Sunny Itzhaki

The 5th Indian-Israeli conference on strings

That is based on something: 1808.02259 and 1811.12117 with Karinne Attali

and work in progress with Amit Giveon and David Kutasov

Related also to

Lior Liram’s

later today.

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and work in progress with Amit Giveon and David Kutasov

The question that we wish to ask is:

What are black holes made of?

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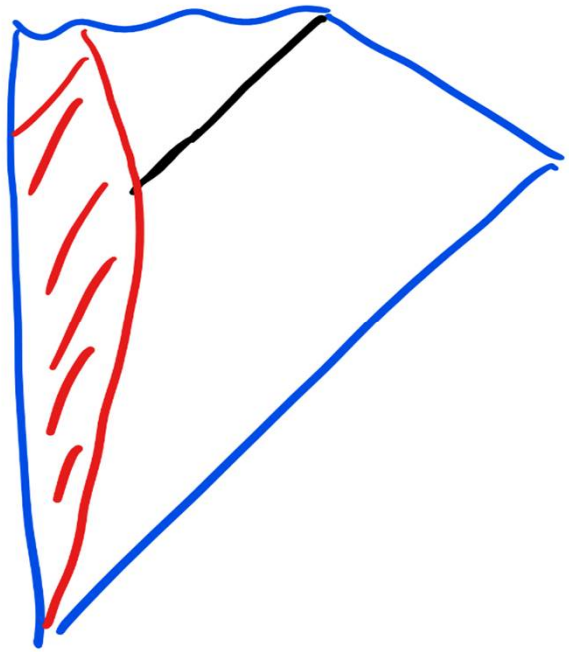
In GR the answer is: nothing

The BH is empty.



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A comment:

This answer is very much related to the BH info puzzle.

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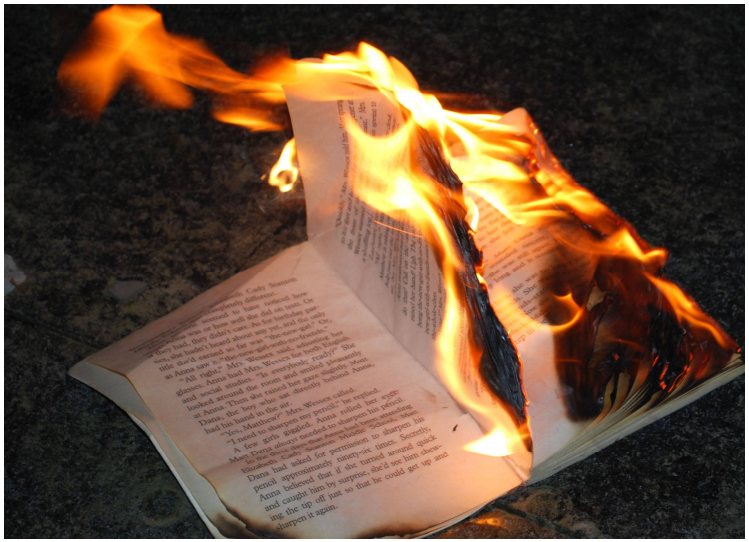
When something is burned info

is lost in practice, but not in principle.



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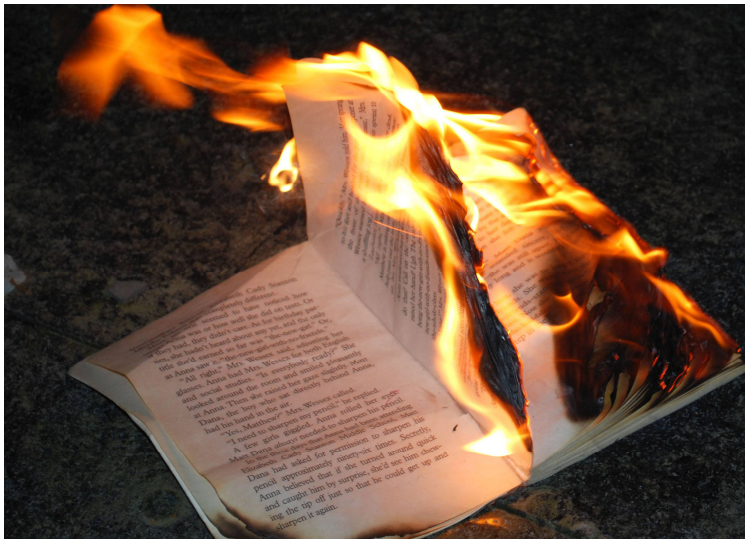

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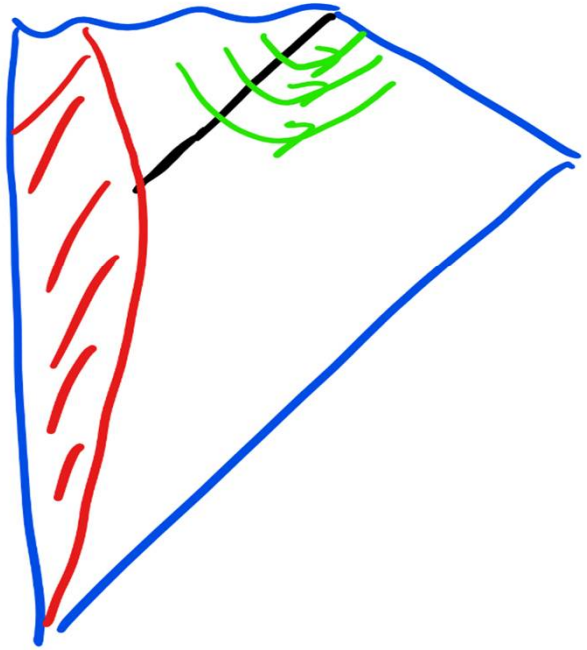

What are black holes made of?

In GR the answer is: nothing. The BH is empty.

There is a simple argument why we expect this

to be the answer in quantum gravity (whatever that is):

everything falls to the BH.

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1. Black NS5-branes are filled with folded strings.

2. We'll see why they don't fall to the BH.

Our starting point is an observation due to Maldacena about long strings in

linear dilaton backgrounds (his motivation was a different aspect of BH physics).

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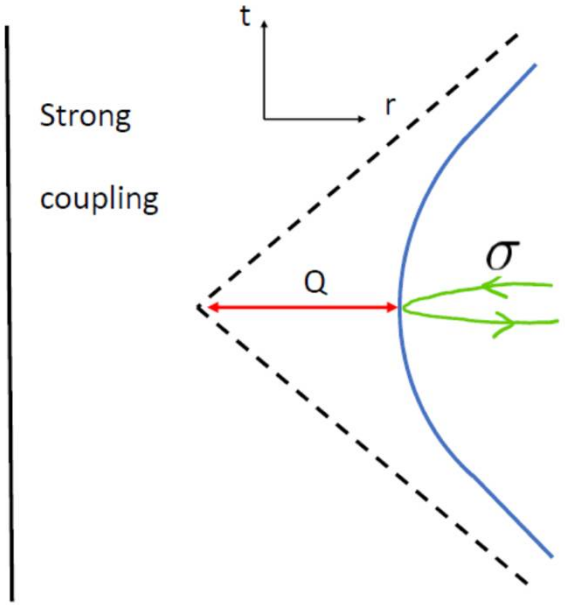

- Can fold only towards weak coupling.

No short strings.

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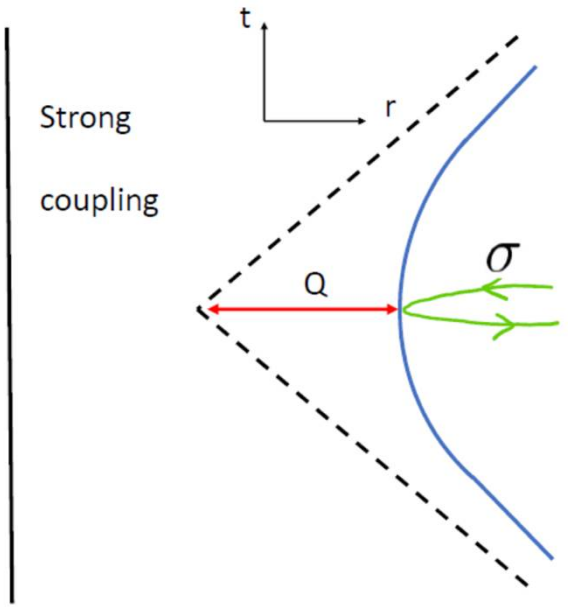
- The length scale is Q .

(compared with the perturbative length scale 1/Q)



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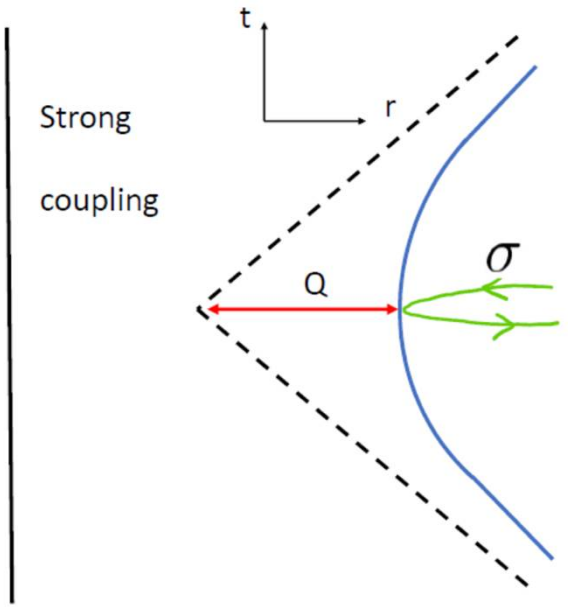

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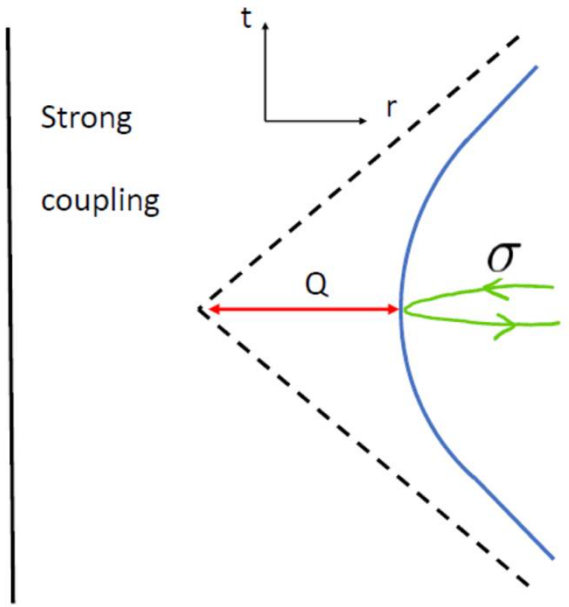

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No short strings whenever we have

