Black hole fireworks

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In collaboration with Carlo Rovelli

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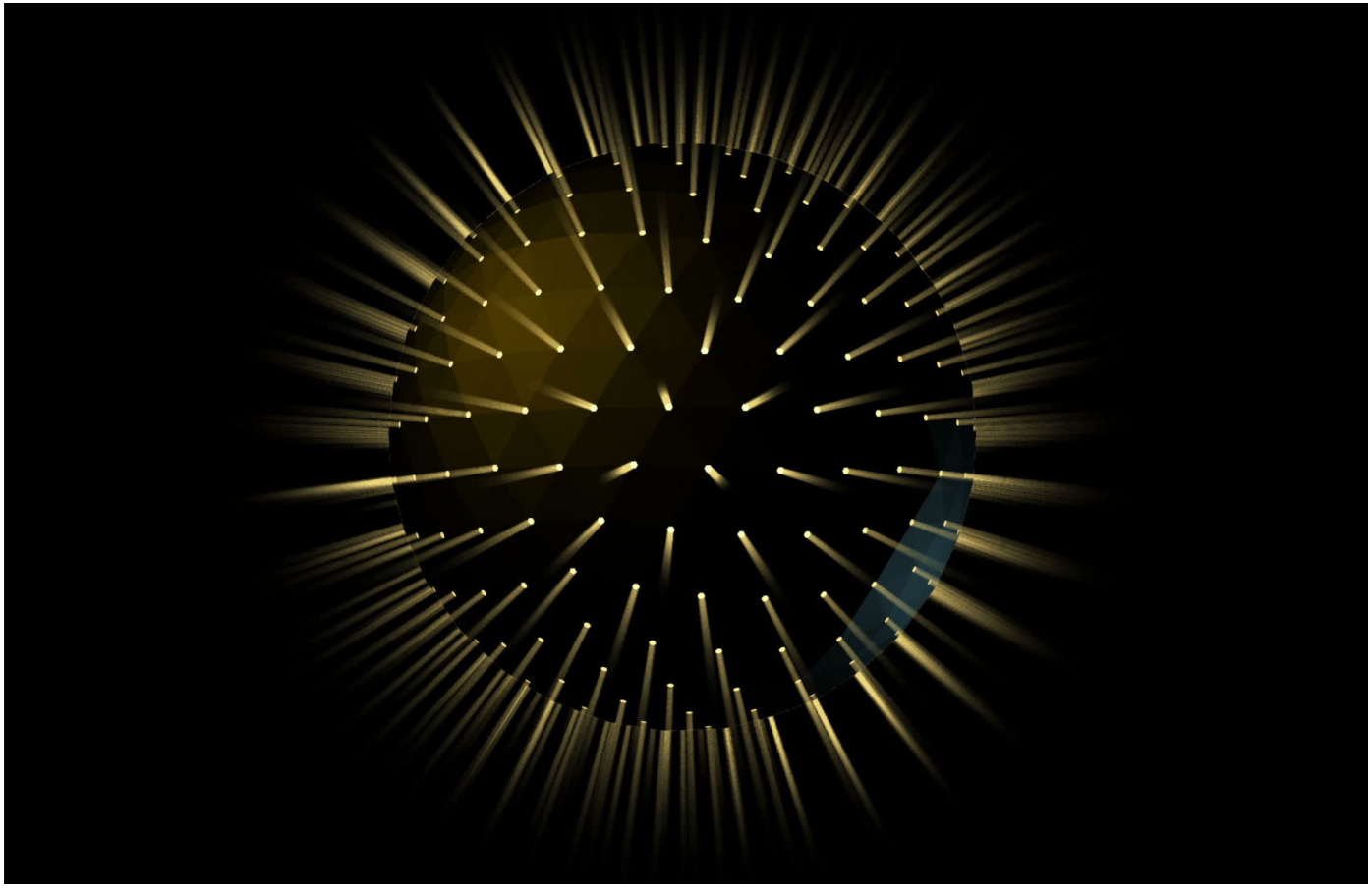
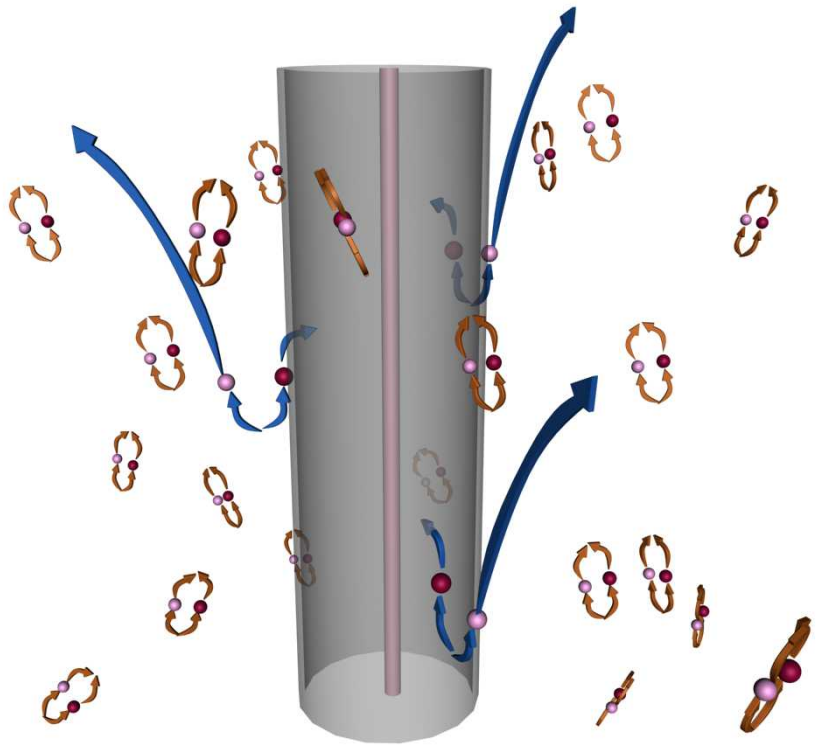
Quantum mechanics allows black holes to evaporate via Hawking radiation



