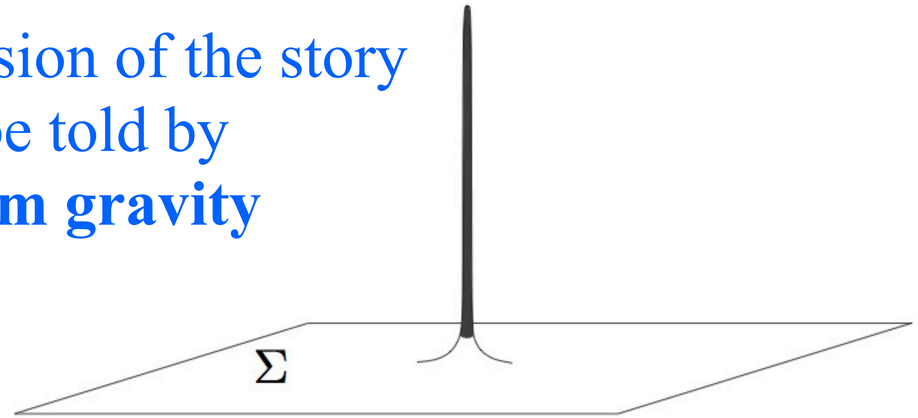

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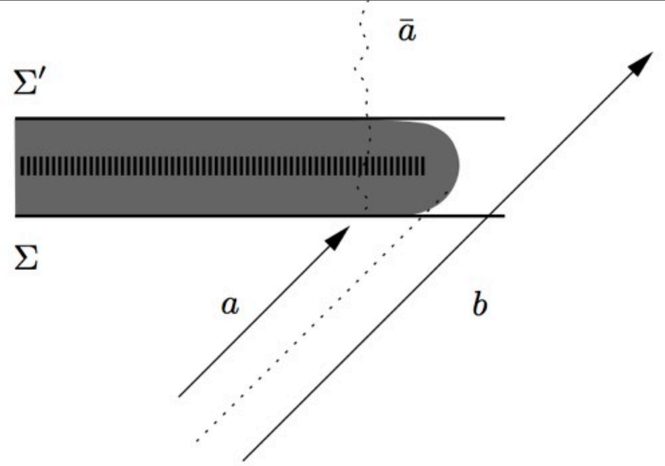


FIG. 5: Two instants of 'time' before and after the *would-be-singularity*. The spacial surface Σ is a latest surface where the space-time notion is still applicable. The surface Σ' is the earliest space-like surface in the flat emerging flat space-time across the *would-be-singularity*. The particles a and b are created close to the BH horizon. Particle b escapes to infinity as Hawking radiation. Particle a falls into the singularity, deposits its negative energy load, striped off its energy it emerges unitarily transformed into a defect $\bar{a}$ in the quantum weave state describing flat space-time to the future of the *would-be-singularity*.

$$\langle T_{ab} u^a u^b \rangle \approx -\frac{\ell_p^2 M}{48 r^5} \left[1 + \left(\frac{r}{u} \right)^4 \right]$$

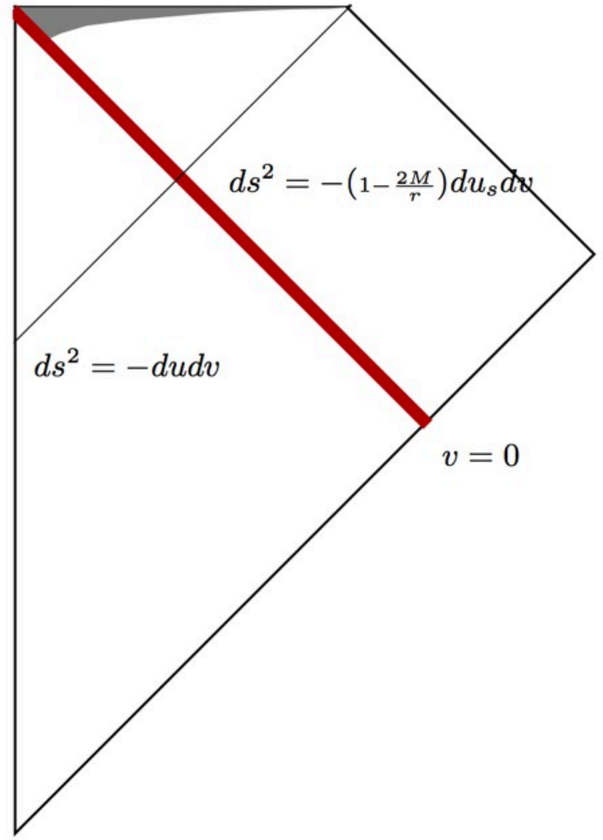
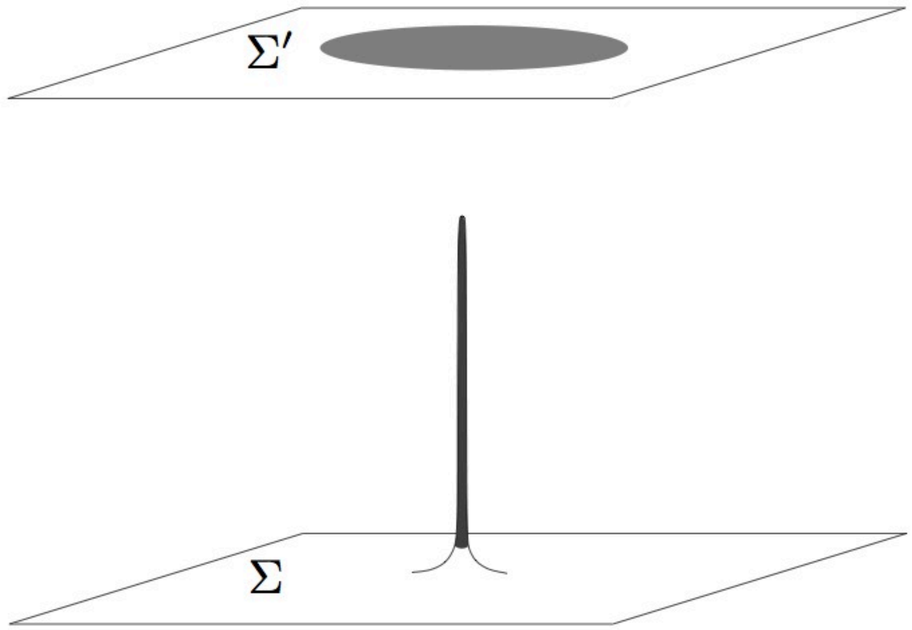