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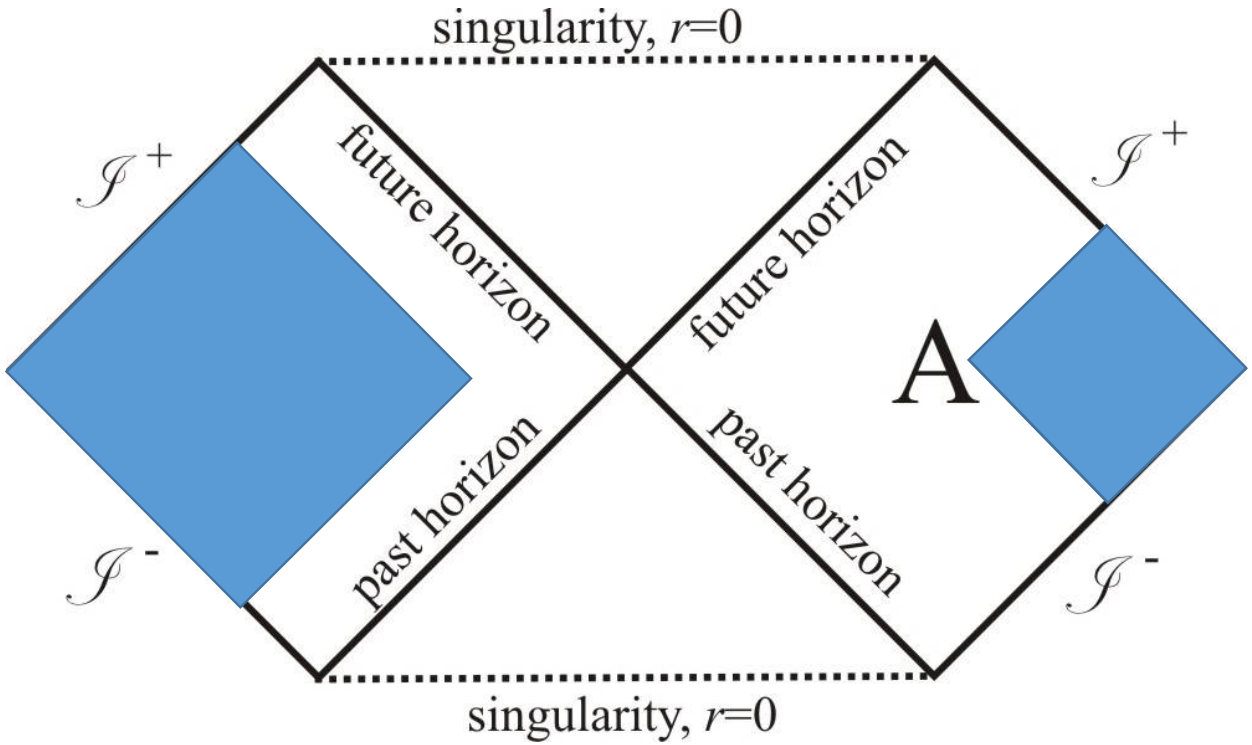
For example: black NS5-branes

that are described by SL(2)/U(1) CFT

The folding is local.

No short string outside the $SL(2,\mathbb{R})_k/U(1)$ BH.

$$ds^2 = -f(r)dt^2 + \frac{dr^2}{f(r)}, \qquad \Phi(r) = \phi_0 - Qr$$



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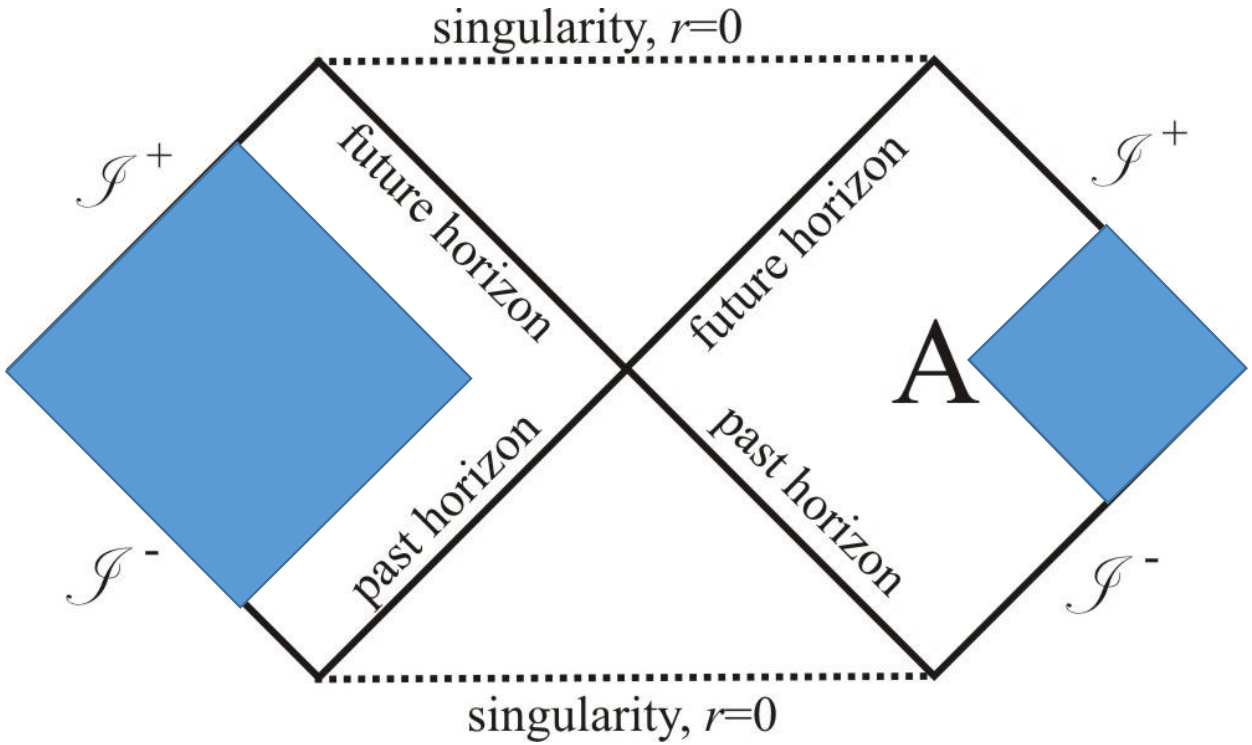

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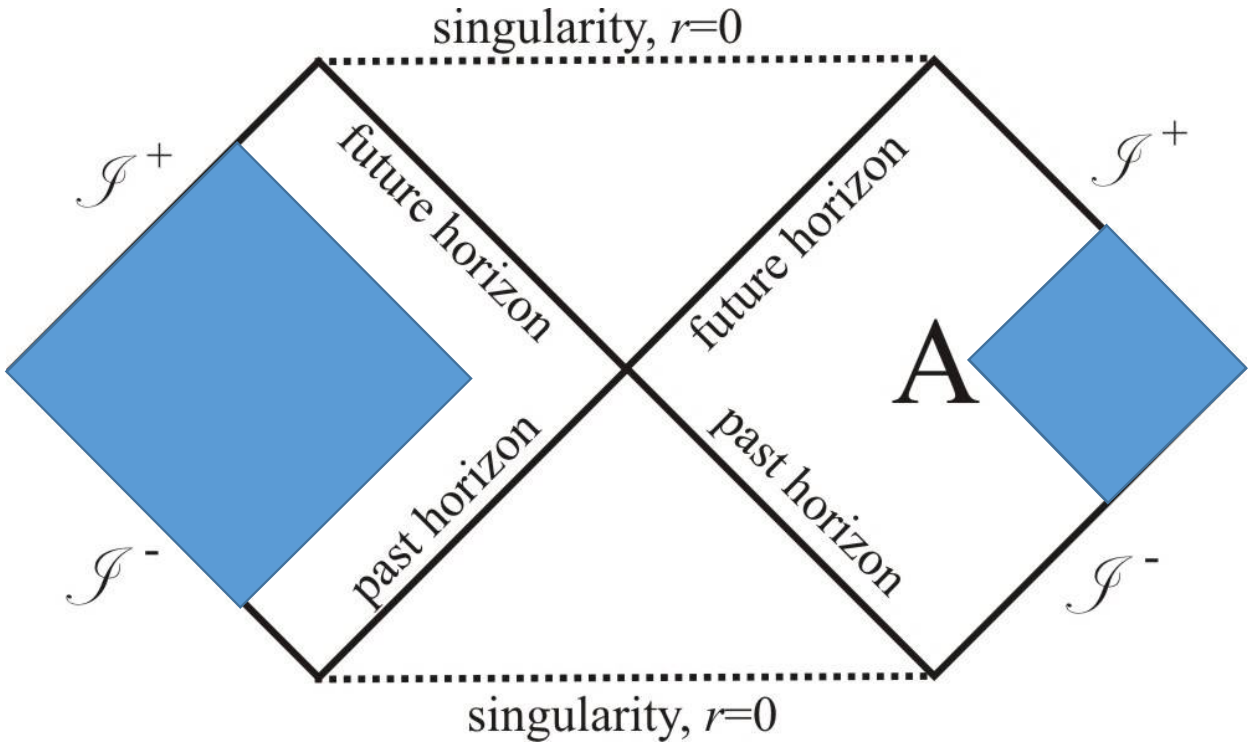
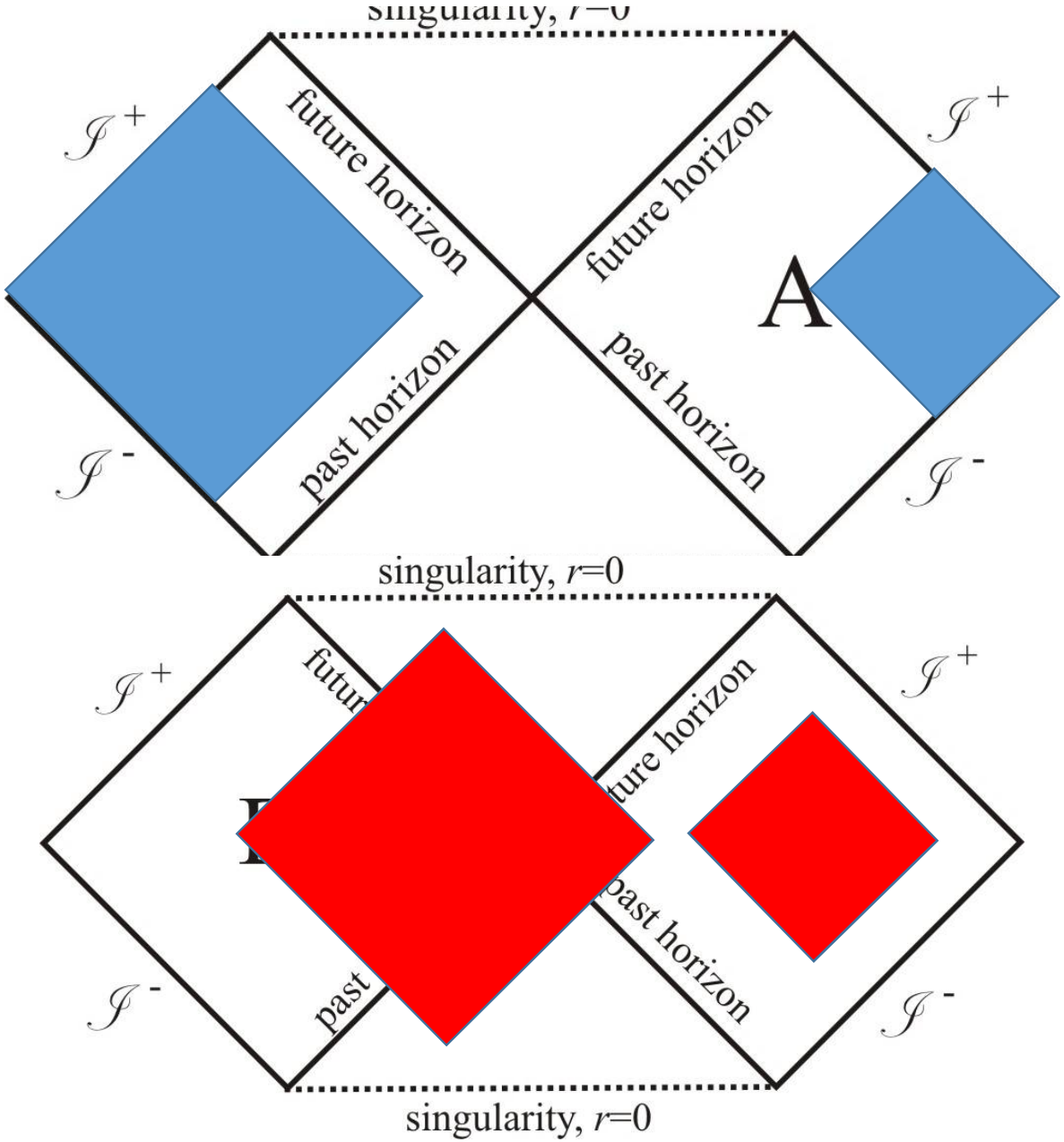
- k is the # of NS5-branes and $Q = 1/\sqrt{k}$.
- The string can fold (for large k) only away from the BH.