Is this the only mode of evolution? Is it even the dominant one?

Hawking radiation

Because Hawking radiation is due to quantum tunneling we know that it must be slow. But how slow?



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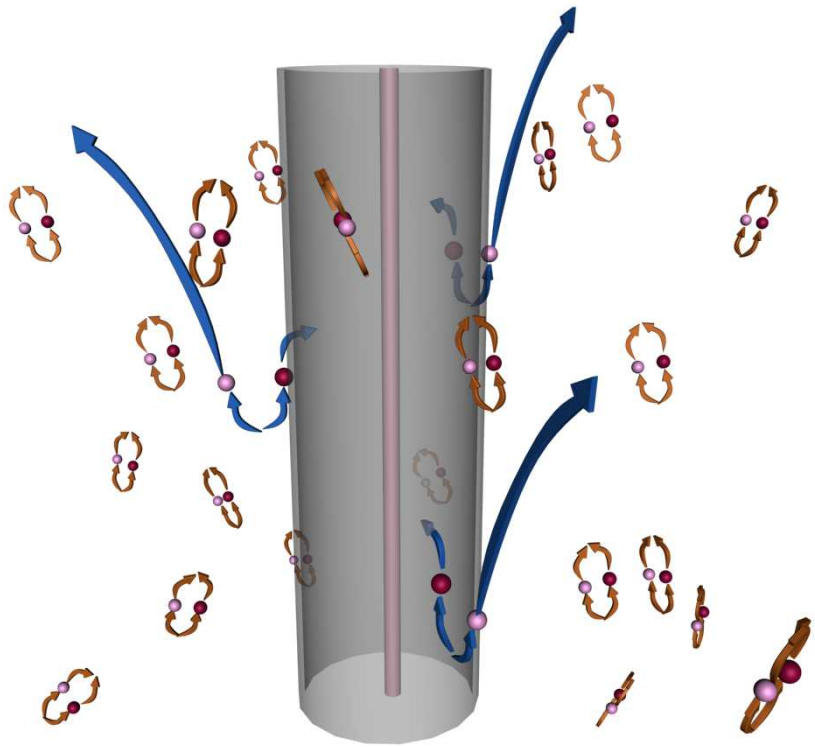
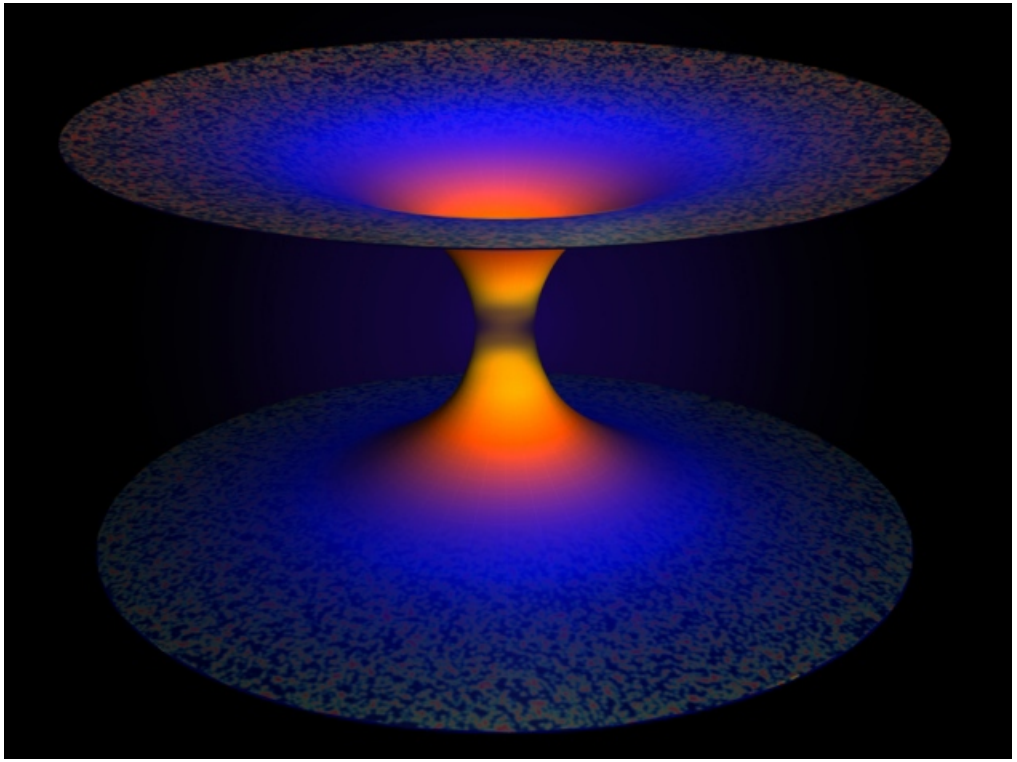


Very, very slow $T_H \sim M^3$. For a solar mass black hole it takes $T_H = 10^{75}$ secs. The age of the universe is $T_U = 10^{17}$ secs.

What happens to collapsing matter?

Small radii $\rightsquigarrow$ deep quantum regime. Does an effective quantum pressure develop, avoiding a singularity?