FIG. 6: 2d spherical black hole made from the gravitational collapse of a spherical pulse of energy M. The metric is flat inside the shell and Schwarzschild outside. Continuity of the metric across the shell implies the following relationship between retarded time $u = t - r$ and $u_s = t - r_*$ (for r_* the standard tortoise coordinate): $u_s = u - 4M \log(1 + \frac{u}{4M})$ and $v_s = v$. Coordinates are chosen so that the shell collapse takes place at $v = 0$. The expectation value of the energy momentum tensor in the Unruh vacuum is known in close form [65] everywhere in the spacetime. The shaded area denotes qualitatively the region where observers falling along ∂_r detect energy densities smaller than some negative fixed value.



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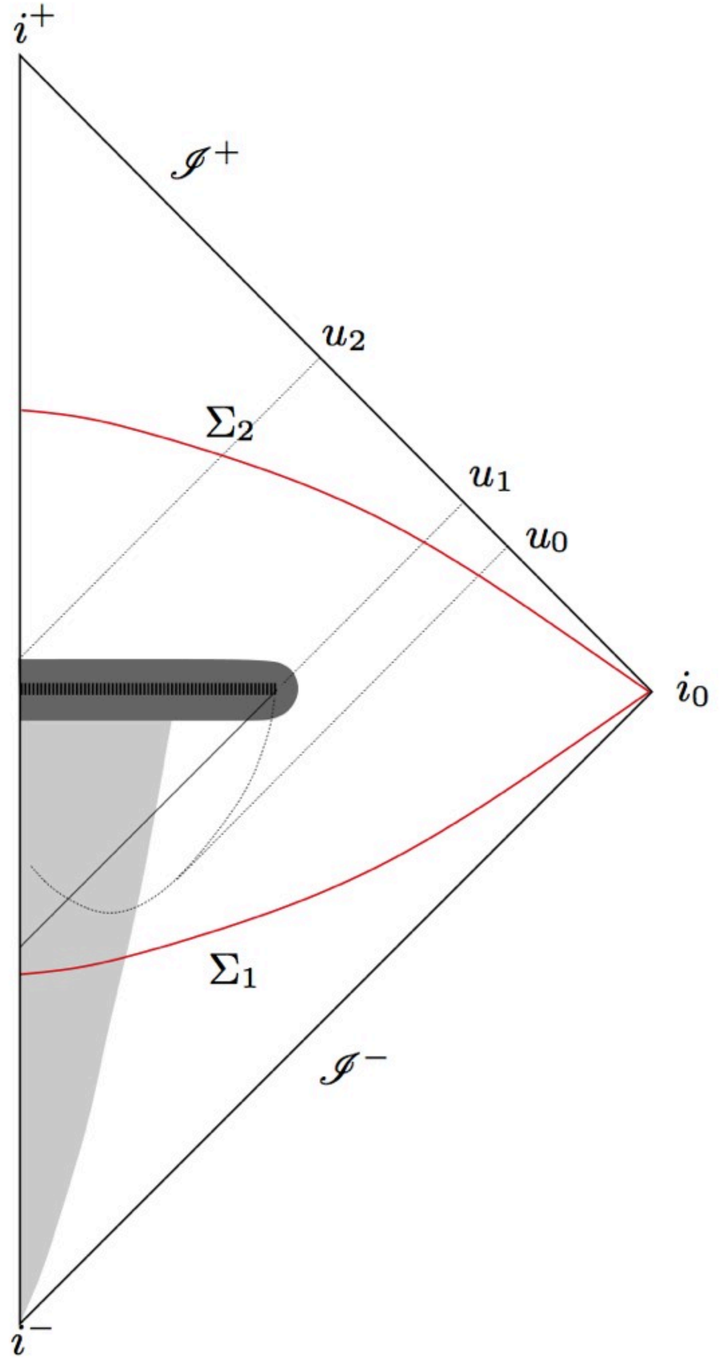
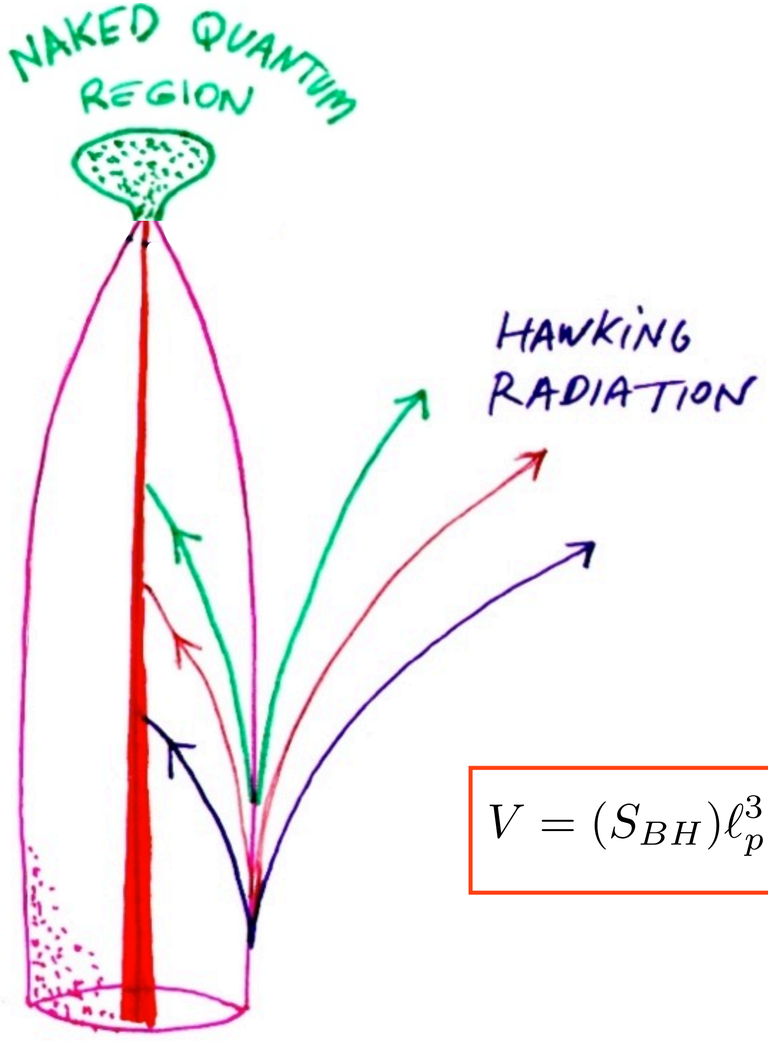
compatible with Rovelli-Christodoulou
arXiv:1411.2854

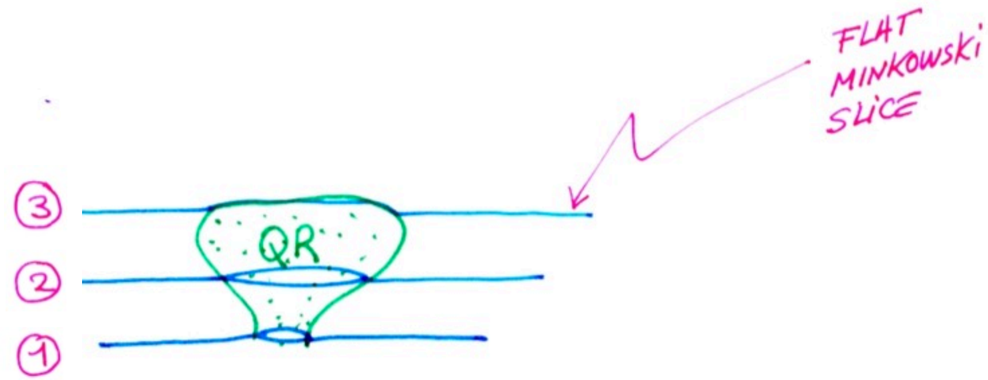
$$V(\Sigma) \propto M^3 (M/\ell_p)^\alpha. \qquad (3)$$

