Title: Black hole decay and Fast Radio Bursts

Date: Jun 04, 2015 02:30 PM

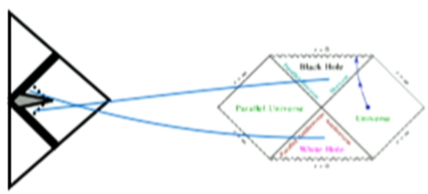
URL: http://pirsa.org/15060006

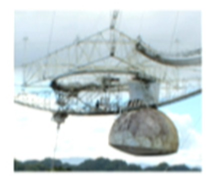
Abstract: <p>Quantum effects render black holes unstable. Besides Hawking radiation there is another, genuinely quantum gravitational, source of instability: the Hajicek-Kiefer explosion via tunnelling to a white hole. A recent result in classical general relativity makes this decay channel plausible: there is an exact external solution of the Einstein equations locally (but not globally) isometric to extended Schwarzschild, which describes an object collapsing into a black hole and then exploding out of a white hole. The tunnelling time can in principle be computed using Loop Quantum Gravity. If it is sufficiently short, present explosions of primordial black hole could be observables, opening a new observational window on quantum gravity. I discuss the possibility that these explosions could be related to the recently observed and mysterious Fast Radio Bursts. </p>

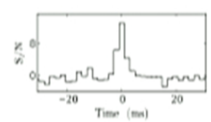
Black hole decay and Fast Radio Bursts

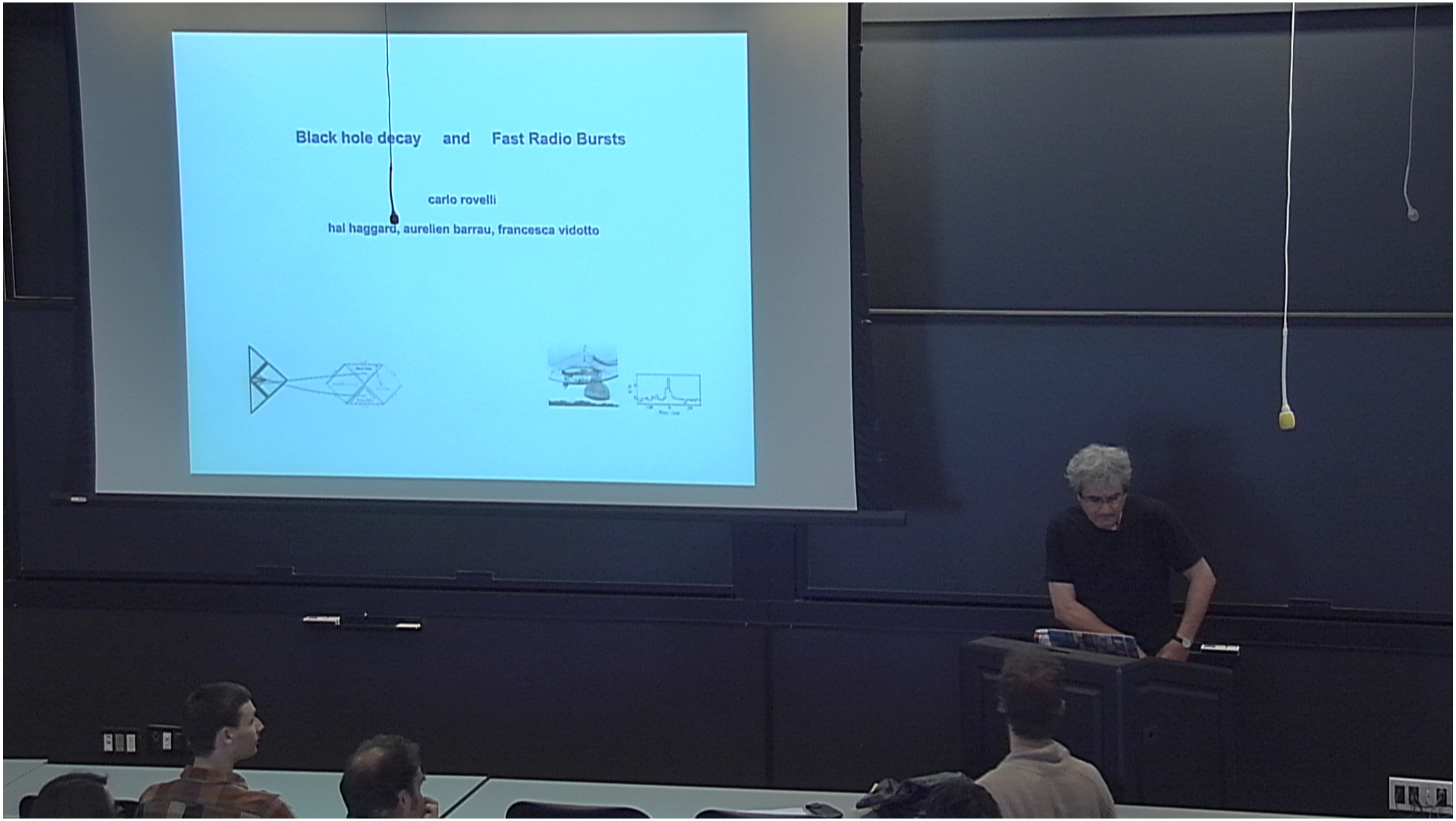
carlo rovelli

hal haggard, aurelien barrau, francesca vidotto





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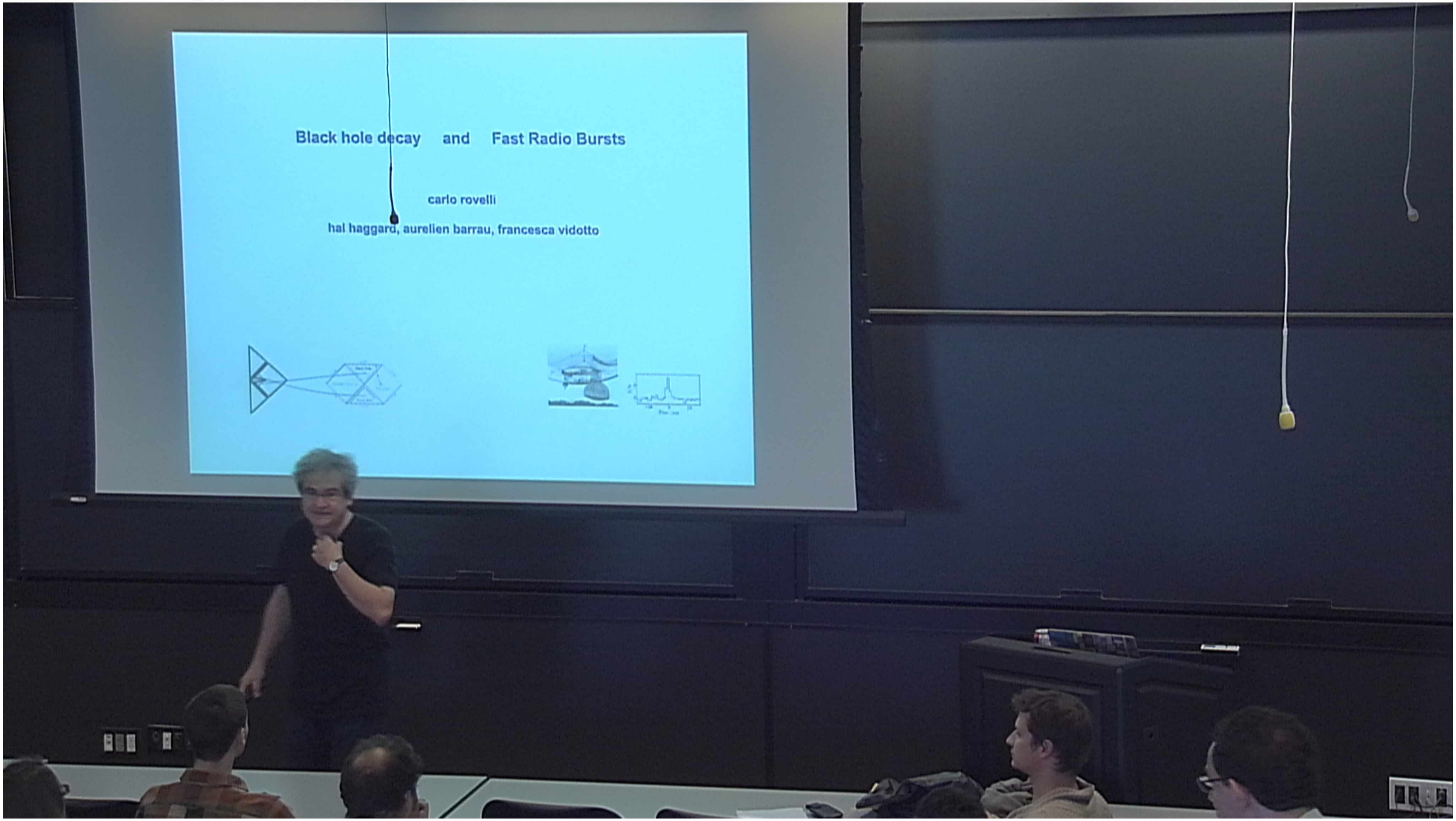
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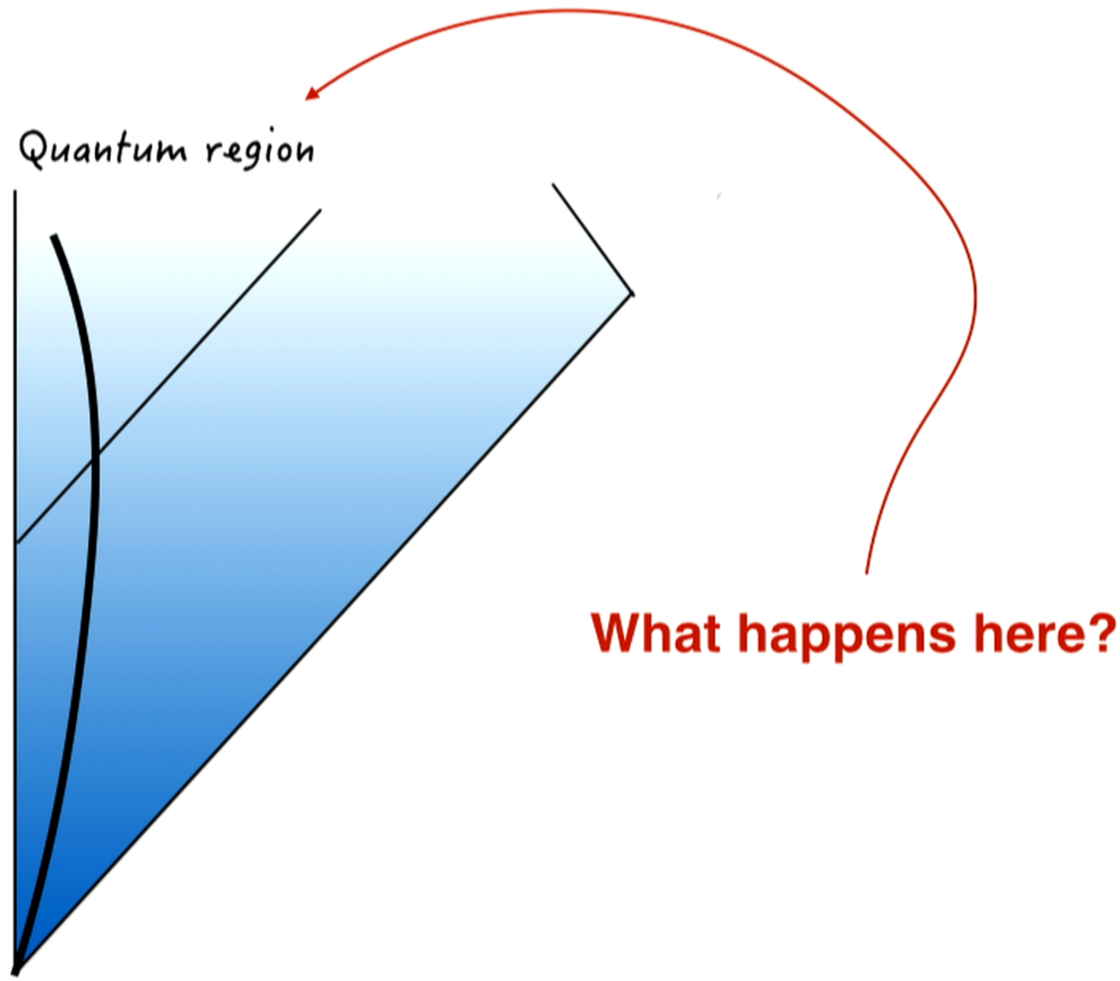
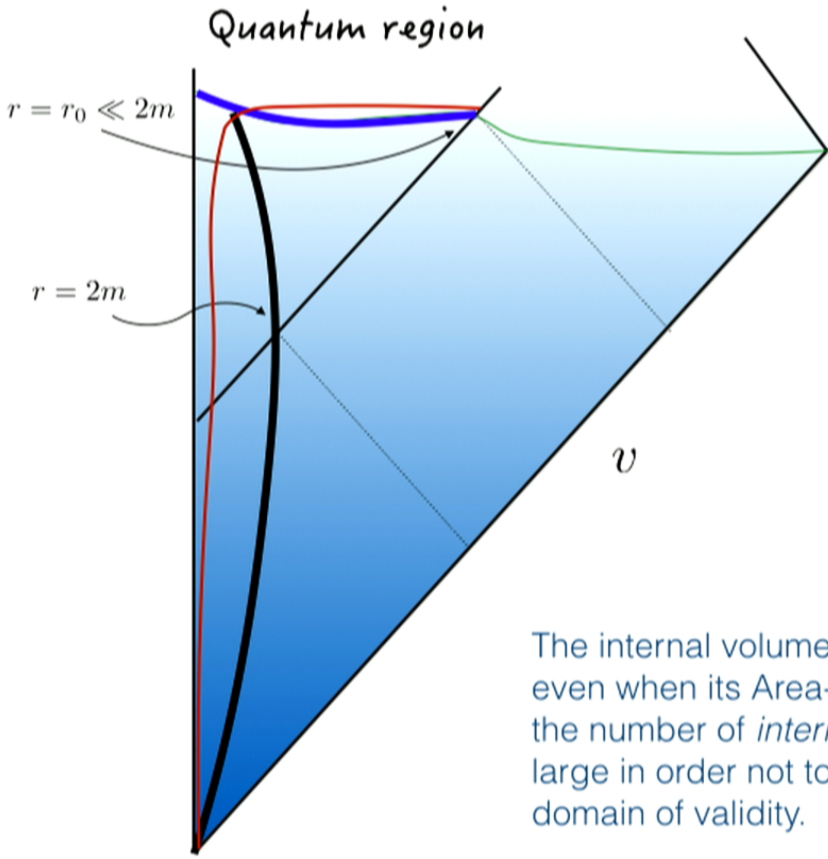
Quantum gravity: we need observations

- Early universe : CMB
- Short scale : Lorentz violations
- Black holes : Observable quantum effects


Quantum region
What happens here?