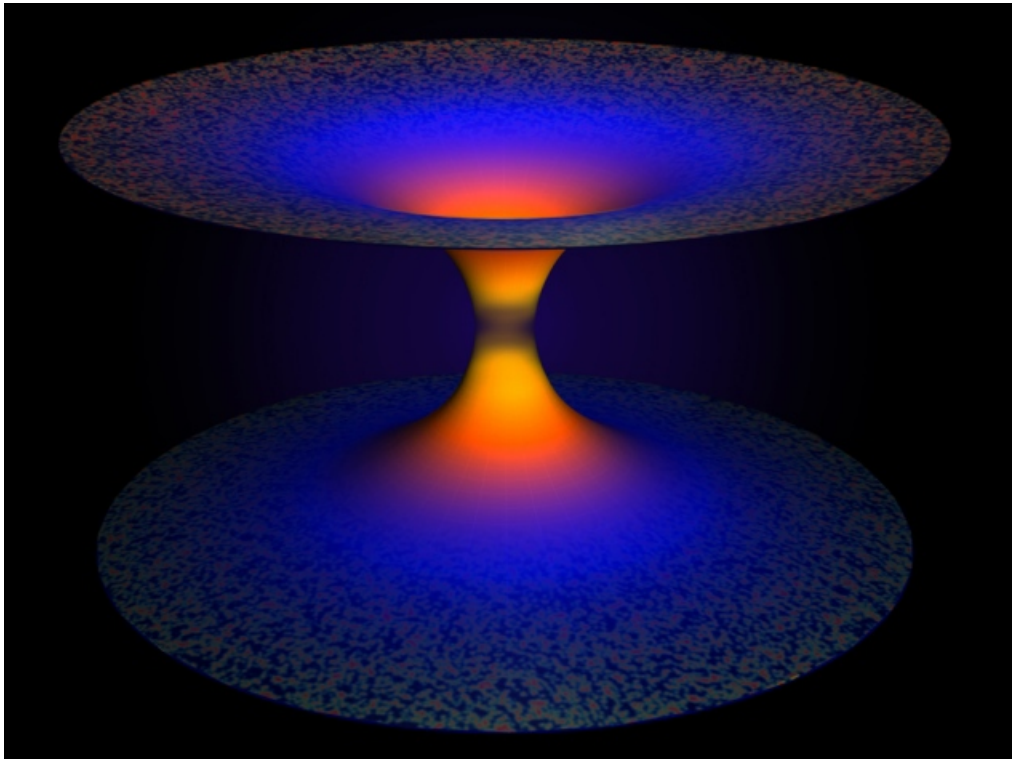
Could this "pressure" push the matter back out? This would be like a cosmological bounce.



$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho\left(1 - \frac{\rho}{\rho_{\mathsf{Pl}}}\right)$$

Bounce?

Hawking radiation focuses attention on the matter—what about the geometry?