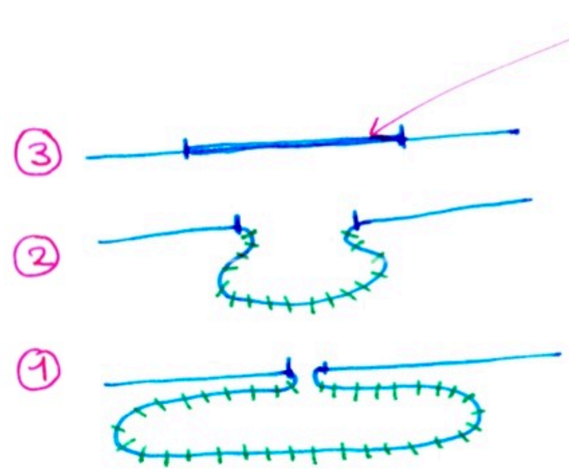
where the missing proportionality constant and α depend on the interior dynamics. For instance one gets $\alpha = 5/2$ if one (toy-)models the evaporation process with an advanced Vaidya metric. We can estimate the scaling of





$$V = (S_{BH})\ell_p^3 \approx M_0^2 \ell_p$$

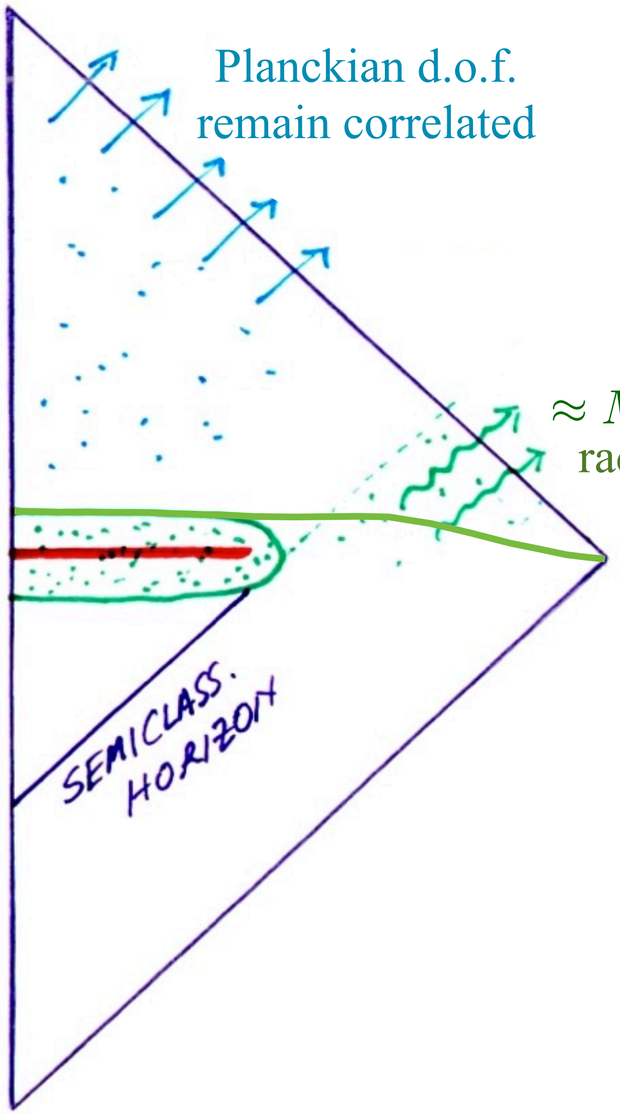




$$L = V^{1/3} \approx \left(\frac{M_0}{M_\odot}\right)^{\frac{2}{3}} \times 10^{-11} m$$