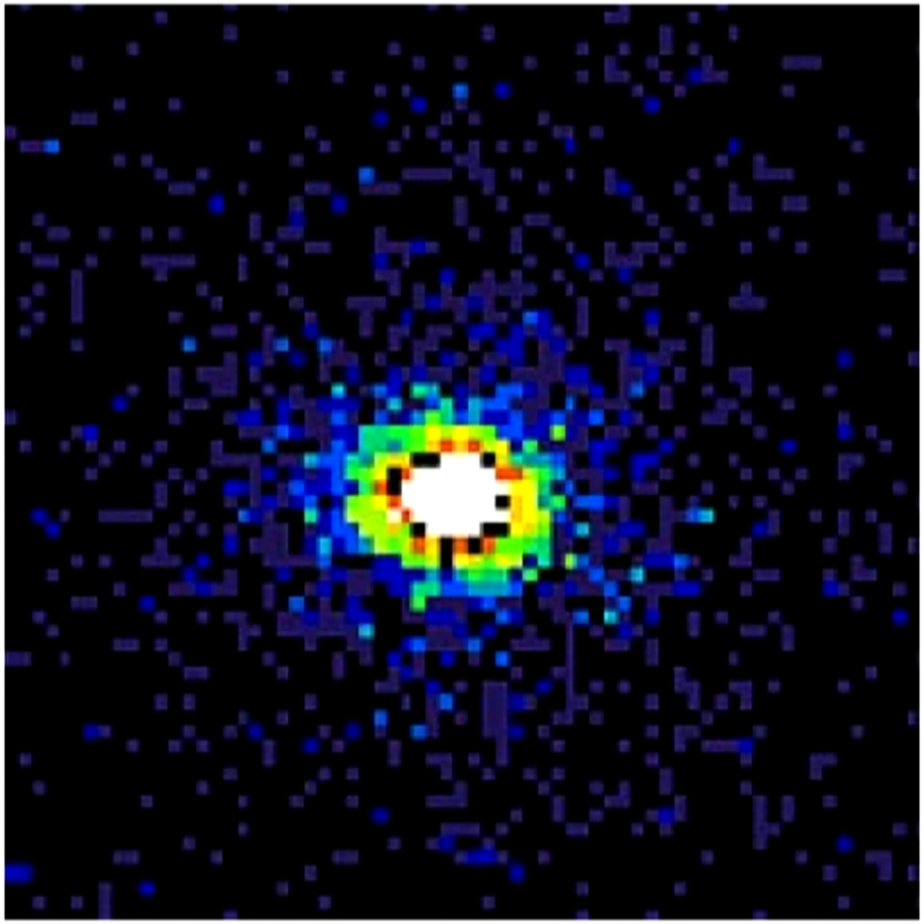
$$V \sim 3\sqrt{3}\,\pi\, m^2 v$$

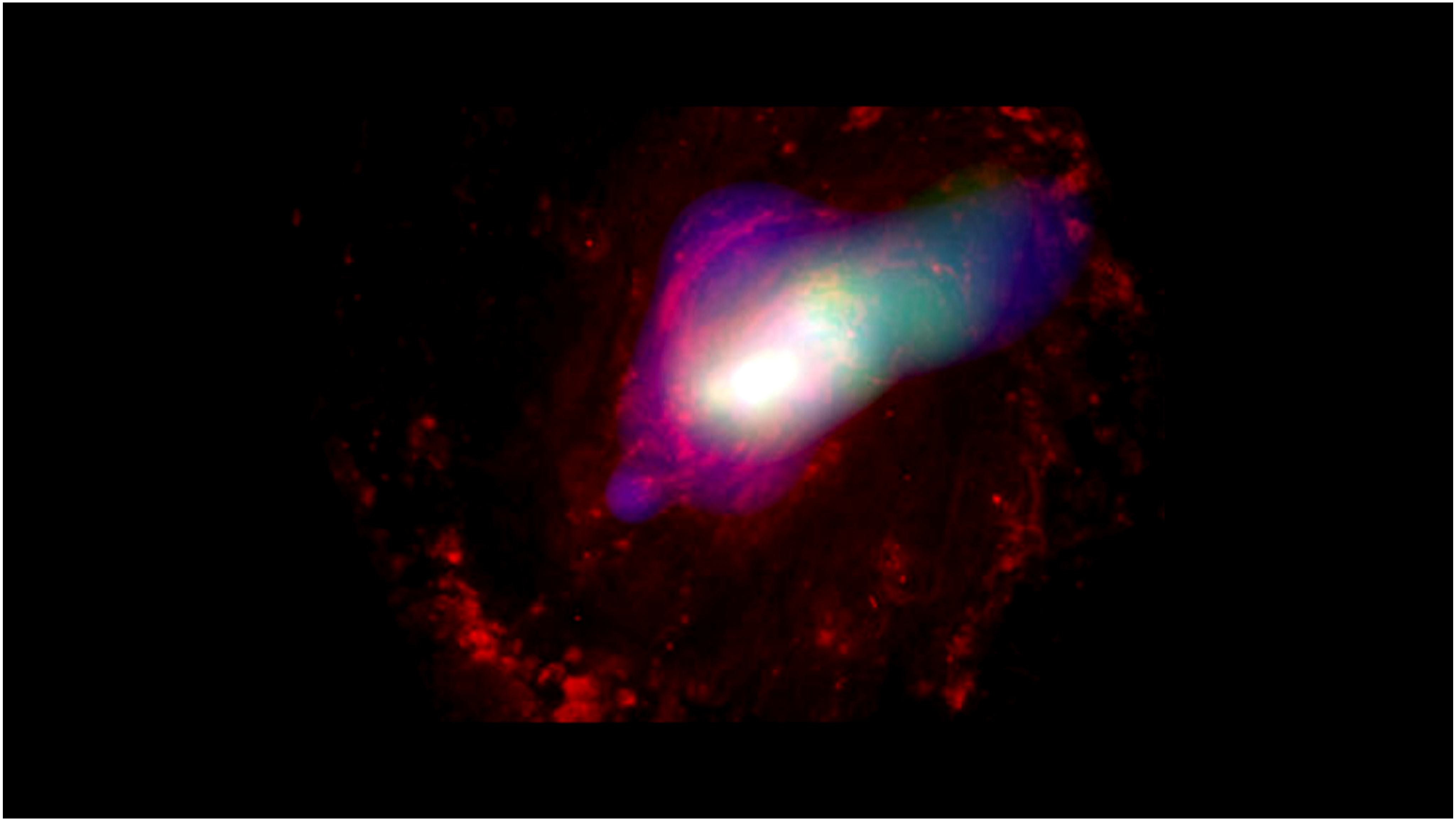
How big is a black hole?
Marios Christodoulou, Carlo Rovelli.
Phys.Rev. D91 (2015) 6, 064046

After a time m^3: $V \sim m^5$

At the end of the evaporation: $V \sim m^{\frac{7}{2}}$

The internal volume of a black hole is large even when its Area-Entropy is small: the number of *internal* degrees of freedom must be large in order not to violate local qft in its own domain of validity. … holography?





What happens to the matter falling into black holes?

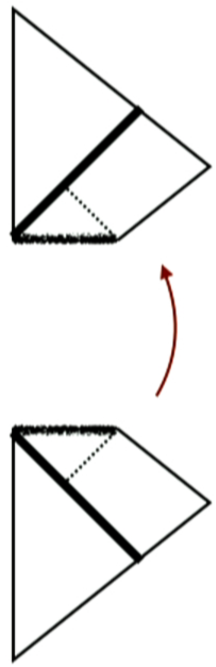
- It disappears (?)
- It creates“another universe” (Lee)
- It stays there forever (nothing is forever)
- It comes out.

The Hajicek-Kiefer bounce

- Spherical symmetry
- Null shell of matter
- Classically: Finite dimensional phase space (v,p) separated in two disconnected components:
    - p>0: shell collapsing into white hole (future singularity)
    - p<0: shell emerging from a white hole (past singularity)

- Can a black hole truly tunnel into a white hole?

Singularity avoidance by collapsing shells in quantum gravity
Petr Hájíček, Clauss Kiefer.
IJMP D, (2001), 775.



Intriguing aspects:

- Classical stable objects often unstable via quantum effects (cfr. nuclear decay).

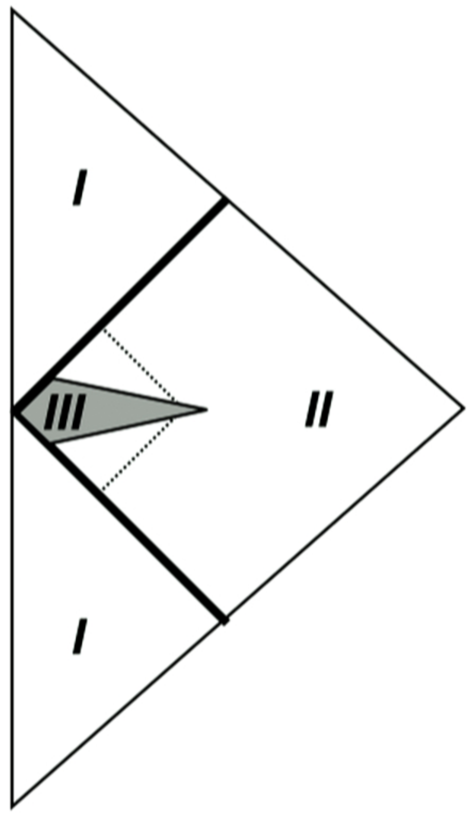
- Hawking radiation takes a huge amount of time ($t \sim m^3$) and is not a full quantum gravitational phenomenon.

Difficulties:

- Two distinct asymptotic regions.

- A quantum jump involving the entire universe.

- What could determine the tunneling time?