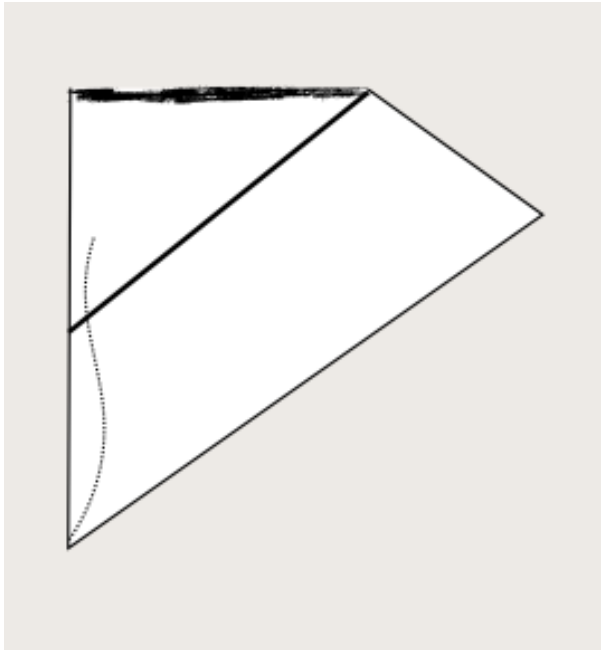


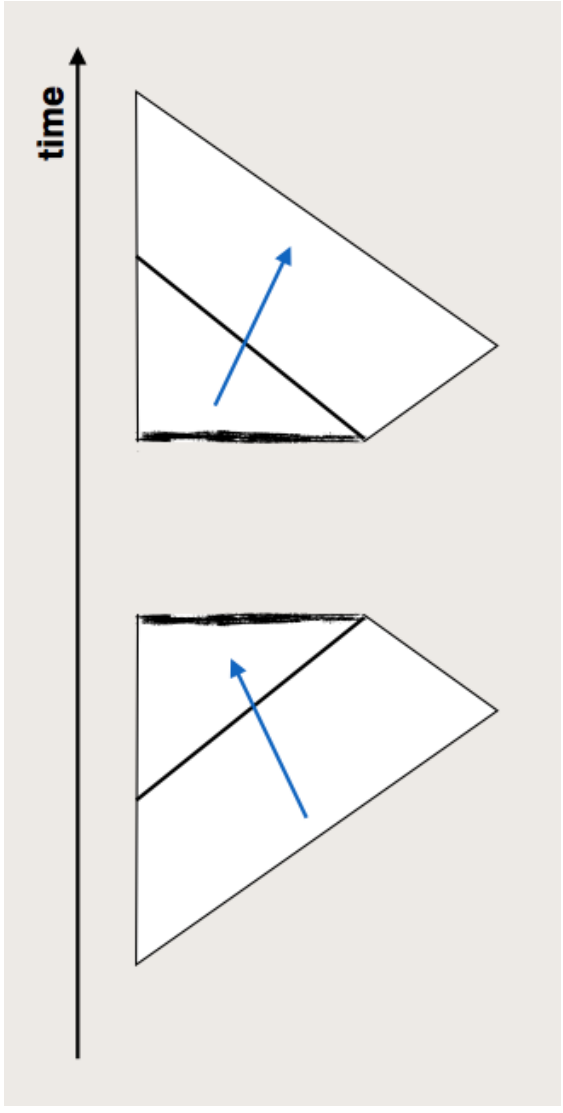
Our ideas:

- E is conserved at $\infty \rightsquigarrow$ elastic bounce
- ♦ Neglect Hawking radiation
- ♣ Quantum process $\rightsquigarrow$ tunneling of geometry Begins outside horizon
- GR is time reversal invariant—black to white hole bounce

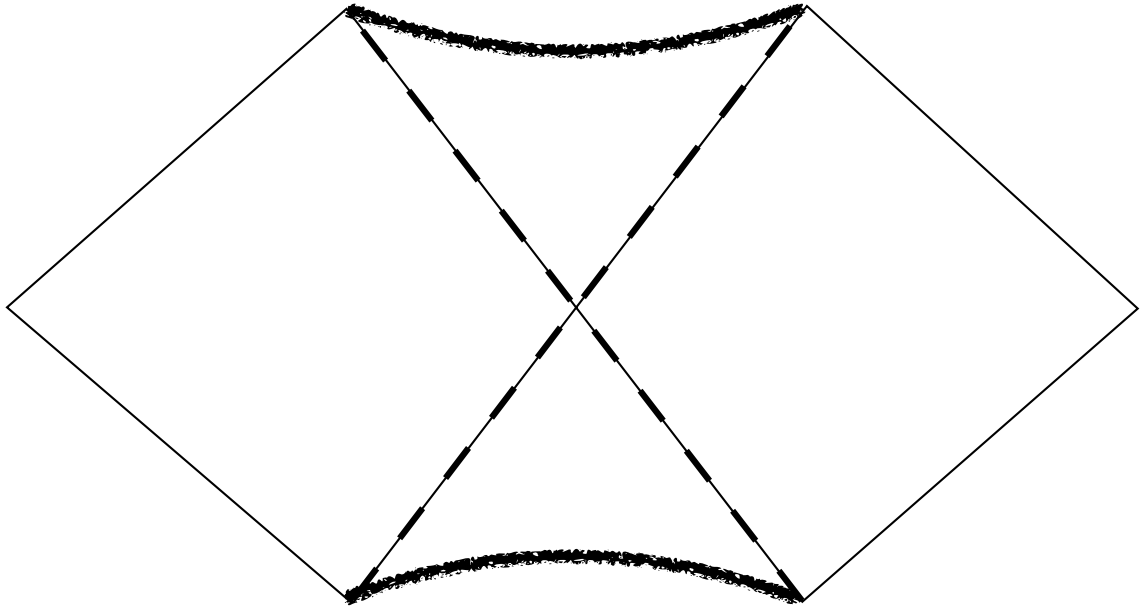
Let's try to build a solution of Einstein's equations where collapsing matter bounces back out.