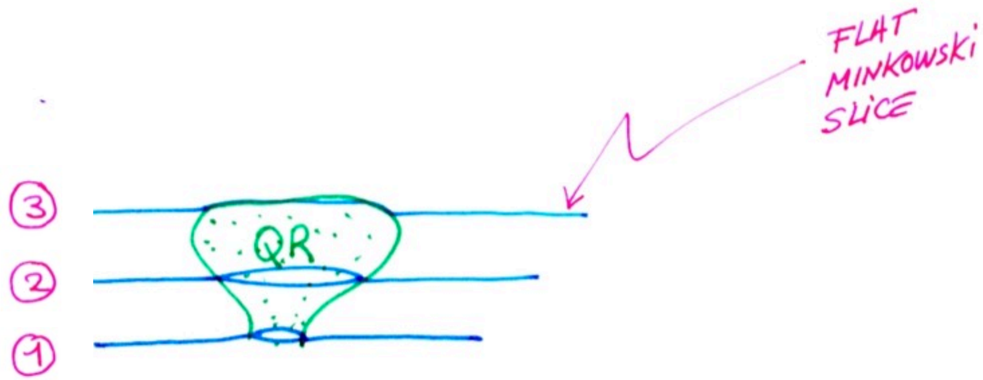
$$L_\odot \approx 10^{-11} m$$

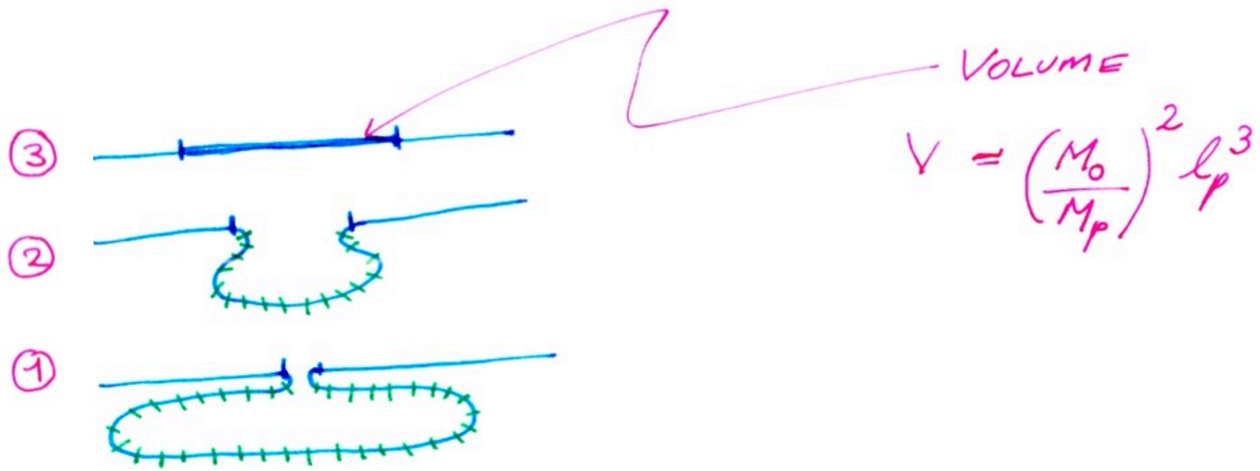
$$L(10^{15} g) \approx 10^{-22} m \approx 10^{-2} \ell_{LHC}$$



$$V \approx \frac{A_0}{4\ell_p^2} \times \ell_p^3$$

$\approx M_0 - m_{pl}$
radiated in
HR





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Gravitational collapse is an irreversible process

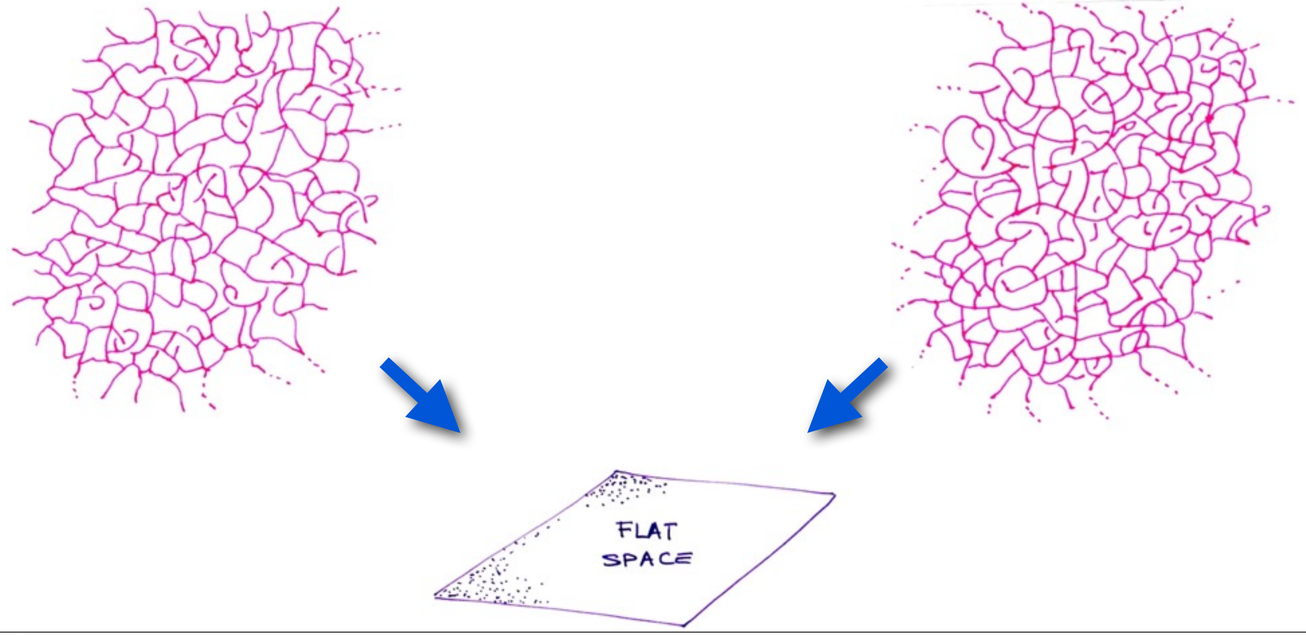
- Gravitational collapse **spacetime is highly asymmetric**.