A technical result in classical GR:

The following metric is an exact vacuum solution, plus an ingoing and outgoing shell, of the Einstein equations outside a finite spacetime region (grey).

$$ds^2 = -F(u,v)dudv + r^2(u,v)(d\theta^2 + sin^2\theta d\phi^2)$$

Region I $F(u_I, v_I) = 1, \qquad r_I(u_I, v_I) = \frac{v_I - u_I}{2}.$

$v_I < 0.$

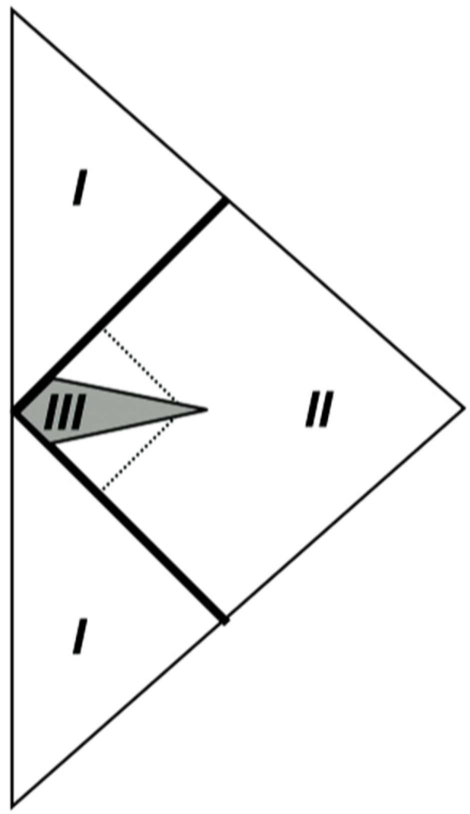
Region II $F(u,v) = \frac{32m^3}{r} e^{\frac{r}{2m}} \qquad \left(1 - \frac{r}{2m}\right) e^{\frac{r}{2m}} = uv.$

Matching: $r_I(u_I, v_I) = r(u,v) \longrightarrow u(u_I) = \frac{1}{v_o}\left(1 + \frac{u_I}{4m}\right) e^{\frac{u_I}{4m}}.$

Region III $F(u_q, v_q) = \frac{32m^3}{r_q} e^{\frac{r_q}{2m}}, \qquad r_q = v_q - u_q.$

Black hole fireworks: quantum-gravity effects outside the horizon spark black to white hole tunneling
Hal M. Haggard, Carlo Rovelli
arXiv:1407.0989