- No short string.
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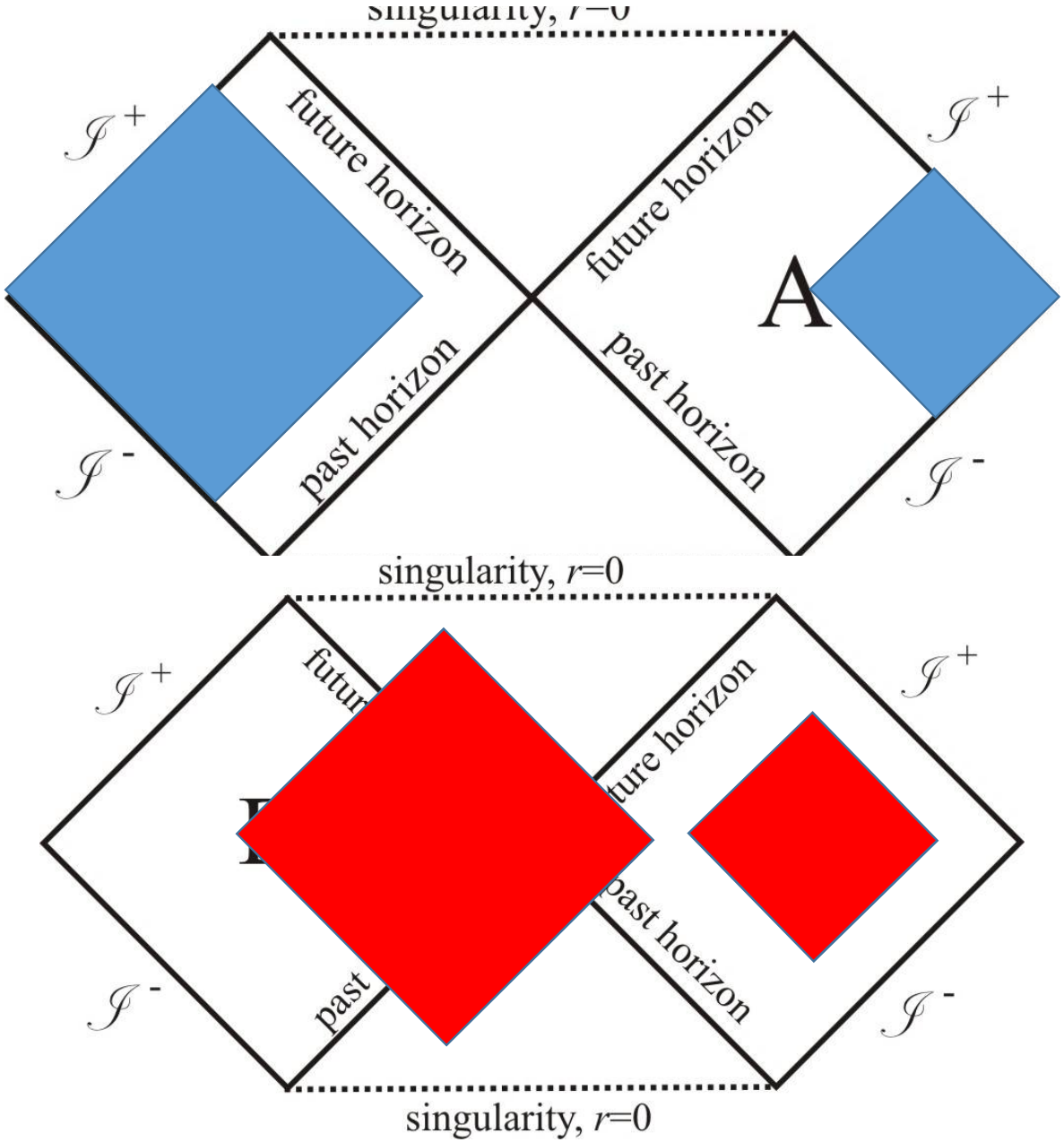

What about inside the BH?

- No short string.
- No finite energy folded strings outside the SL(2)/U(1) BH.

What happens inside the BH?

We have a time like linear dilaton $ds^2 = -(dX^0)^2 + (dX^1)^2, \quad \Phi = QX^0.$

Now the classical solutions is

$$X^0 = x^0 + Q \log\left(\frac{1}{2}\left(\cosh\left(\frac{X^1 - x^1}{Q}\right) + \cosh\left(\frac{\tau}{Q}\right)\right)\right).$$

What happens beyond the horizon?

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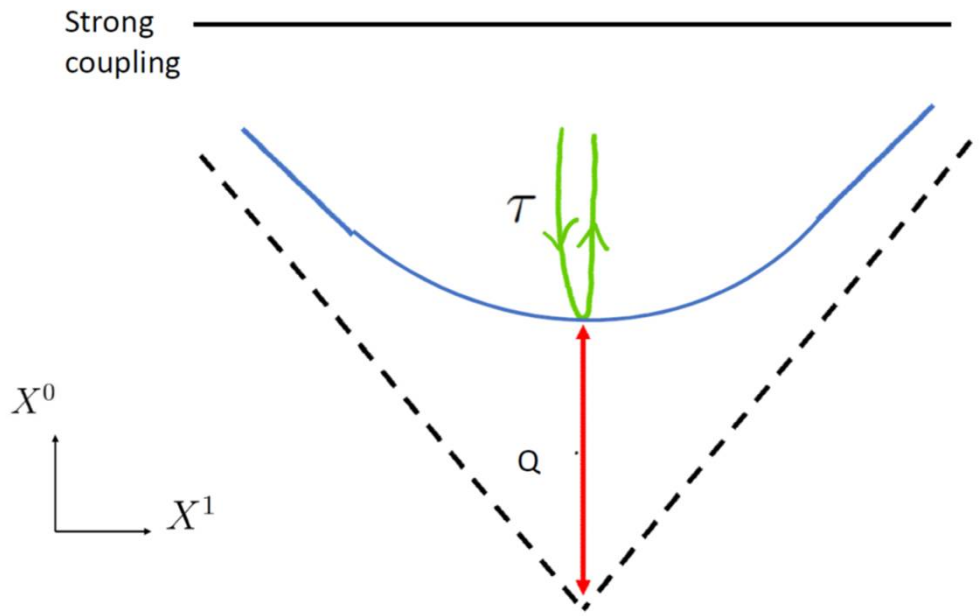

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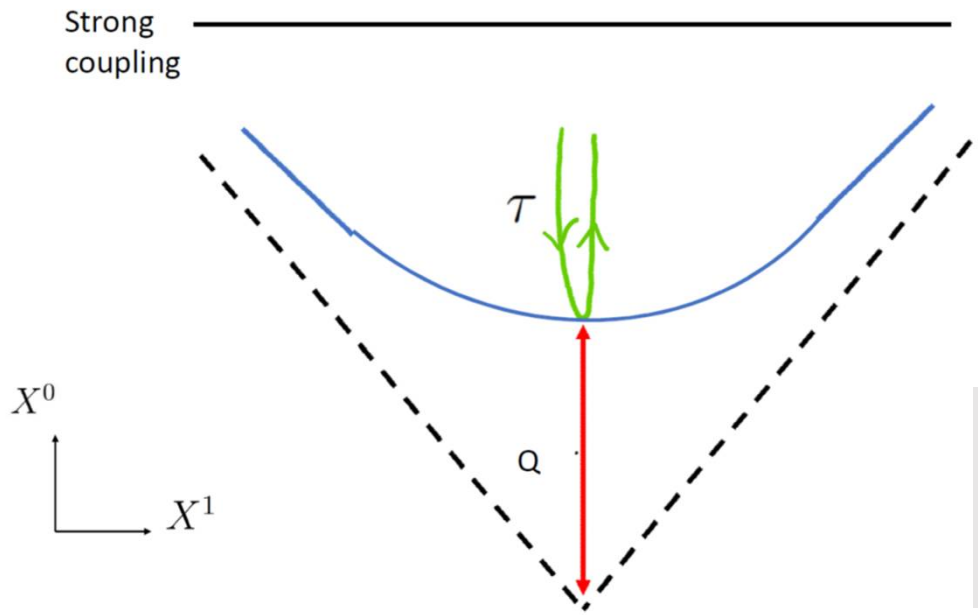
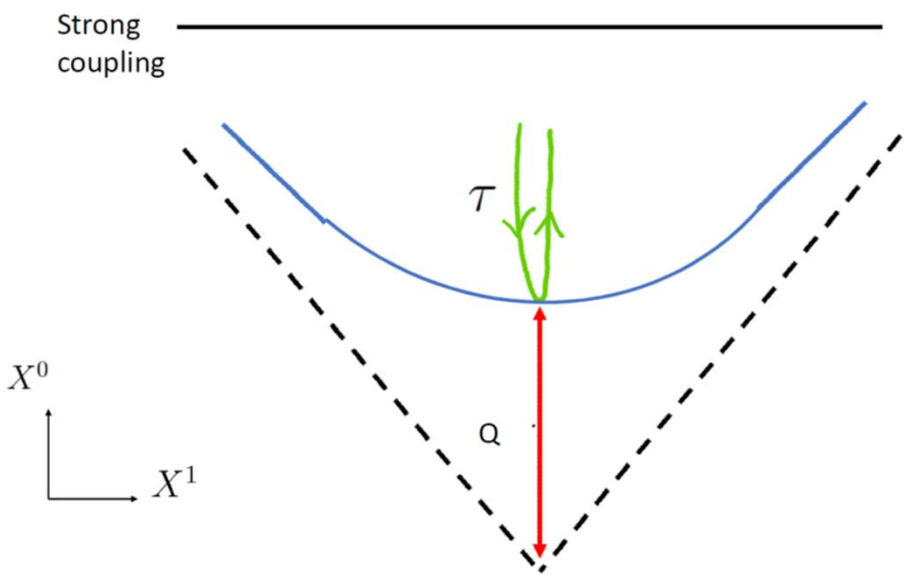
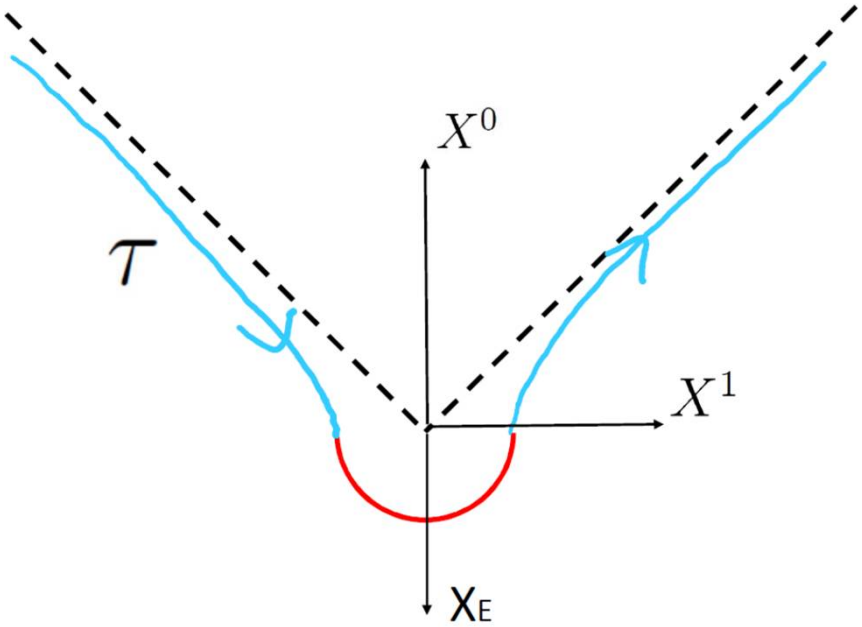