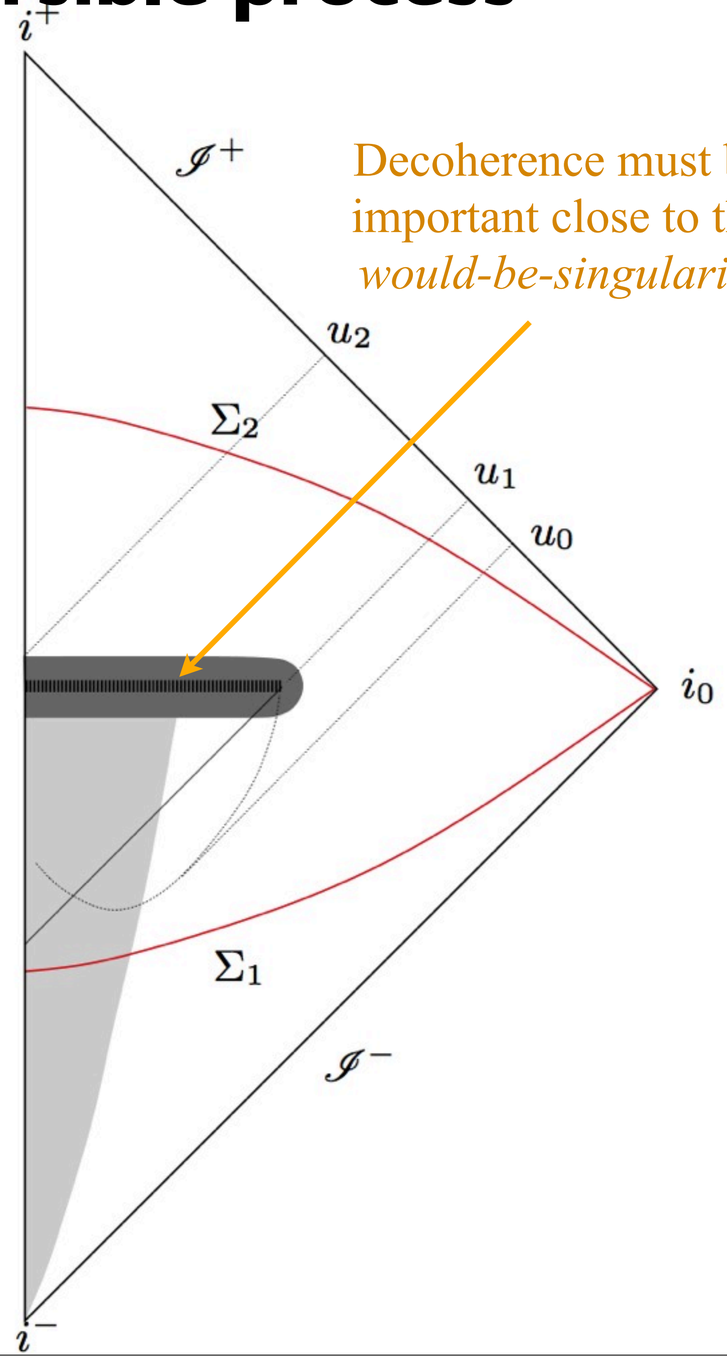
- **Firewalls:** Purification cannot take place during Hawking era.

- Purification via EQFT degrees of freedom after Hawking era on an effective non-singular background is not possible (Hayward scenario) (from results by Bianchi-De Lorenzo-Smerlak).

- **Natural possibility:** Purification via decoherence with Planckian quantum geometry structure.

- **Initial and final "flat" space-times are not the same.**





LQG IS NOT HOLOGRAPHIC

But what about all the holographic phenomenology? (e.g. the **Bousso bound**; a theorem by Bousso-Casini-Maldacena, Phys.Rev. D90 (2014) 4, 044002)

$$S_{\rho_0}(\rho) = -\mathrm{Tr}[\rho \log \rho] + \mathrm{Tr}[\rho_0 \log \rho_0].$$