The metric is determined by three constants: m, ϵ, δ



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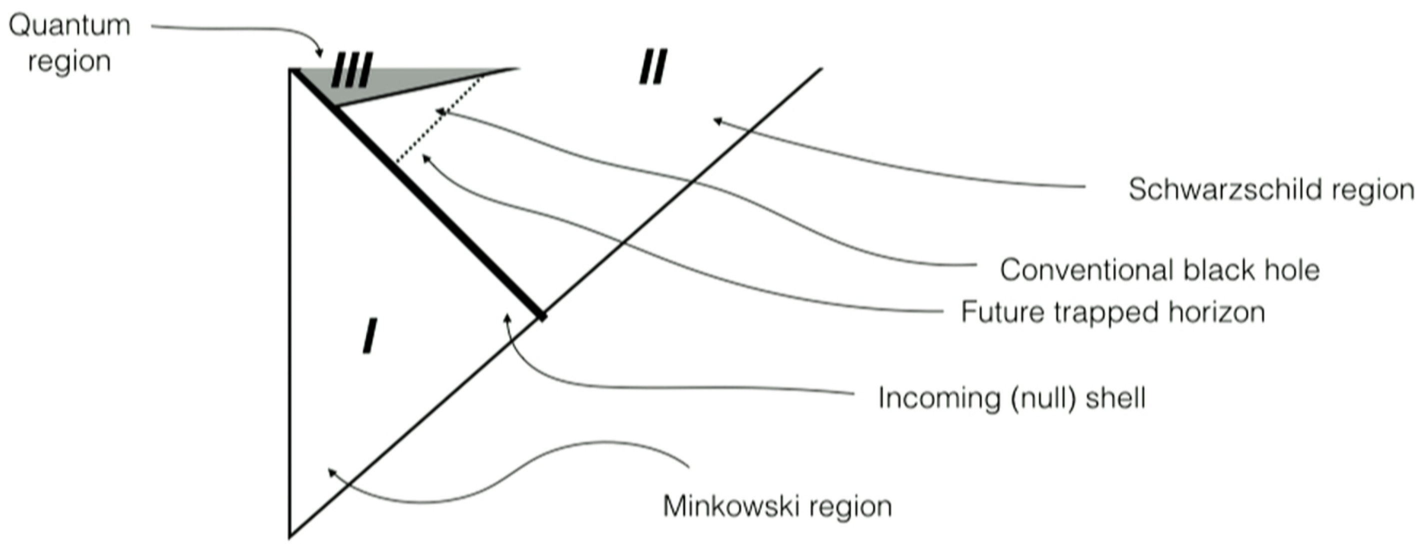
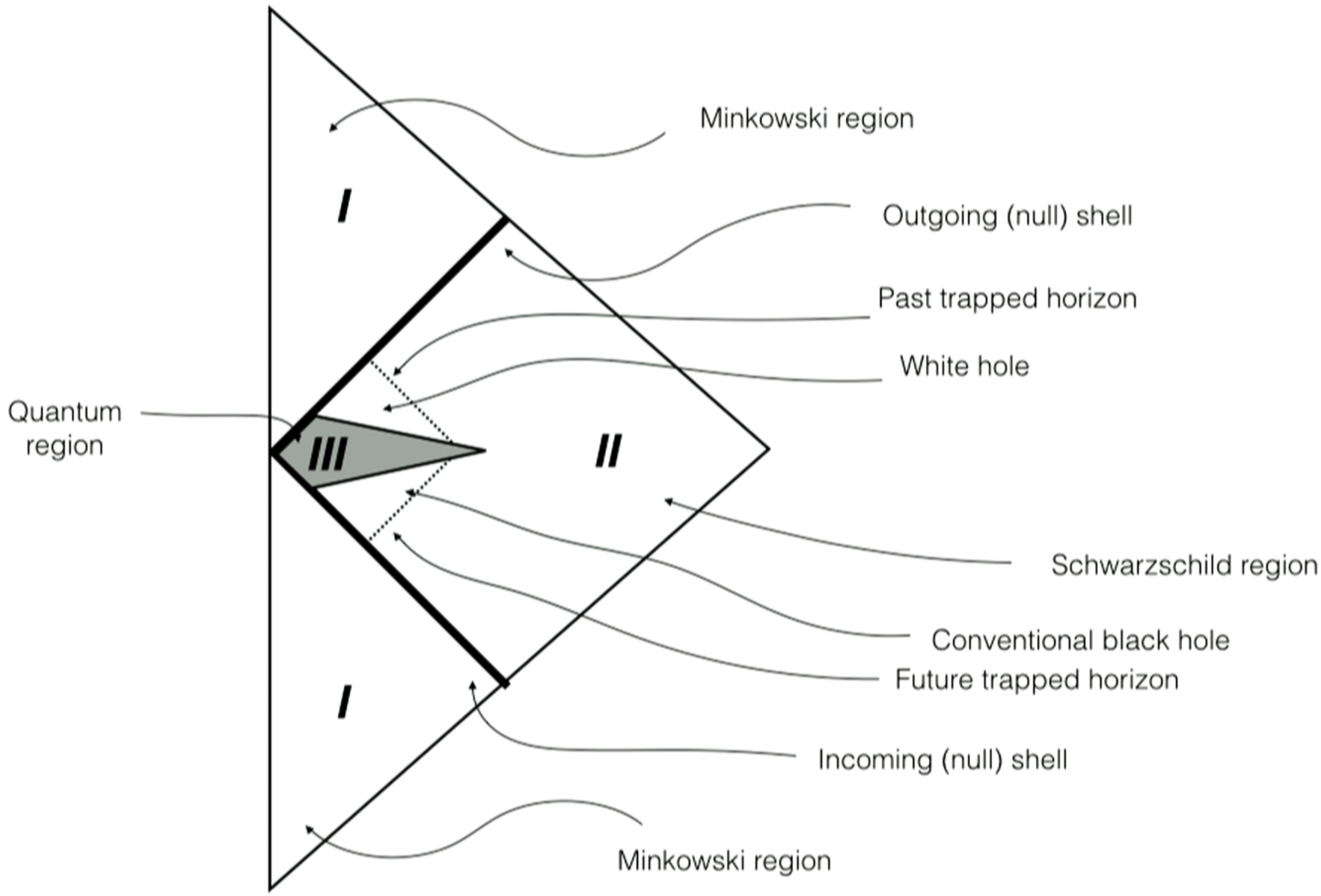
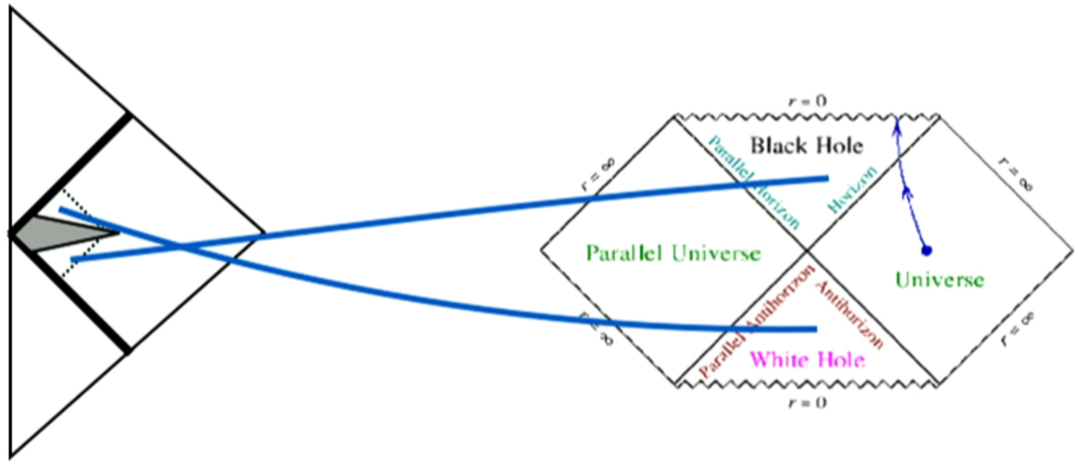
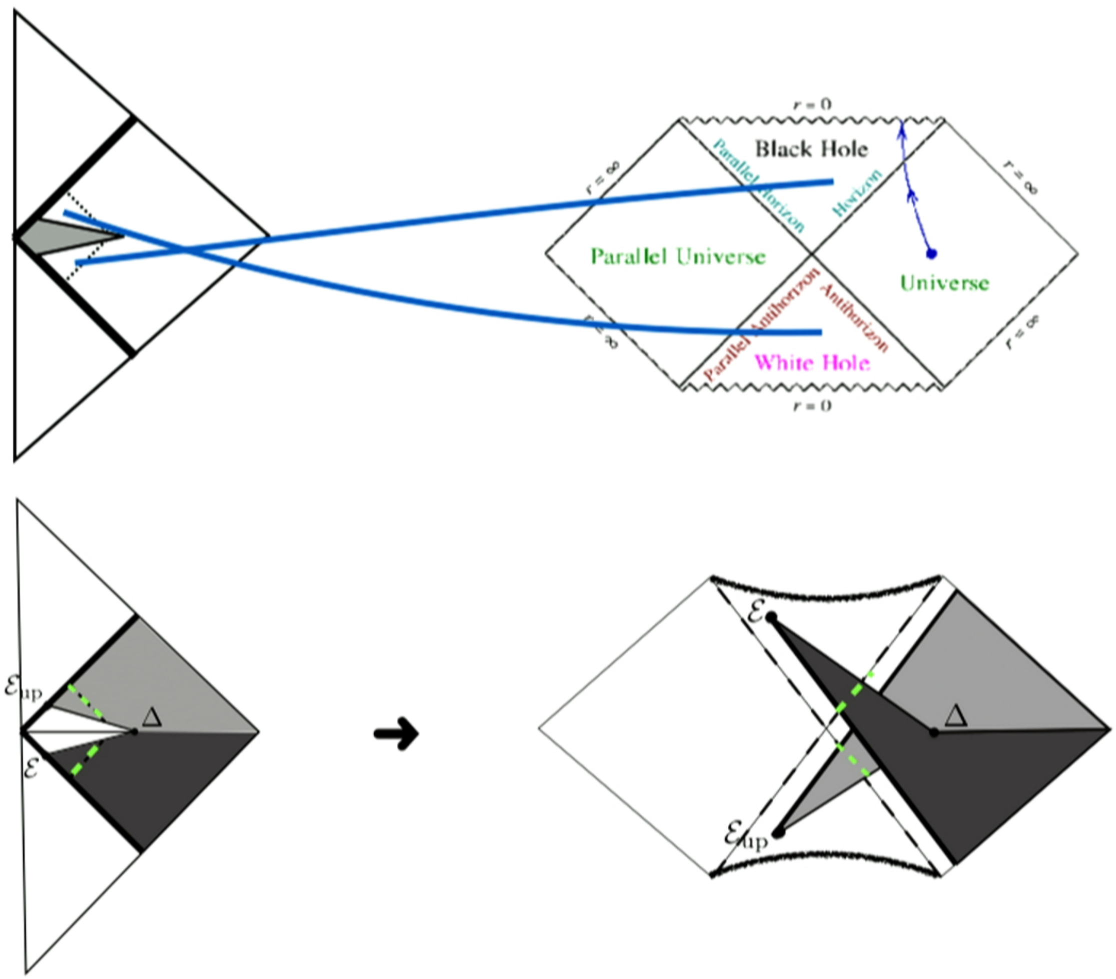
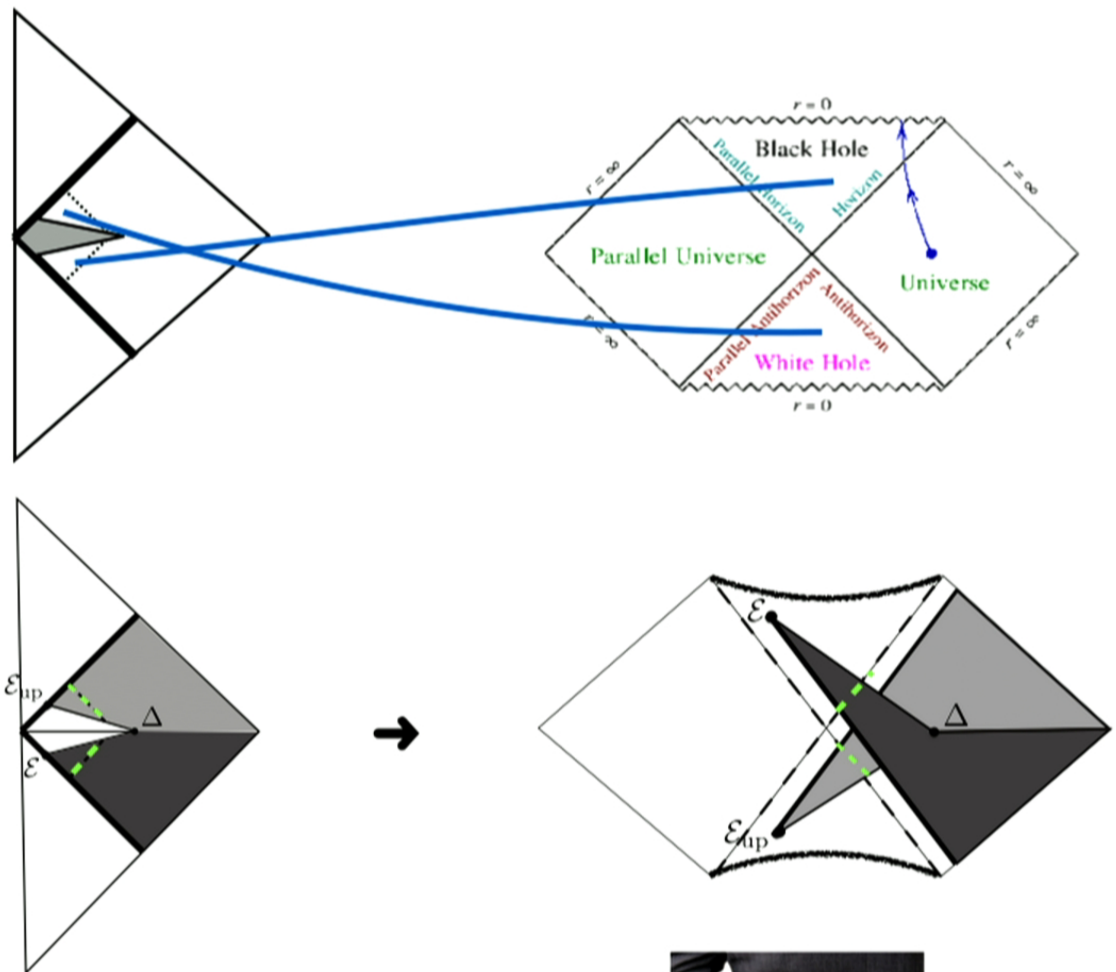