A closed (folded) string is created at a certain point in space-time.

Very different than standard spontaneous creation.

Comparison to the Schwinger mechanism





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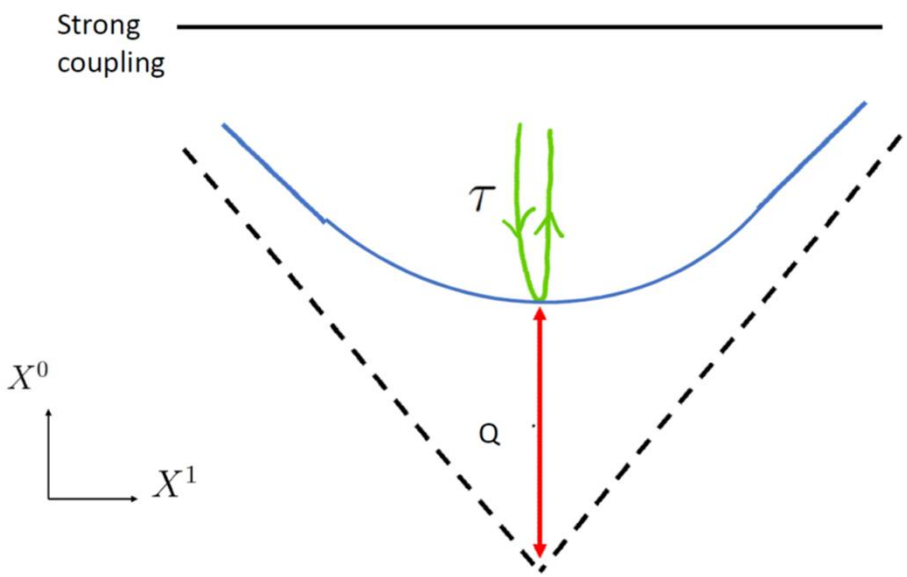

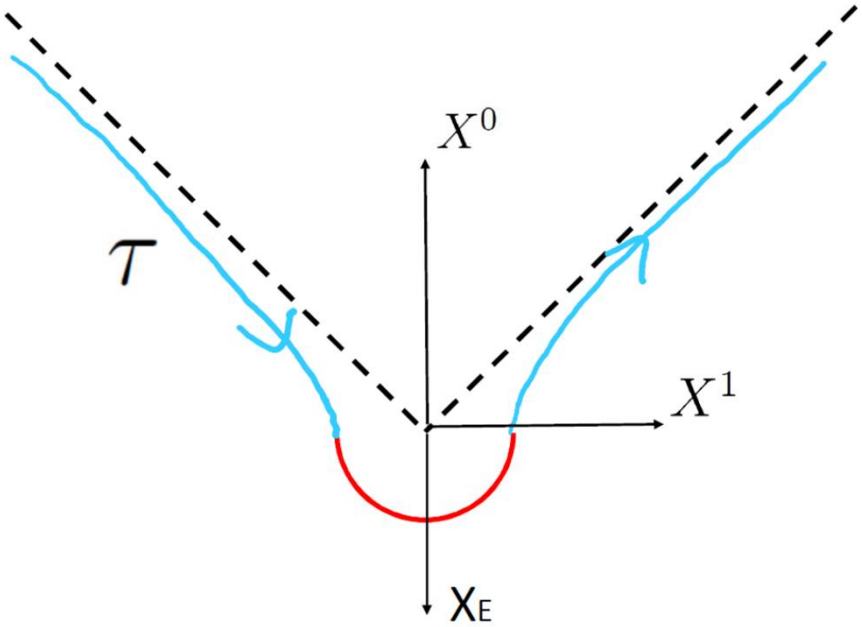

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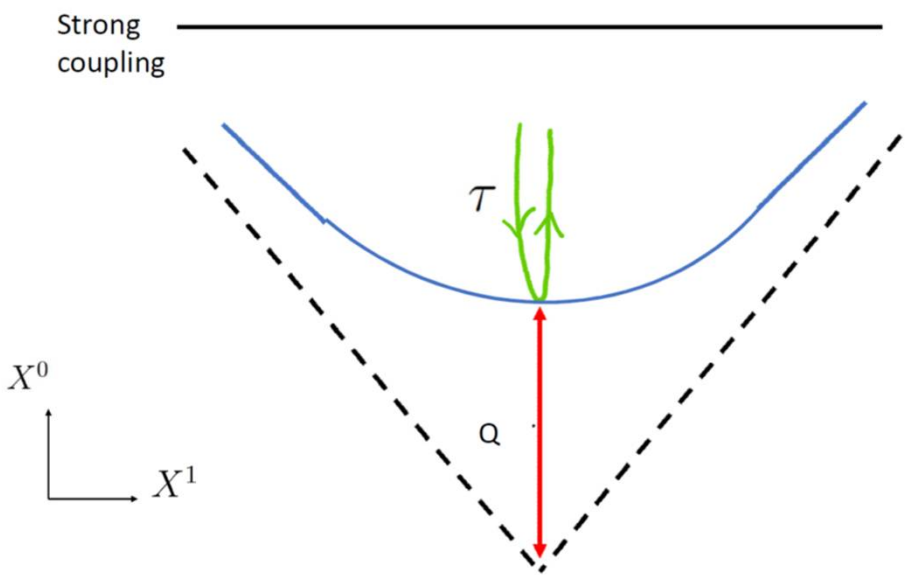

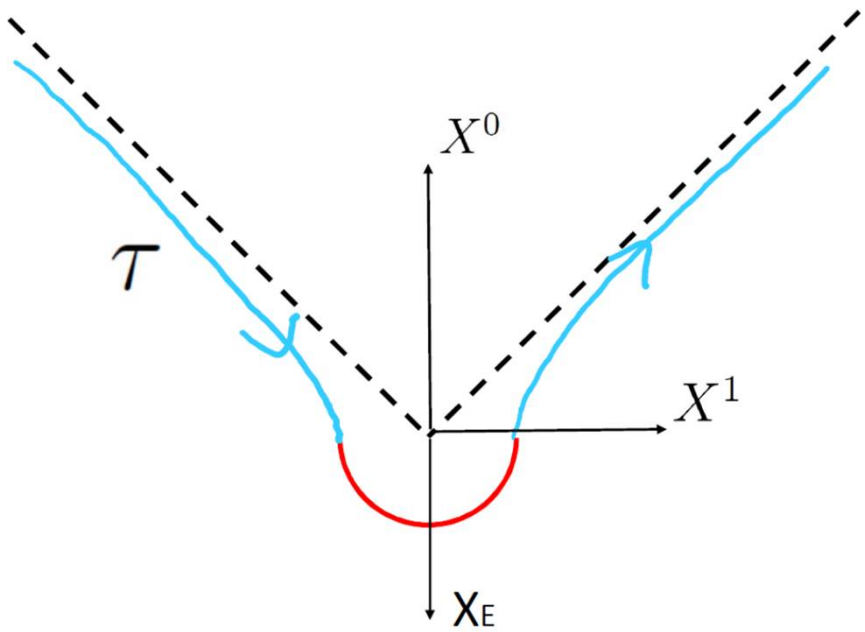

- Classical solution in Min. space ➡ no tunneling ➡ no exp. suppression.

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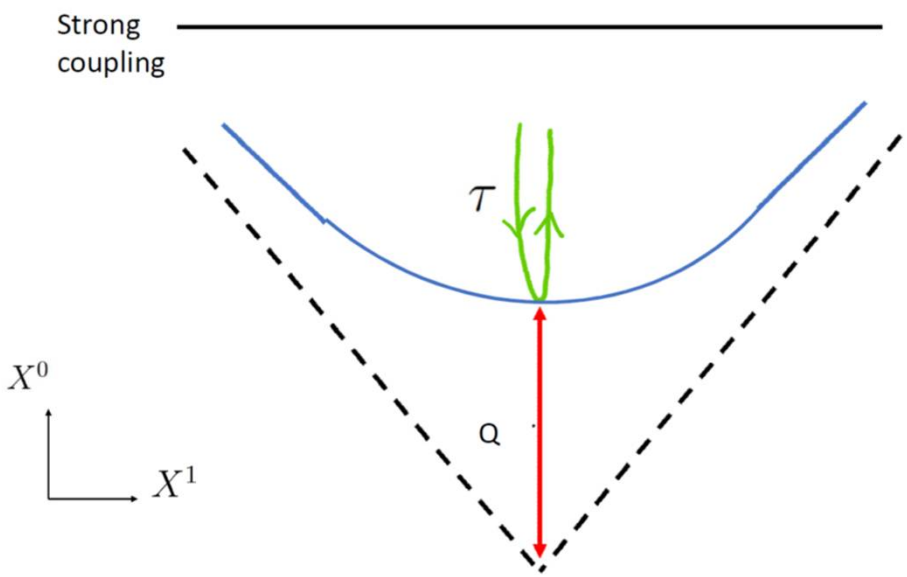