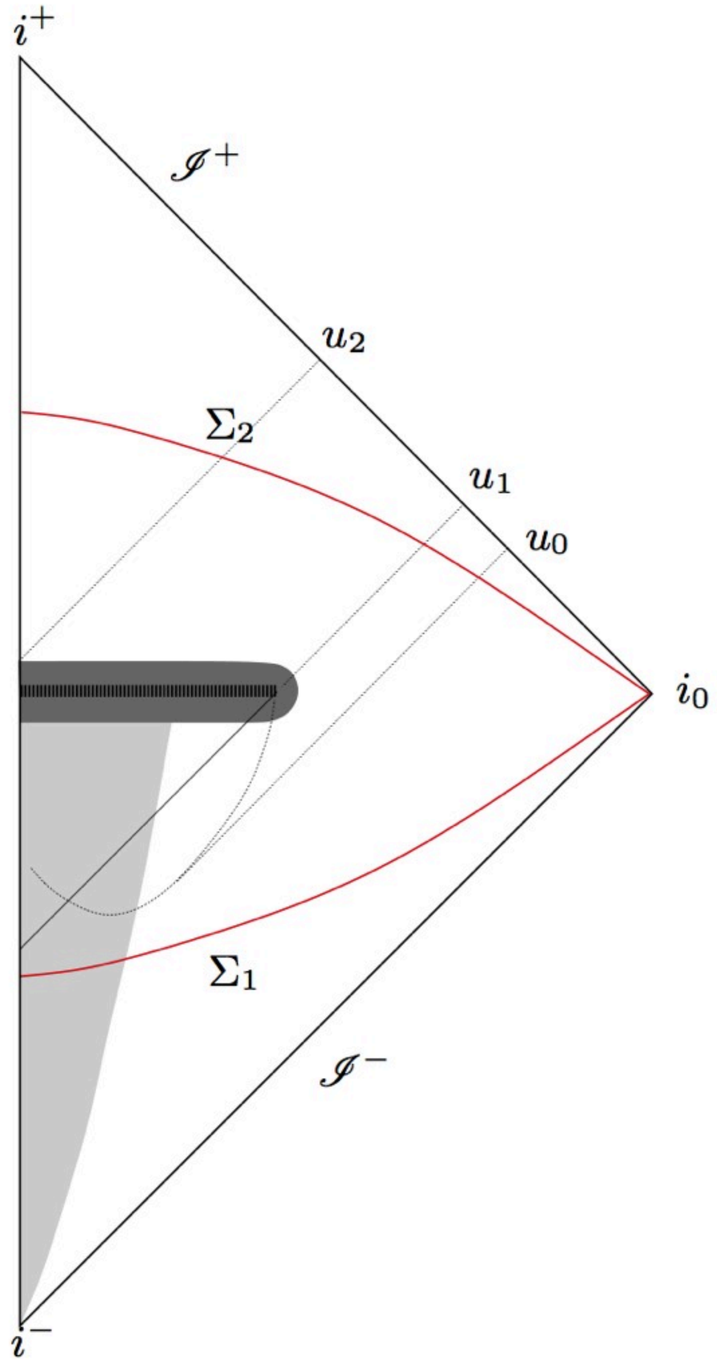
a fact about EQFT degrees of freedom that does not contradict a non-holographic fundamental framework.

Bianchi's computation of BH entropy changes (Semiclassics: Einsteins equations+QFT) **arXiv:1211.0522**

$$\delta S_{thermo} = \frac{\delta A}{4 G_N \hbar}$$

versus the computation of BH entropy in LQG (microstructure of quantum geometry)

$$S_{stat} = \frac{A}{4 G_N \hbar} + \eta \frac{\sqrt{A}}{\sqrt{\gamma G \hbar}}$$



INFORMATION need not have WEIGHT

From Unruh 2012 "Decoherence without dissipation"

Consider two particles, which for sake of simplicity I will assume have the same mass, and live in a 1+1 dimensional spacetime. They interact only when in contact with each other, and their interaction is mediated by some hidden degrees of freedom which are represented by a number N of spin 1/2 objects, with spins operators $\vec{S}_i$. The interaction Hamiltonian is assumed to be of the form $\delta(x_1 - x_2)\sum_i S_i^3$ where $S^3 = \frac{1}{2}\sigma^3$ the third Pauli spin matrix, while the Kinetic energy is the usual $\frac{1}{2m}(p_1^2. + p_2^2)$.

$$Y = (x_1 + x_2)/2 \tag{1}$$

$$y = (x_1 - x_2) \tag{2}$$

the Schroedinger equation becomes

$$i\partial_t \Psi(t, Y, y, \{s_i\}) = -\frac{1}{m}\partial_Y^2 \Psi - \frac{1}{2m}\partial_y^2 \Psi + \mu\delta(y)(\sum_i S_i^3)\Psi \tag{3}$$

From Unruh and Wald 95

$$H = \frac{1}{2}\int \left\{[\pi(t,x) - h(x)q]^2 + [\partial_x \phi(t,x)]^2\right\} dx + \frac{\omega}{2}(p^2 + q^2 - \tfrac{1}{2})[1 + \alpha(S_z + s)] + F(S_z),$$

Conclusions

- Quantum geometry is expected to be ‘atomistic‘ in non perturbative QG

- Smooth spacetime arises from coarse graining.

- Discrete Planckian structure explains Hawking entropy.

- Purification via EQFT degrees of freedom does not work:

1. During Hawking era due to the **firewall problem**.
2. After Hawking era on an effective non-singular background due to **energy conservation**.

- **Natural possibility:** Purification via decoherence with Planckian quantum geometry structure (important close to the *would-be-singularity*).

- **Initial and final “flat” space-times are not the same:** EQFT scattering approach cannot describe the fundamental physics.