Quantum region
III
II
I
Schwarzschild region
Conventional black hole
Future trapped horizon
Incoming (null) shell
Minkowski region


Minkowski region
I
Outgoing (null) shell
Past trapped horizon
White hole
Quantum region
III
II
Schwarzschild region
Conventional black hole
Future trapped horizon
I
Incoming (null) shell
Minkowski region

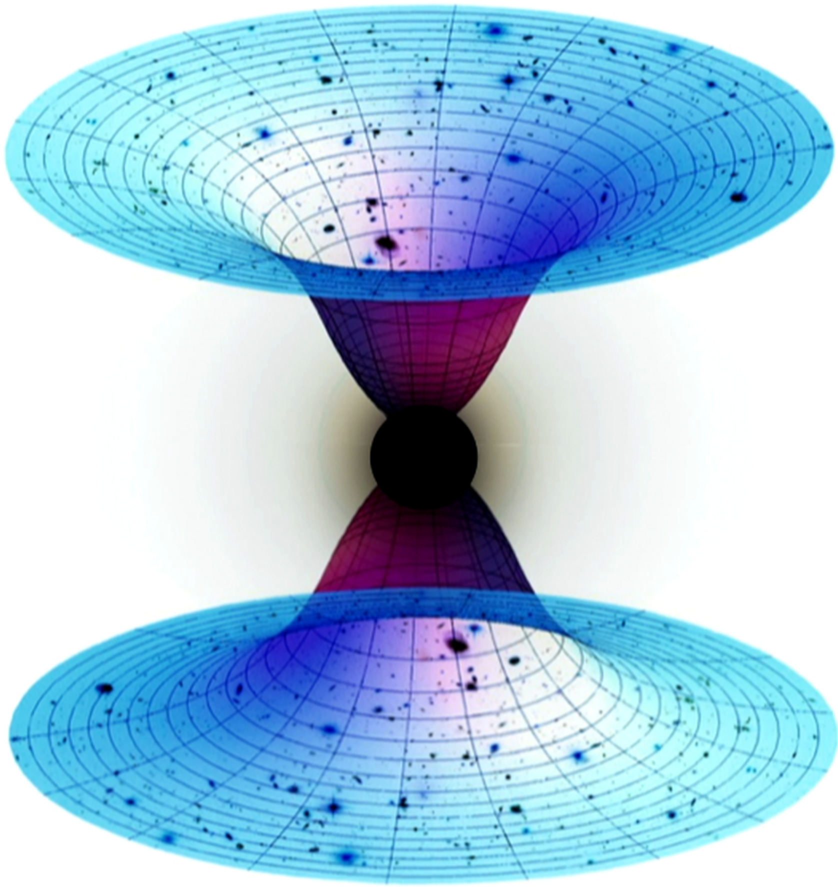

r = 0
Black Hole
r = ∞
Parallel Horizon
Horizon
r = ∞
Parallel Universe
Universe
Parallel Antihorizon
Antihorizon
r = ∞
r = ∞
White Hole
r = 0



r = 0
Black Hole
Parallel Horizon
Horizon
r = ∞
Parallel Universe
Universe
Parallel Antihorizon
Antihorizon
White Hole
r = ∞
r = 0
$\mathcal{E}_{up}$
$\mathcal{E}$
Δ
$\mathcal{E}$
Δ
$\mathcal{E}_{up}$



The Fingers Crossed



The metric is determined by three constants:

- m is the mass of the collapsing shell.

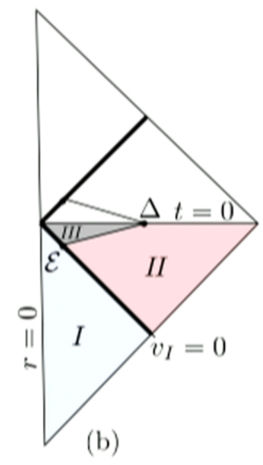
- ϵ is the radius where quantum effect start on the shell: $\epsilon \sim \left(\frac{m}{m_P^3}\right)^{\frac{1}{3}} l_P.$

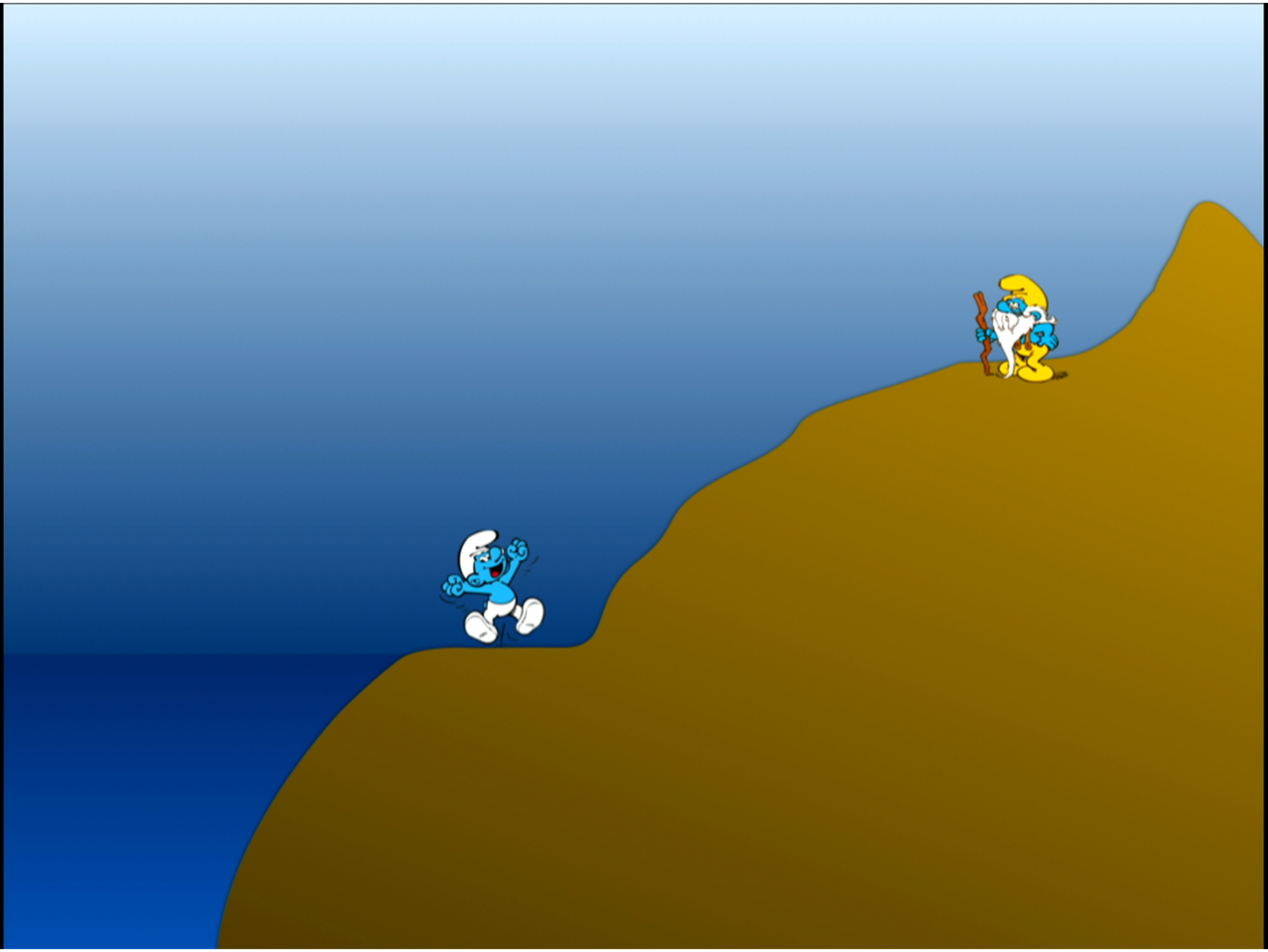
Quantum pressure causes the bounce

Planck stars
Carlo Rovelli, Francesca Vidotto
Int.J.Mod.Phys. D23 (2014) 12, 1442026

- δ is related to the distance from the horizon where the theory is entirely classical

What does δ represent and what determines it?