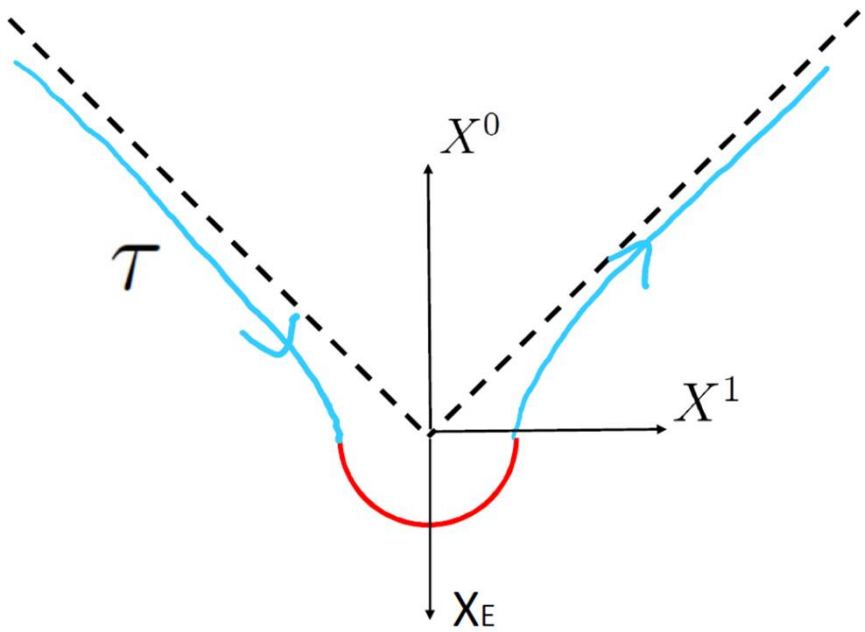

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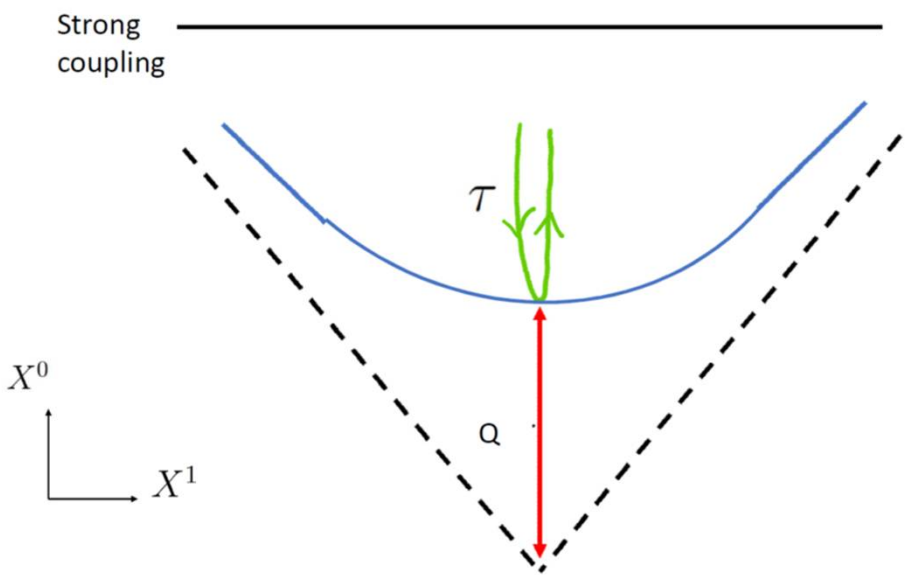

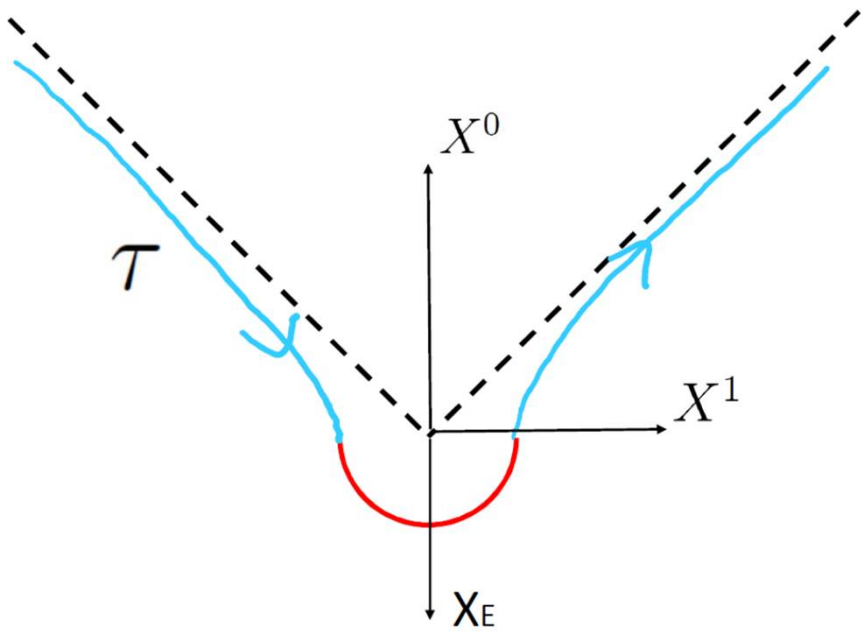

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- No suppression in the string coupling constant either.
- The point where the string folds is traveling faster than light.

So we have a lot of these folded strings, but what can we say about them?

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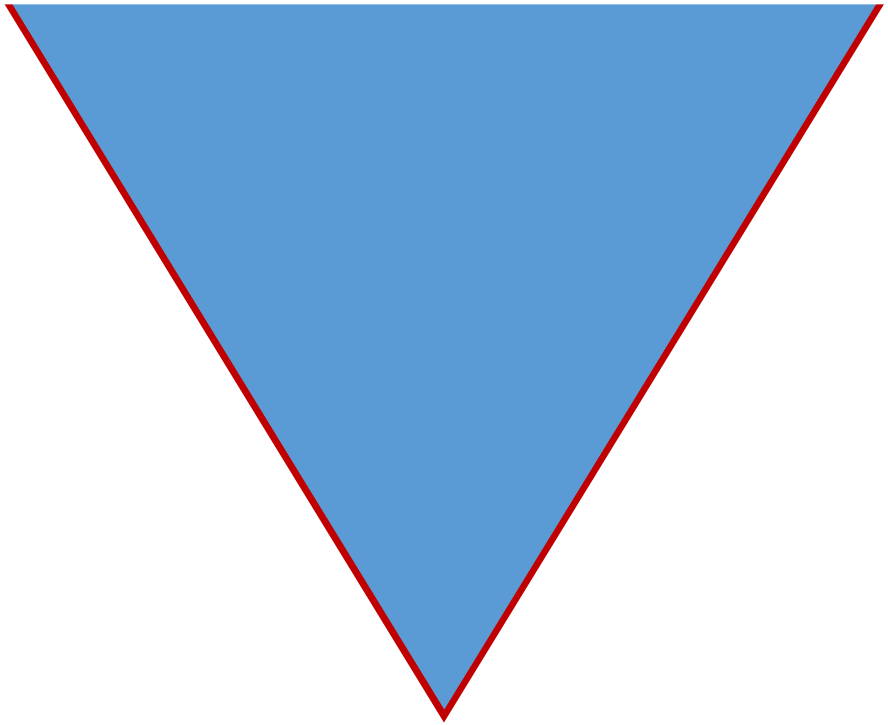
Since they are created at a certain point in space-time their total energy (and momentum)

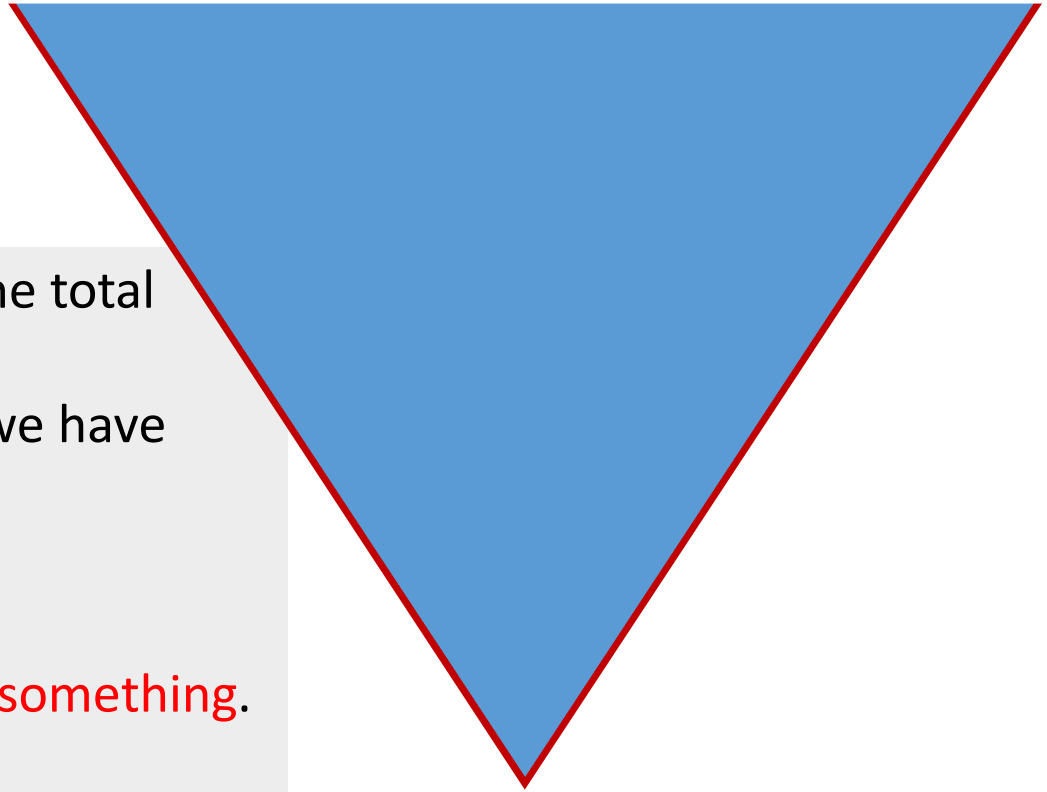
must vanish. Indeed

$$T^{00} = \frac{1}{2\pi\alpha'} \frac{-4\cosh\left(\frac{x-x_0}{Q}\right) + 4e^{\frac{t-t_0}{Q}}}{\sqrt{-1 + \left(2e^{\frac{t-t_0}{Q}} - \cosh\left(\frac{x-x_0}{Q}\right)\right)^2}}$$



and E=0 .

Total energy vanishes



Normally when the total energy vanishes we have nothing.

But this is clearly something.

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In short: they violate the ANEC.

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They do so in the right way (as if they know they have to solve the BH info puzzle).