- The firewall argument is a problem for ADS-CFT type of scenarios not for `atomistic’ QG theories.

- In this scenario the Hawking evaporation process is analogous to standard irreversible processes (breaking a glass, burning a newspaper)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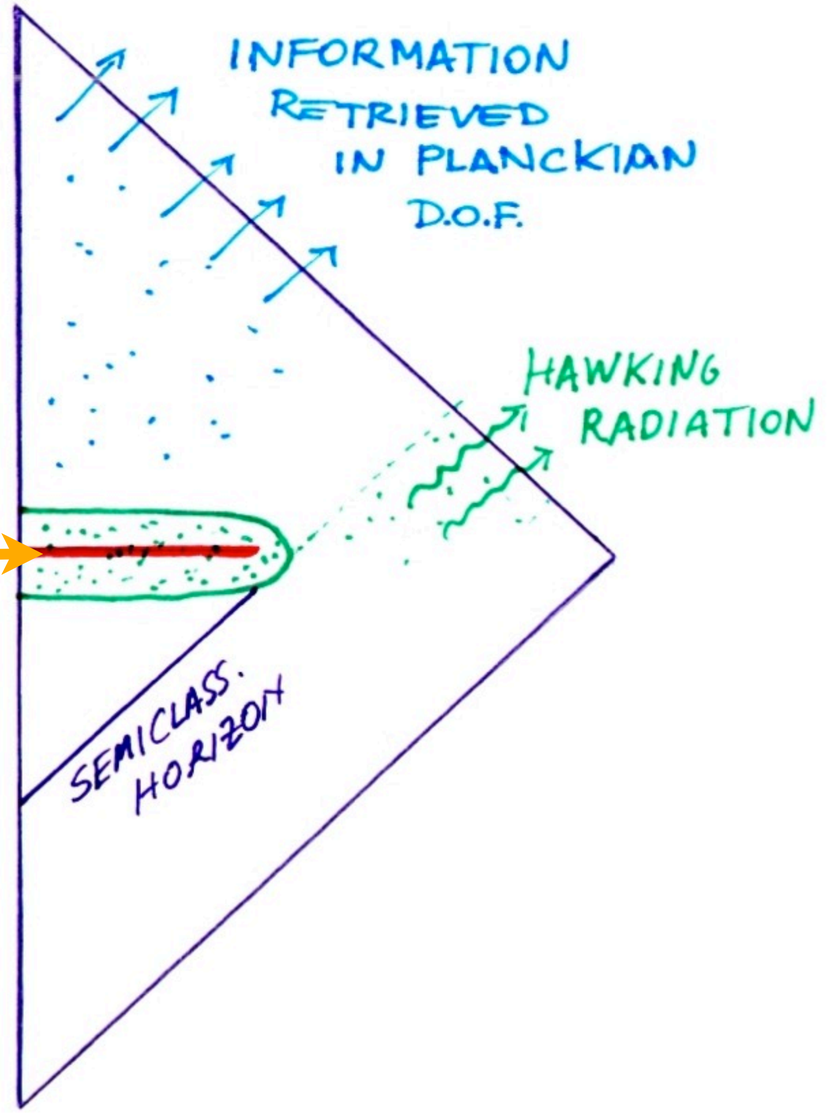
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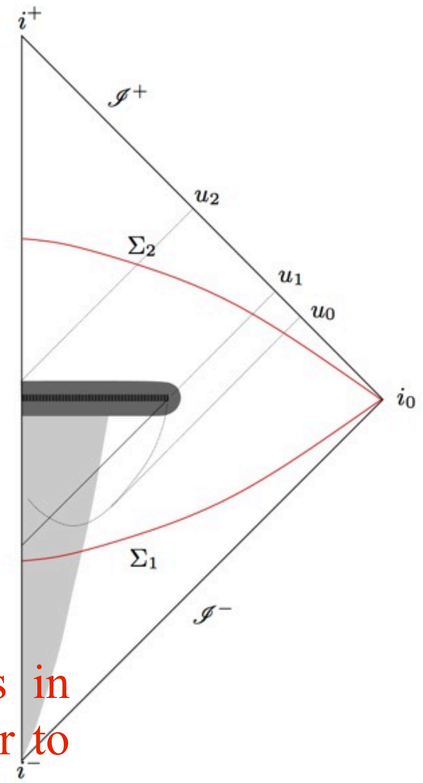

•Can one take into account non perturbative back reaction effects in spherical quantum gravity? (Gambini-Pullin theory with scalar matter to show 'time asymmetry' of *would-be-singularity*)

•Can one effectively describe the decoherence effect of EQFT? (quantum cosmology, structure formation effects, unitarity loss in QFT)

Thank you very much!

For further reading:
"No firewalls in quantum gravity: the role of discreteness of quantum geometry in resolving the information loss paradox"
arXiv:1410.7062
to appear in CQG

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