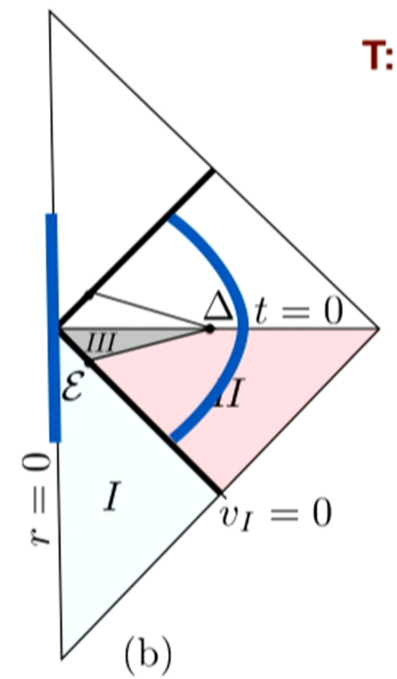


Time dilation

$$\tau_R = 2R - m\ln(\delta/m)$$

T: bounce time (very large)

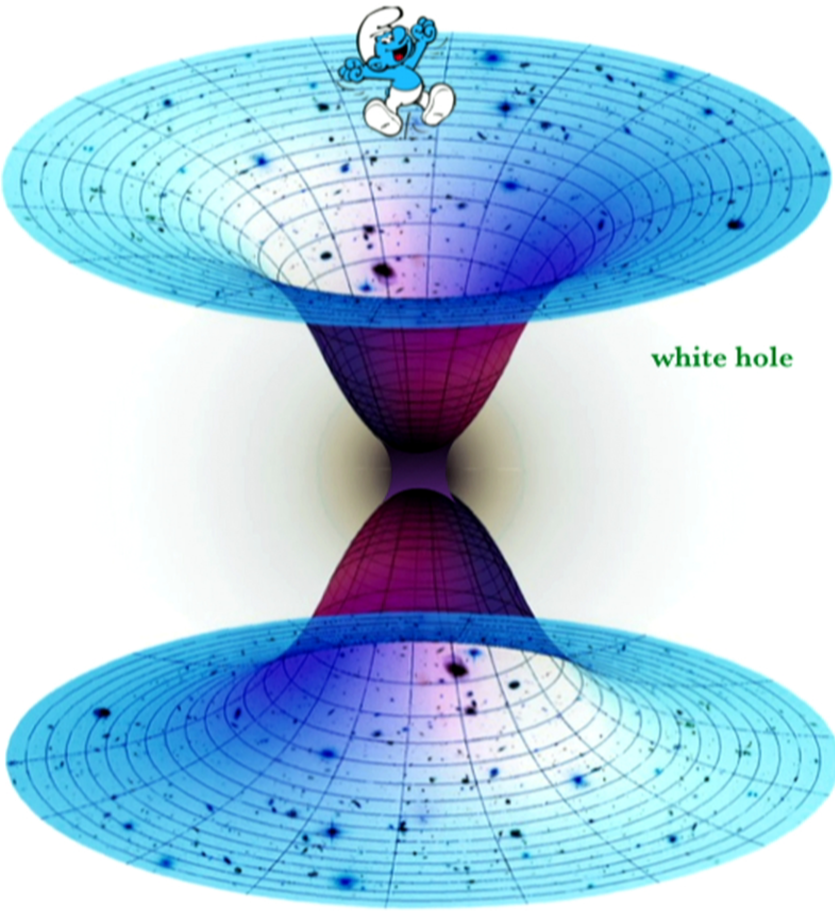
$\tau_{internal} \sim m \sim 1ms$



$\tau_{external} \sim m^2 \sim 10^9 years$

"A black hole is a short cut to the future"

Time inside: 1 ms

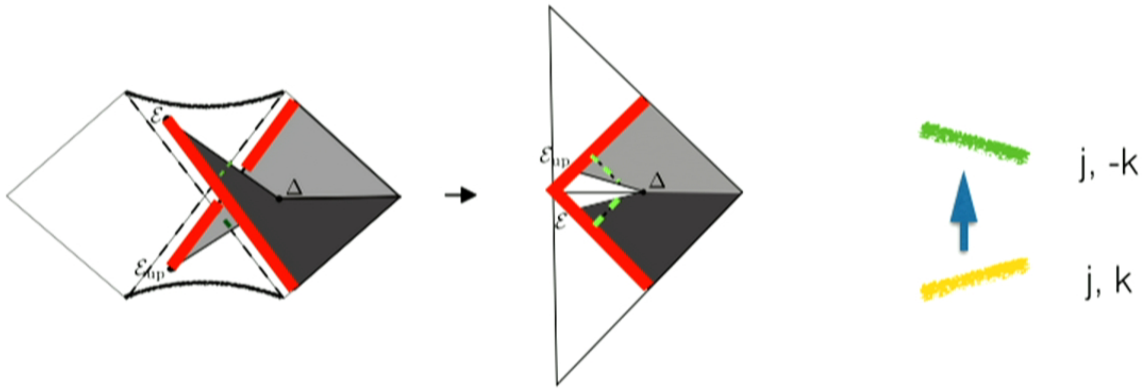


What do we expect of the bouncing time:

$$T = \begin{cases} \sim e^{m} & \text{Naive expectation from analogy with tunnelling in space} \\ \sim m^{3} & \text{Page time. Requiring that AMPS firewall are avoided} \\ \sim m^{2} & \text{Minimal failure of local qft: } RT > L_{Planck}^{-1} \\ \sim m \ln m & \text{Calculation from LQG, first contribution (too short!)} \end{cases}$$

Fast Radio Bursts and White Hole Signals
Aurélien Barrau, Carlo Rovelli, Francesca Vidotto.
Phys.Rev. D90 (2014) 12, 127503

- Covariant loop quantum gravity. Calculation of T(m).

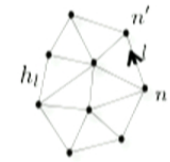


Covariant loop quantum gravity. Full definition.

Kinematics
Boundary

State space $\mathcal{H}_\Gamma = L^2[SU(2)^L/SU(2)^N]_\Gamma \quad \ni \psi(h_l) \qquad \mathcal{H} = \lim_{\Gamma\to\infty} \mathcal{H}_\Gamma$

Operators [cfr: Steve]: $\vec{L}_l = \{L_l^i\}, i = 1,2,3 \qquad L^i\psi(h) \equiv \frac{d}{dt}\psi(he^{t\tau_i})\Big|_{t=0}$

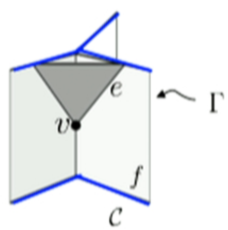


Γ spin network
(nodes, links)

Dynamics
Bulk

Transition amplitudes $W_\mathcal{C}(h_l) = N_\mathcal{C} \int_{SU(2)} dh_{vf} \prod_f \delta(h_f) \prod_v A(h_{vf}) \qquad W = \lim_{\mathcal{C}\to\infty} W_\mathcal{C} \qquad h_f = \prod_v h_{vf}$