Two minutes about the Averaged Null Energy Condition (ANEC):

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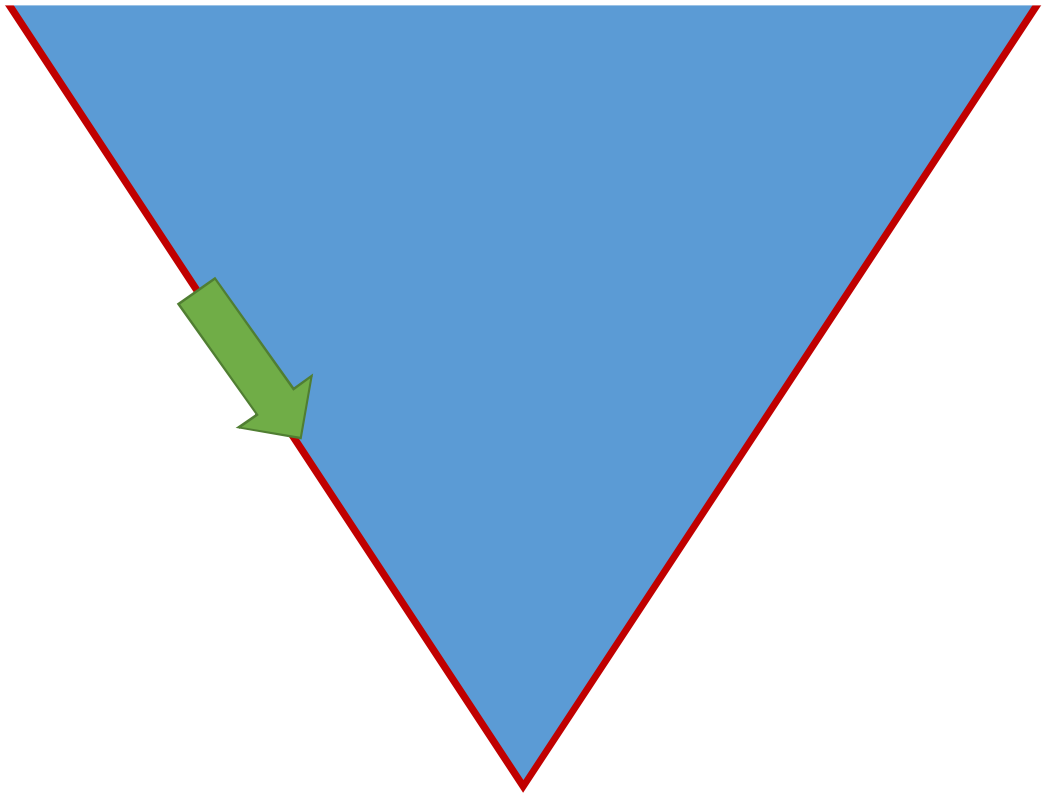
It is the statement that

$$\langle \Phi | \int du T_{uu} | \Phi \rangle \geq 0,$$

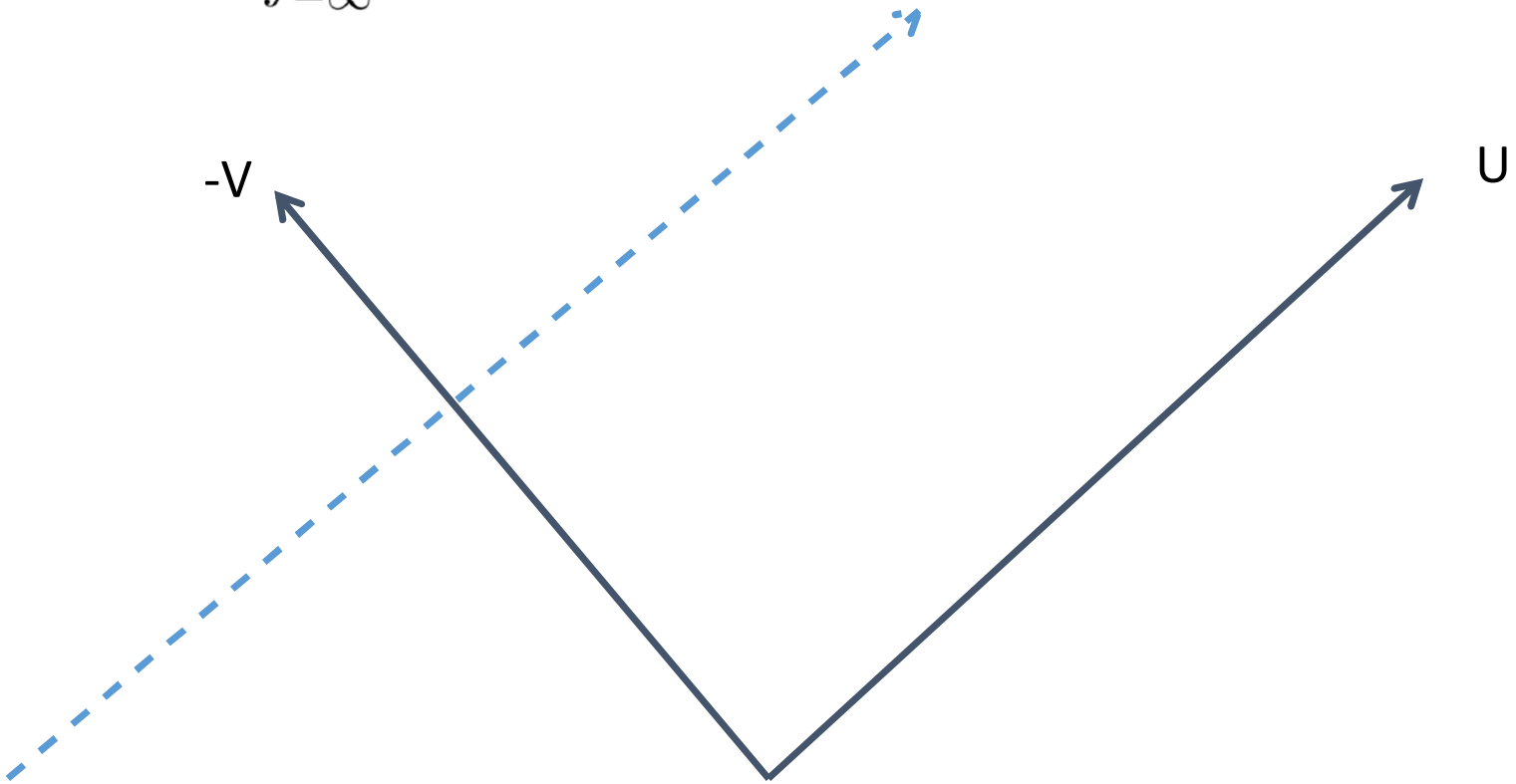
Useful in QFT (where it can be proved) and is sufficient to prove various fundamental properties of BH and Cosmology. For example that the BH is empty.

$$T_{uu} = \frac{1}{2\pi\alpha'} \frac{-e^{-\frac{x-x_0}{Q}}}{\sqrt{-1+\left(2e^{\frac{t-t_0}{Q}} - \cosh\left(\frac{x-x_0}{Q}\right)\right)^2}} < 0$$



Same with ANEC

$$\int_{-\infty}^{\infty} du\, T_{uu} = (v - Q\log(4)) < 0$$



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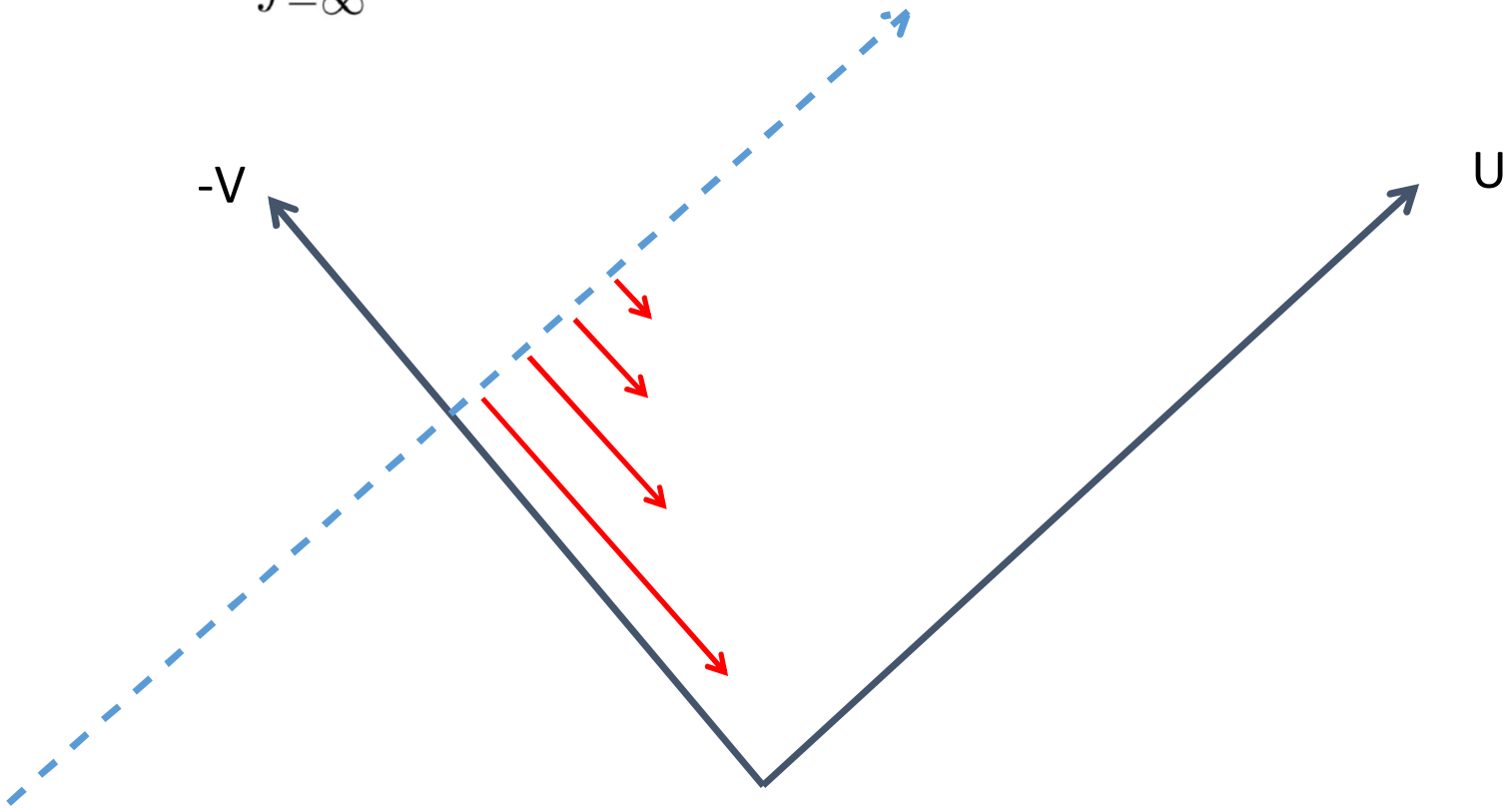

What about causality?