- Idea: glue a black hole to a white hole.





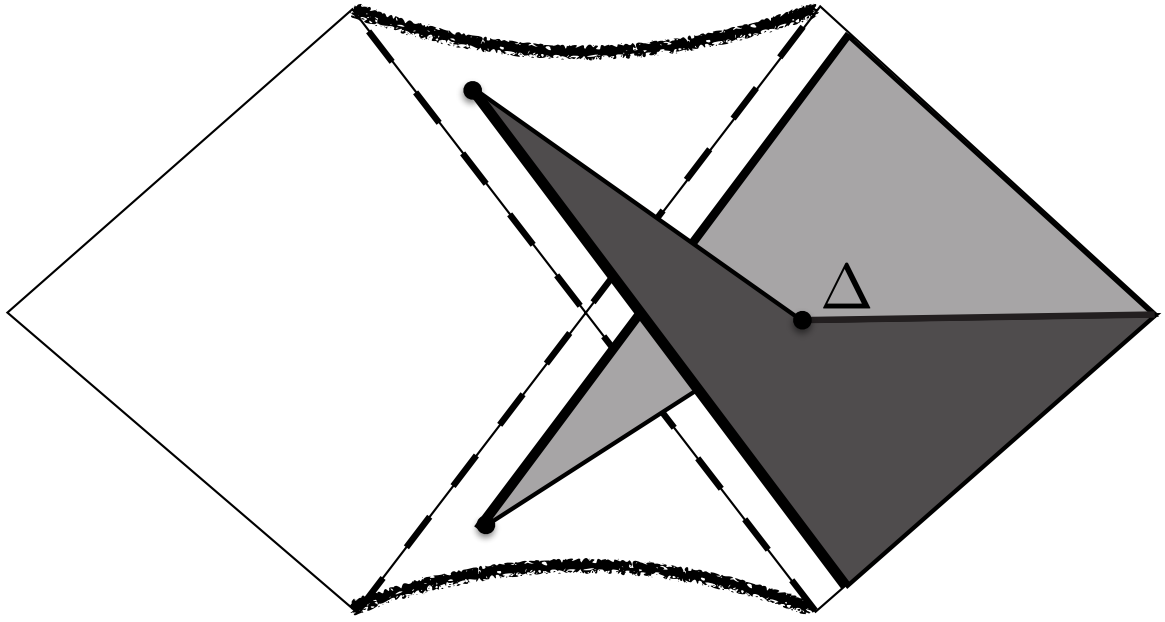
A glued version of these two space times exists



but it's upside down.