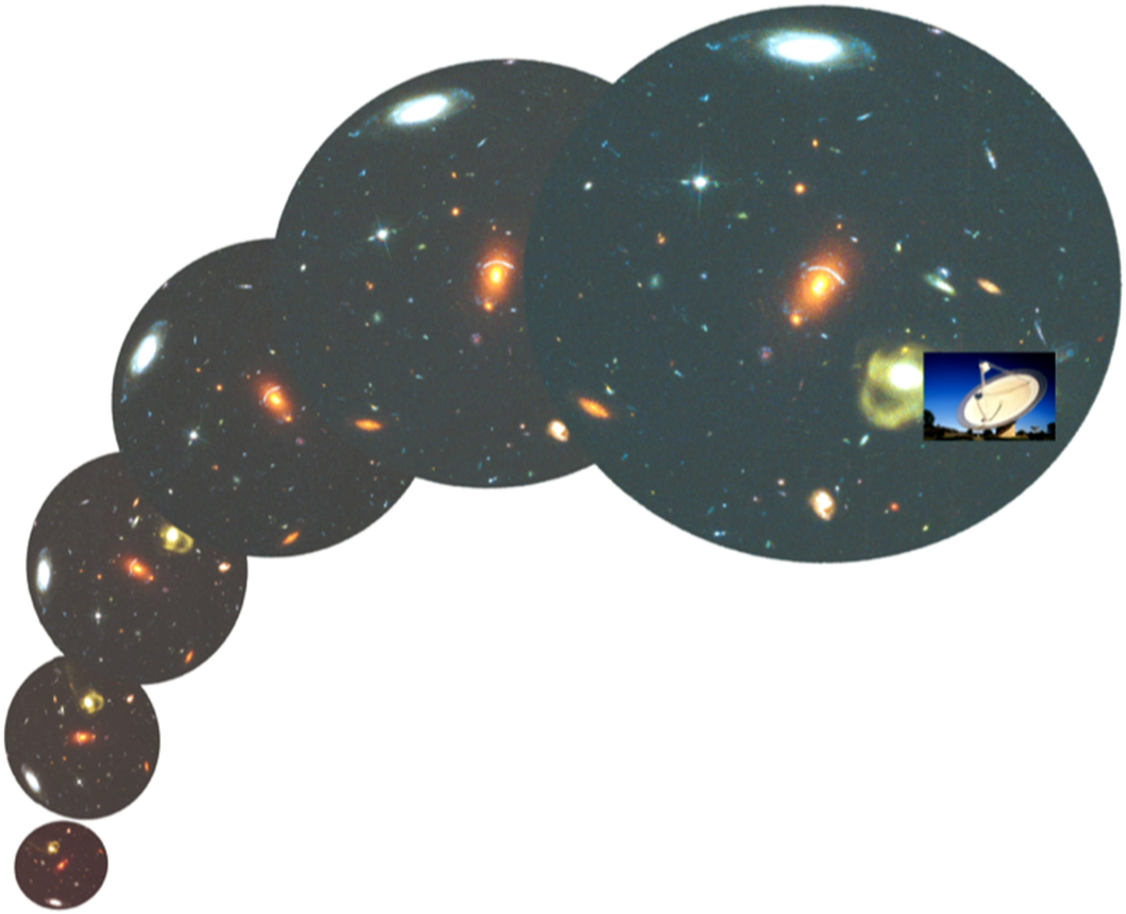
Vertex amplitude $A(h_{vf}) = \int_{SL(2,\mathbb{C})} dg'_e \prod_f \sum_j (2j+1)\ D^j_{mn}(h_{vf}) D^{\gamma(j+1)\,j}_{jmjn}(g_e g_{e'}^{-1}) \qquad 8\pi\gamma\hbar G = 1$



spinfoam
(vertices, edges, faces)

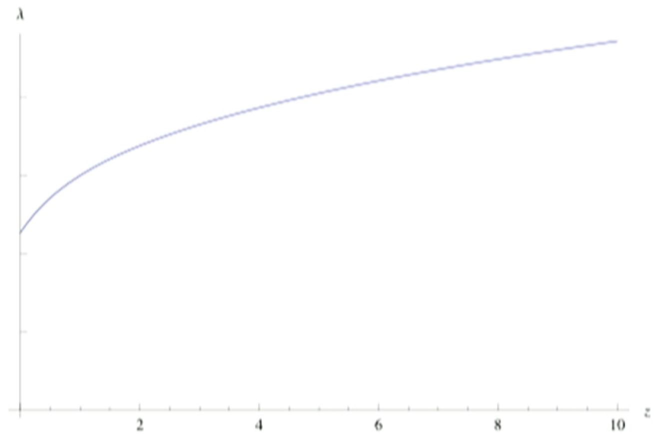
With cosmological constant:

SL(2,C) Chern-Simons Theory, a non-Planar Graph Operator, and 4D Loop Quantum Gravity with a Cosmological Constant
Hal M. Haggard, Muxin Han, Wojciech Kamiński, Aldo Riello.
arXiv:1412.7546



Signature: peculiar wavelength versus distance relation

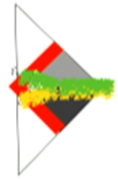
$$\lambda_{obs} \sim \frac{2Gm}{c^2}(1+z)\sqrt{\frac{H_0^{-1}}{6\,k\Omega_\Lambda^{1/2}}\ \sinh^{-1}\left[\left(\frac{\Omega_\Lambda}{\Omega_M}\right)^{1/2}(z+1)^{-3/2}\right]}.$$



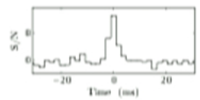
Summary

- Technical results: black holes may tunnel to white holes locally.

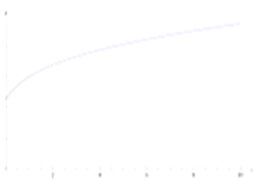
- The tunnelling time can in principle be computed with LQG.

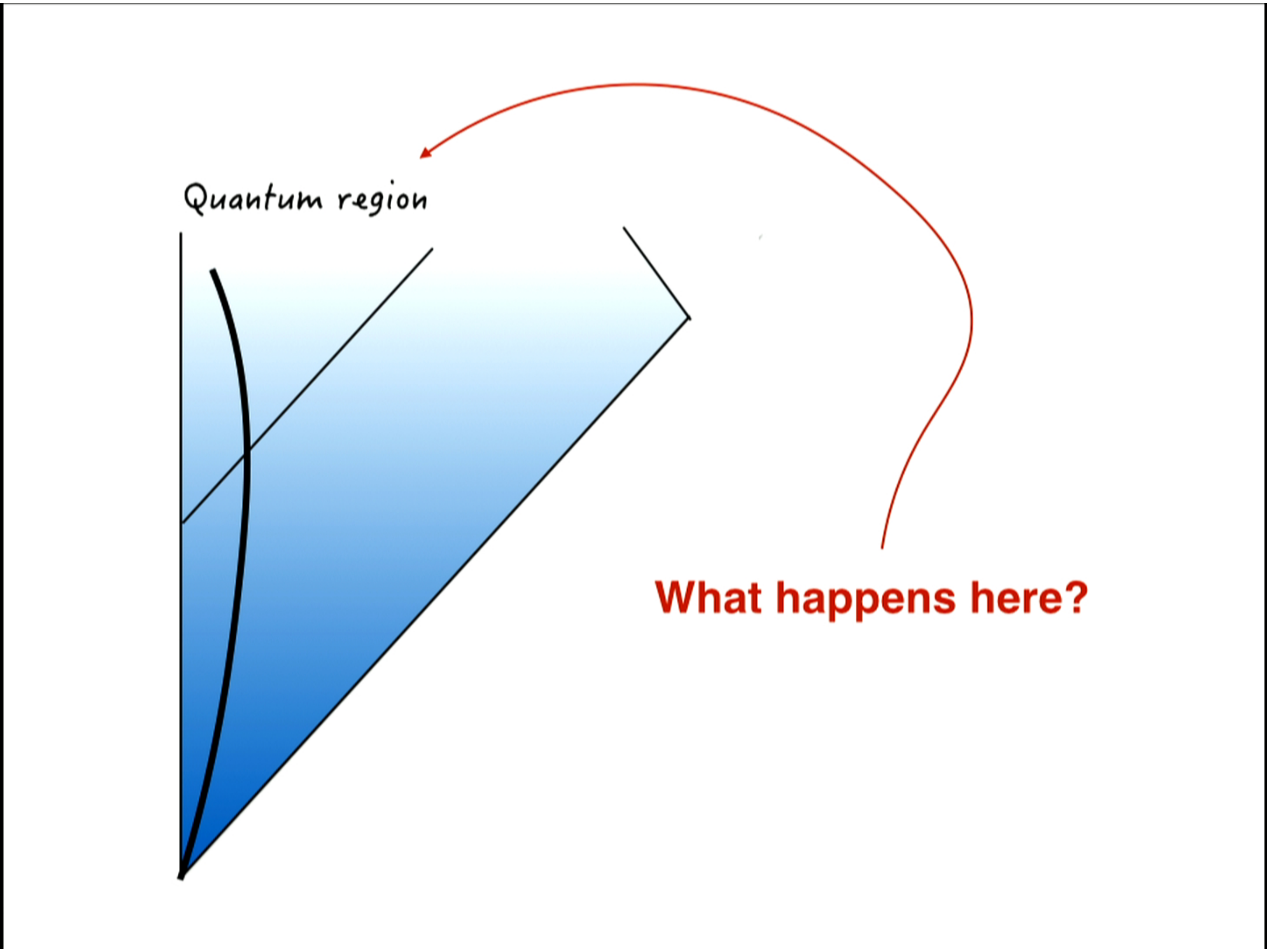


- Gamma-rays or Fast Radio Bursts possible phenomenology.



- Peculiar wavelength to distance signature.

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