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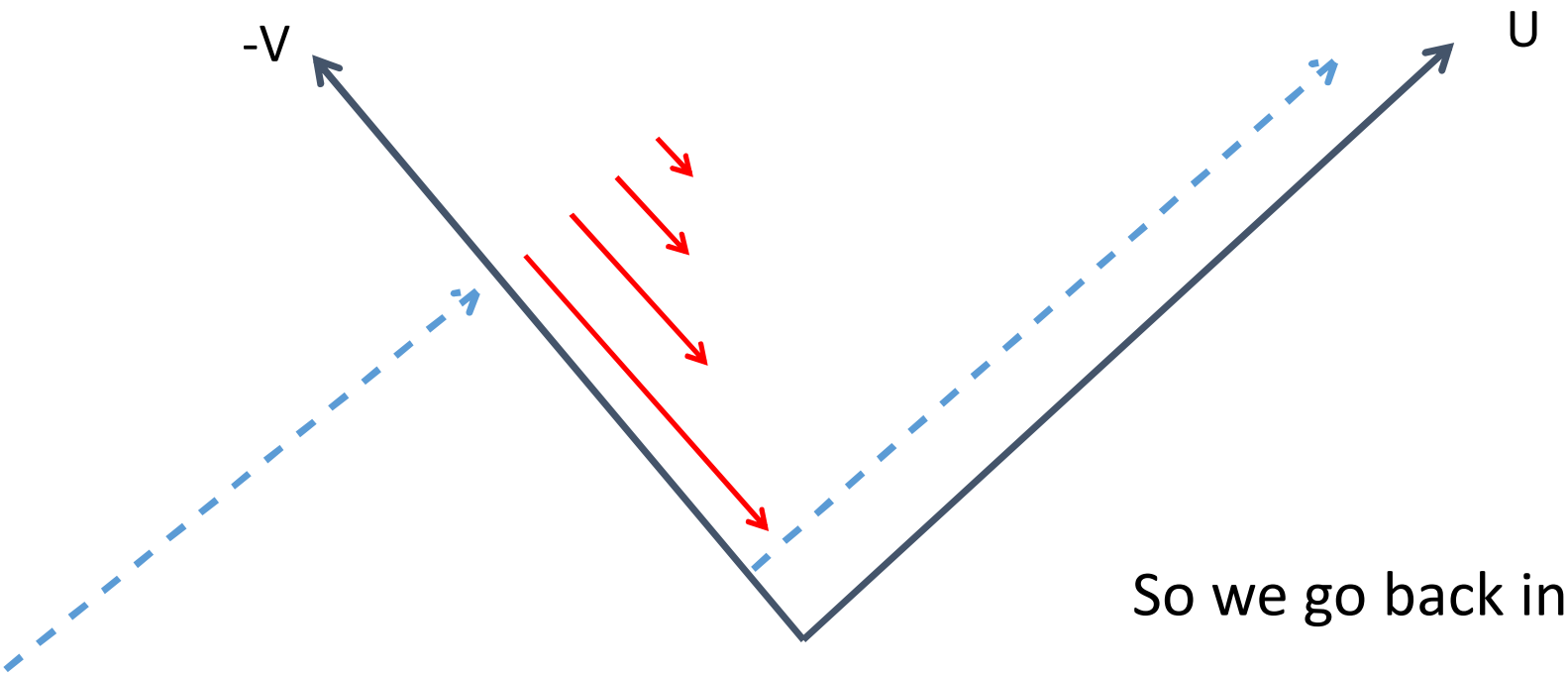

So we go back in time!

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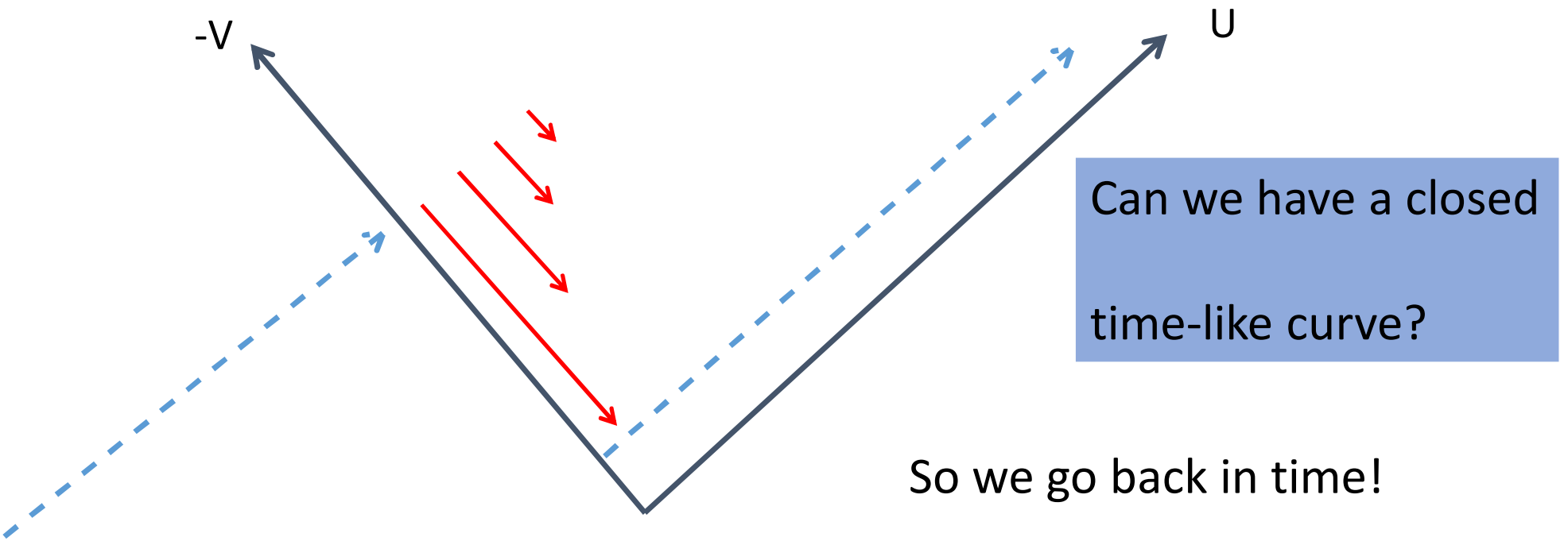
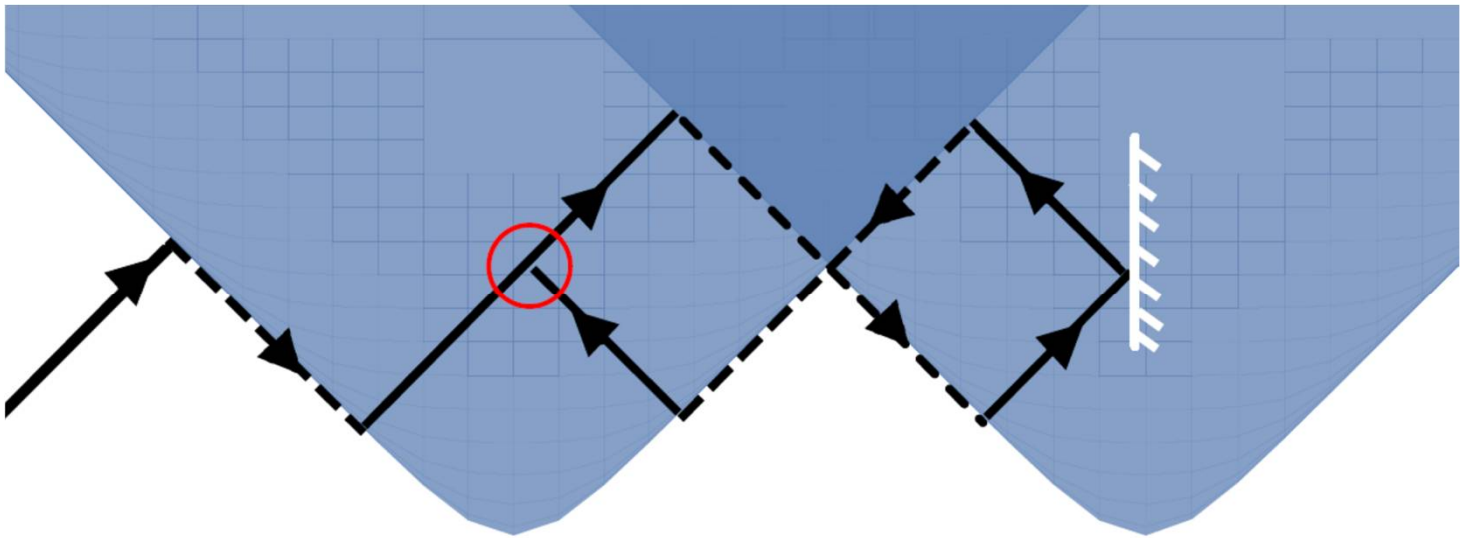


Can we have a closed time-like curve?

So we go back in time!

Yes we can



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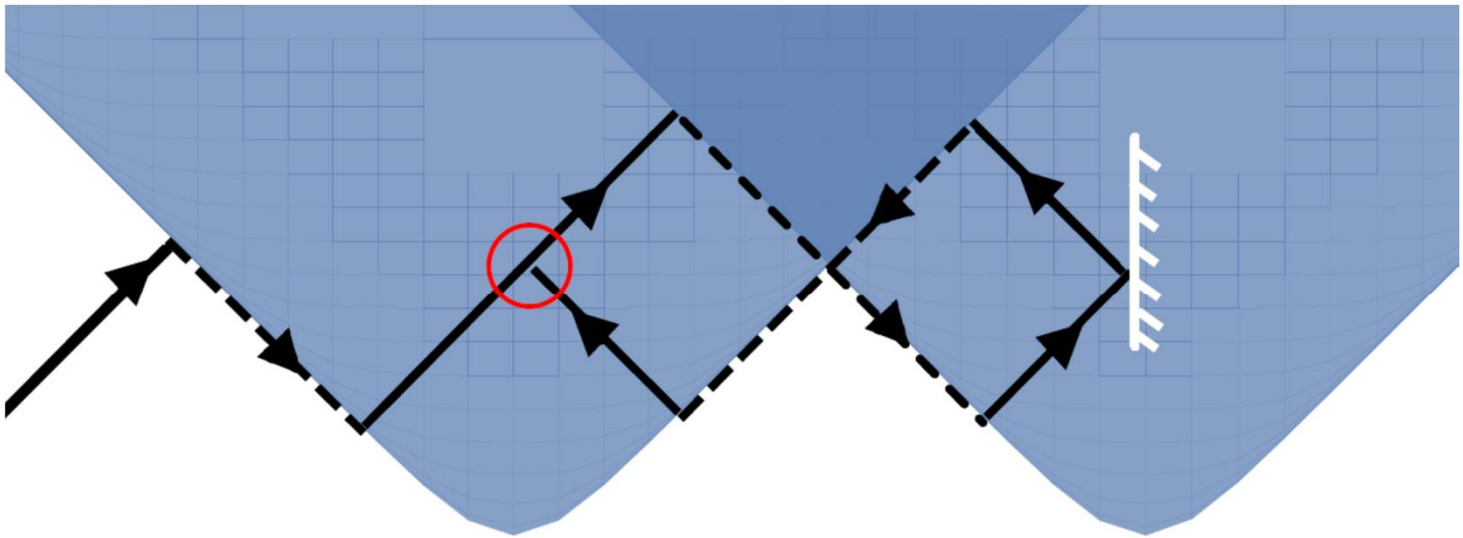
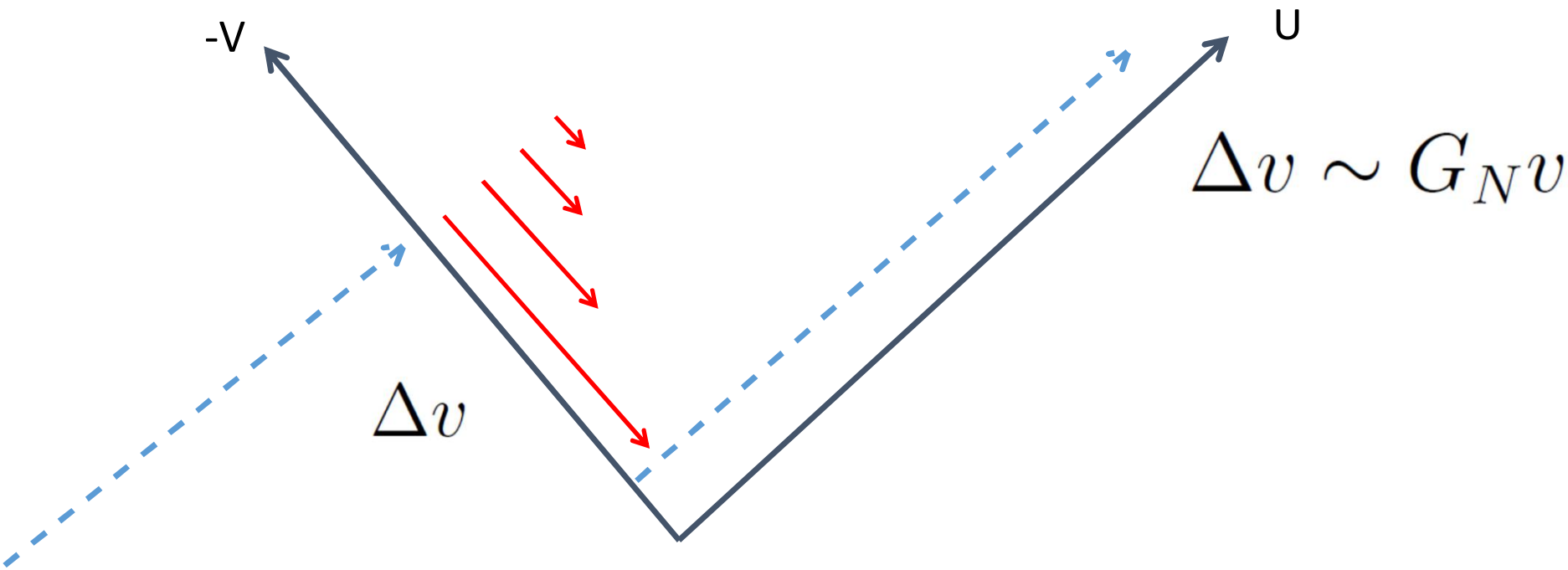