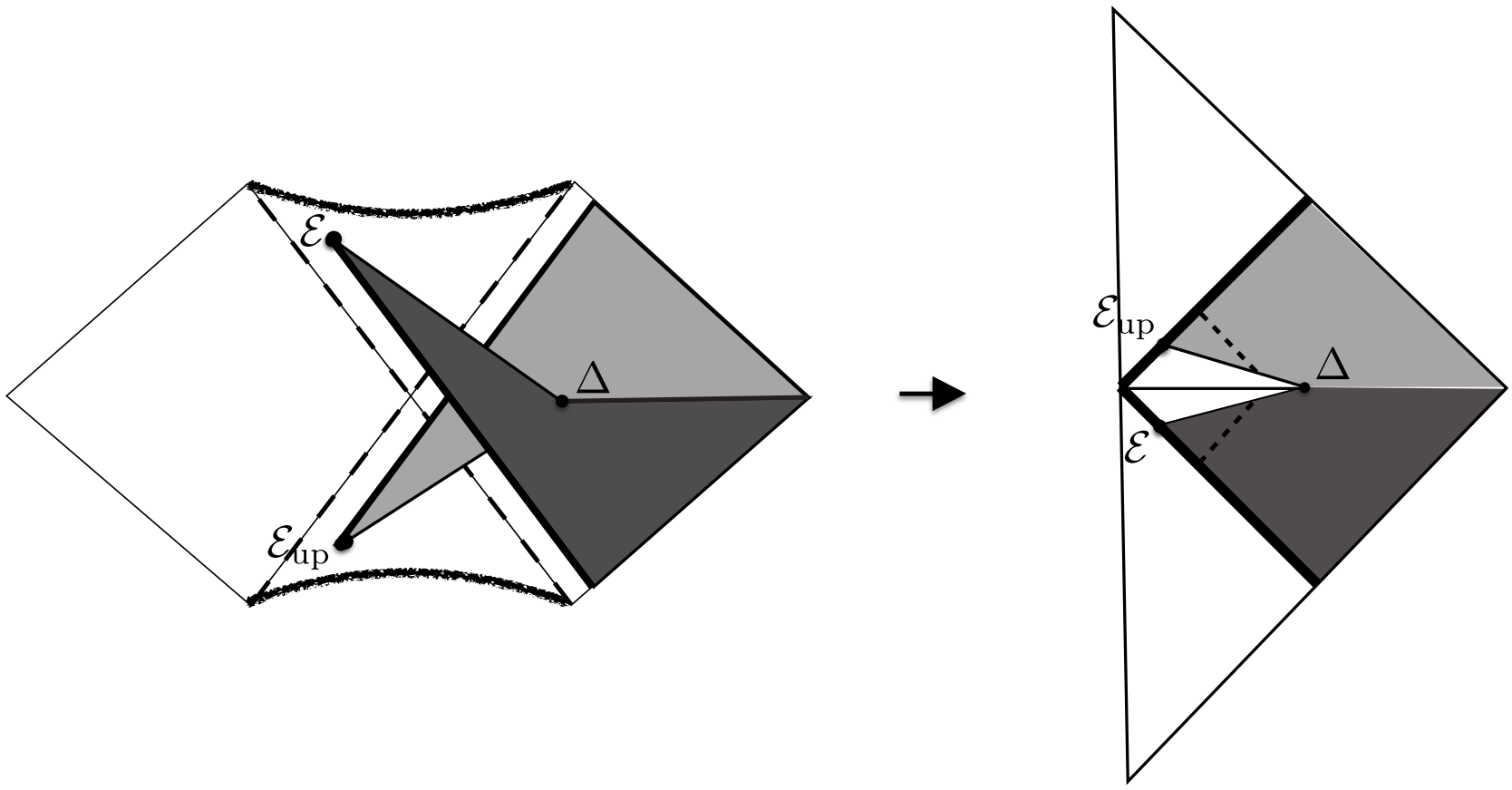
Let us cut it up.

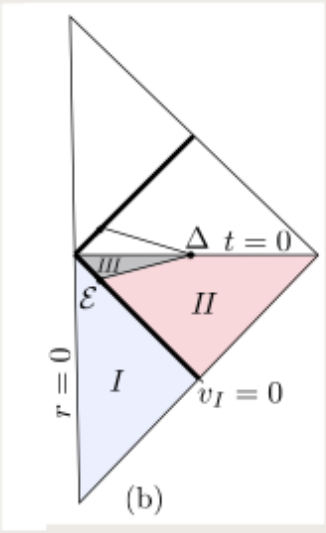
Use the crossed fingers —



... and sew in a quantum region...

The spacetime





Full metric: join the pieces

Spherical symmetry:

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

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

Bounded by: $v_I < 0.$

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

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

Conclusions

- Collapsing matter bounces in a short time locally but a long time from far away, $\sim M^2$.
  Solar mass: $\tau_q \sim 10^{32}$ sec, $\tau_H \sim 10^{75}$ sec, $\tau_U \sim 10^{17}$ sec.

- Possible to describe using a metric with no singularity, two trapped regions, and all matter exiting $\rightsquigarrow$ all info escapes

- Could a black hole be a bouncing star seen in super slow motion? With the constructed metric we can attack this question rigorously.

- I want to calculate the WKB amplitude for a gravitational instanton giving this bounce process; now I can in principle!