- Clear tension with causality.
- In fact also with unitarity.

Just like, you can't be half pregnant, if you violate the ANEC you have to fully violate it:



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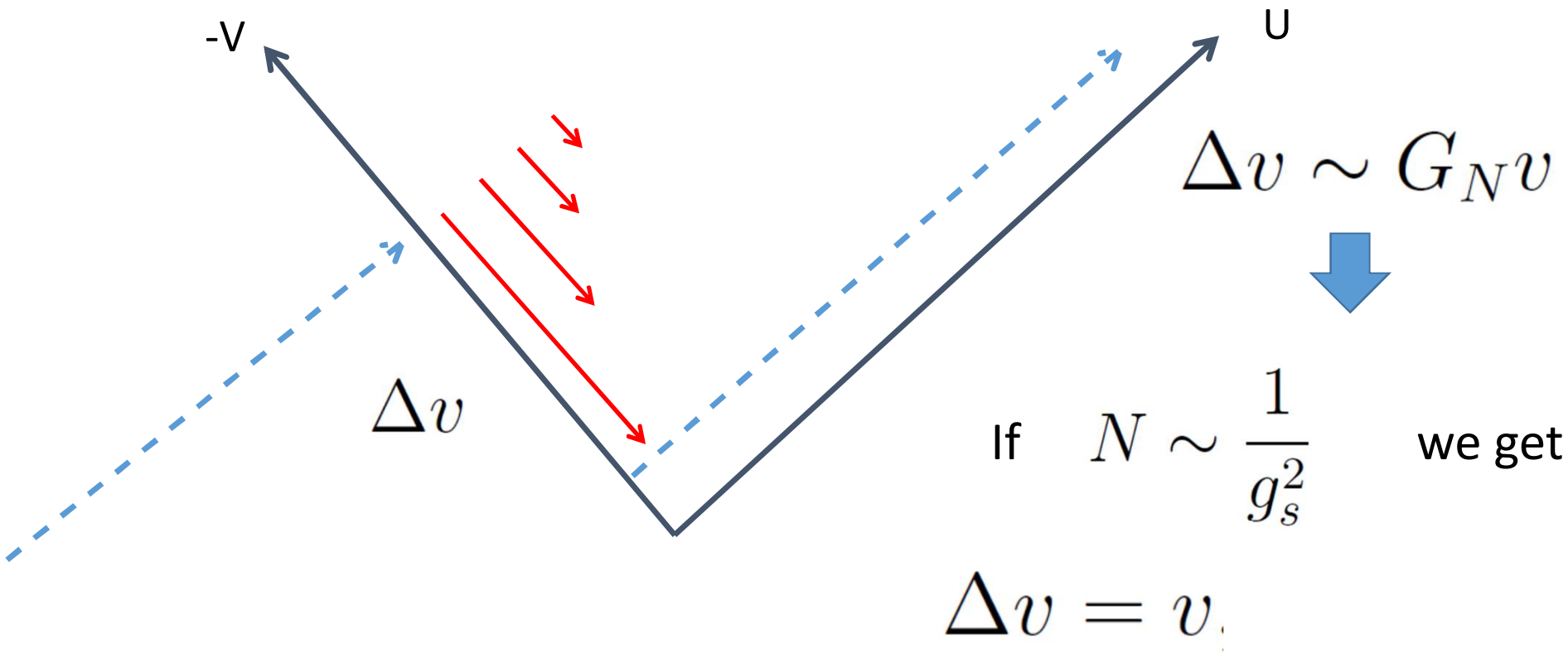

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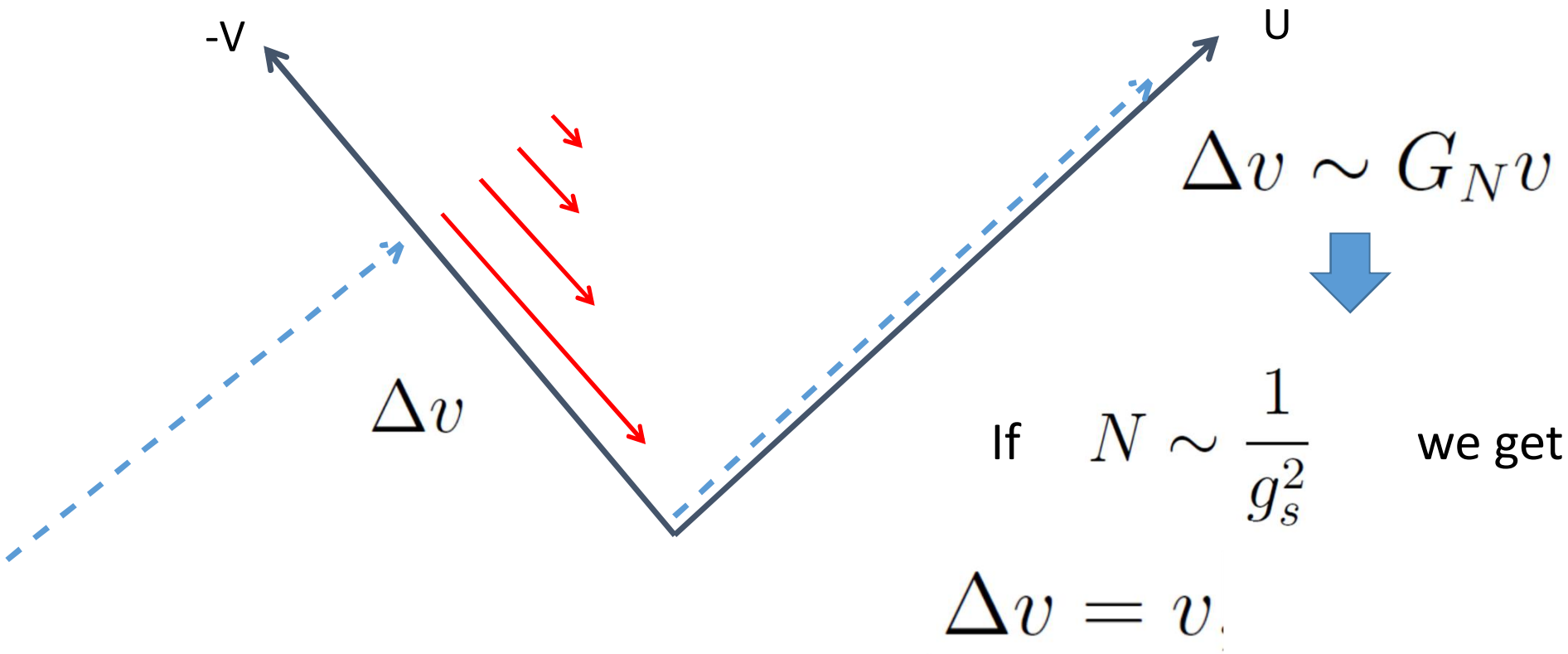
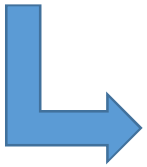


$$\Delta v \sim G_N v$$

If $N \sim \frac{1}{g_s^2}$ we get

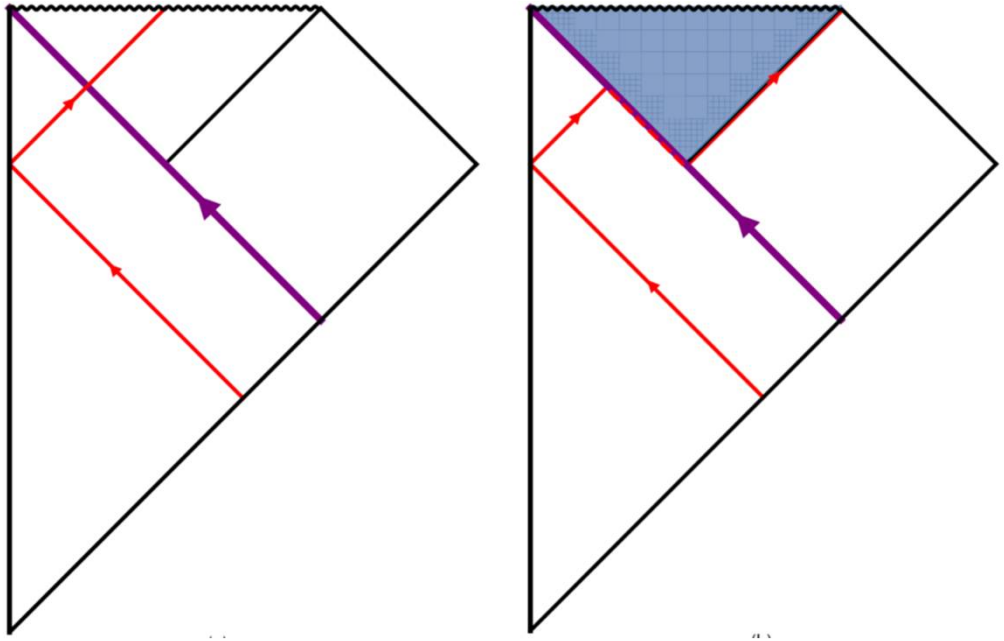
$$\Delta v = v$$



A conjecture: $N \sim \frac{1}{g_s^2}$

A conjecture: $N \sim \frac{1}{g_s^2}$

The BH is cloaked by the folded strings



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But can we see more directly the folded string at infinity?

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So again something that looks like nothing.

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And what about Cosmology?

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Objects that violate the ANEC can completely change the rules of the game

in Cosmology.

Thank you