

Title: Wormholes, Warp Drives, and Time Machines: Fact and Fiction

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Abstract:

# Wormholes, Warp Drives, and Time Machines: Fact and Fiction

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Department of Physics and Astronomy  
UBC

Thanks to NSERC and PI for support  
(based on work done in collaboration with D. Witt)

Waterloo, March 2006

## The Time Machine: H. G. Wells (1895)

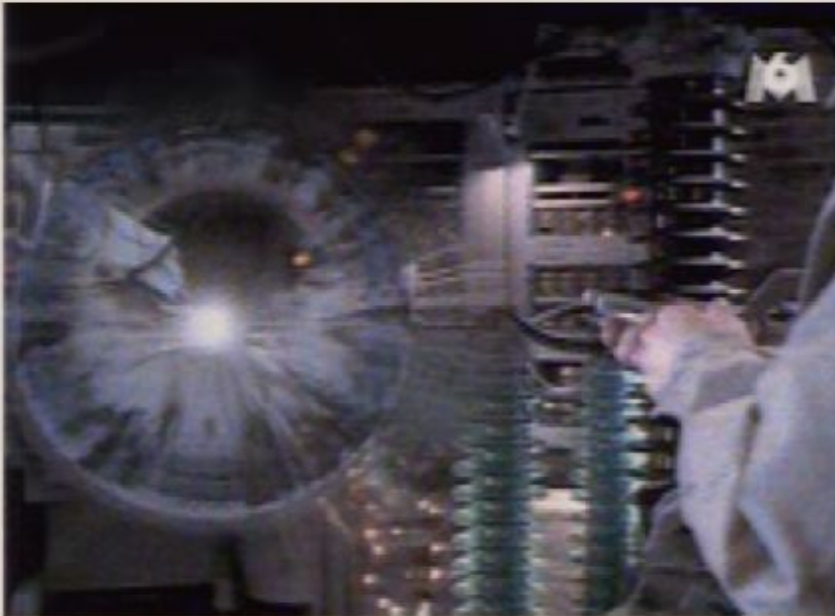


## Time Machine: Doctor Who (1963)

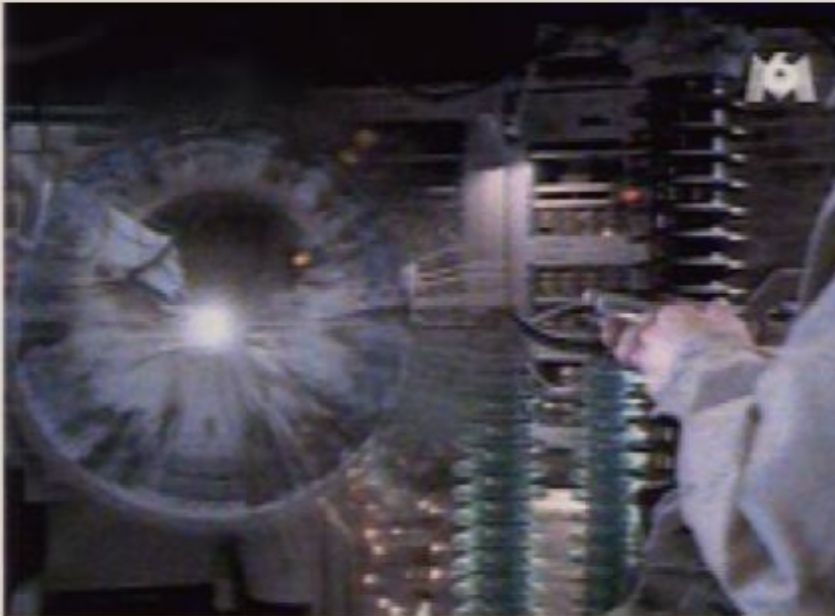


## Warp Drive: Star Trek (1966)





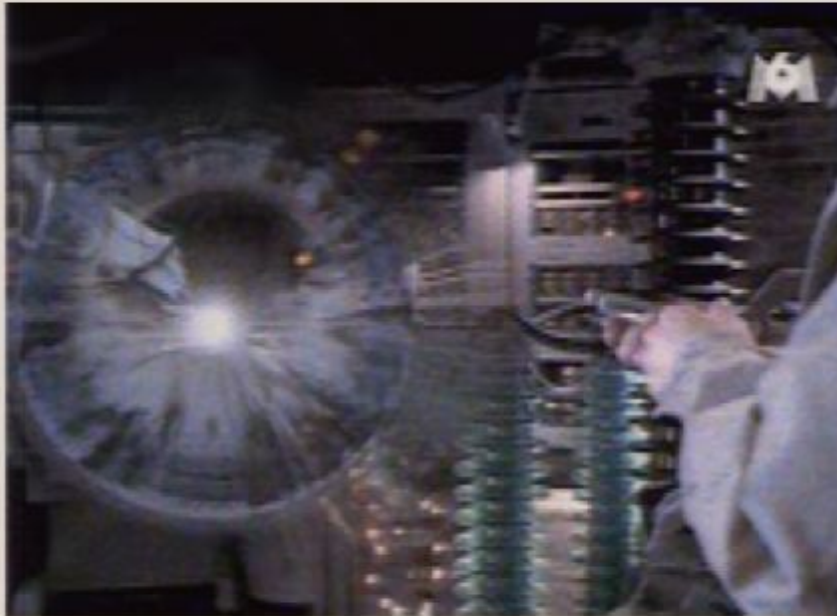
Wormhole:  
Sliders (1995)



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## Wormhole: Sliders (1995)





- Clearly time machines, warp drives and wormholes are entertaining fiction. But how about in fact?
  - All exist as solutions to Einstein's equations
  - However, said solutions require negative energy
- I will discuss
  - How do we know this?
  - How physical is negative energy?mostly in the context of traversable wormholes.

## How to build a warp drive, traversable wormhole or time machine in three easy steps

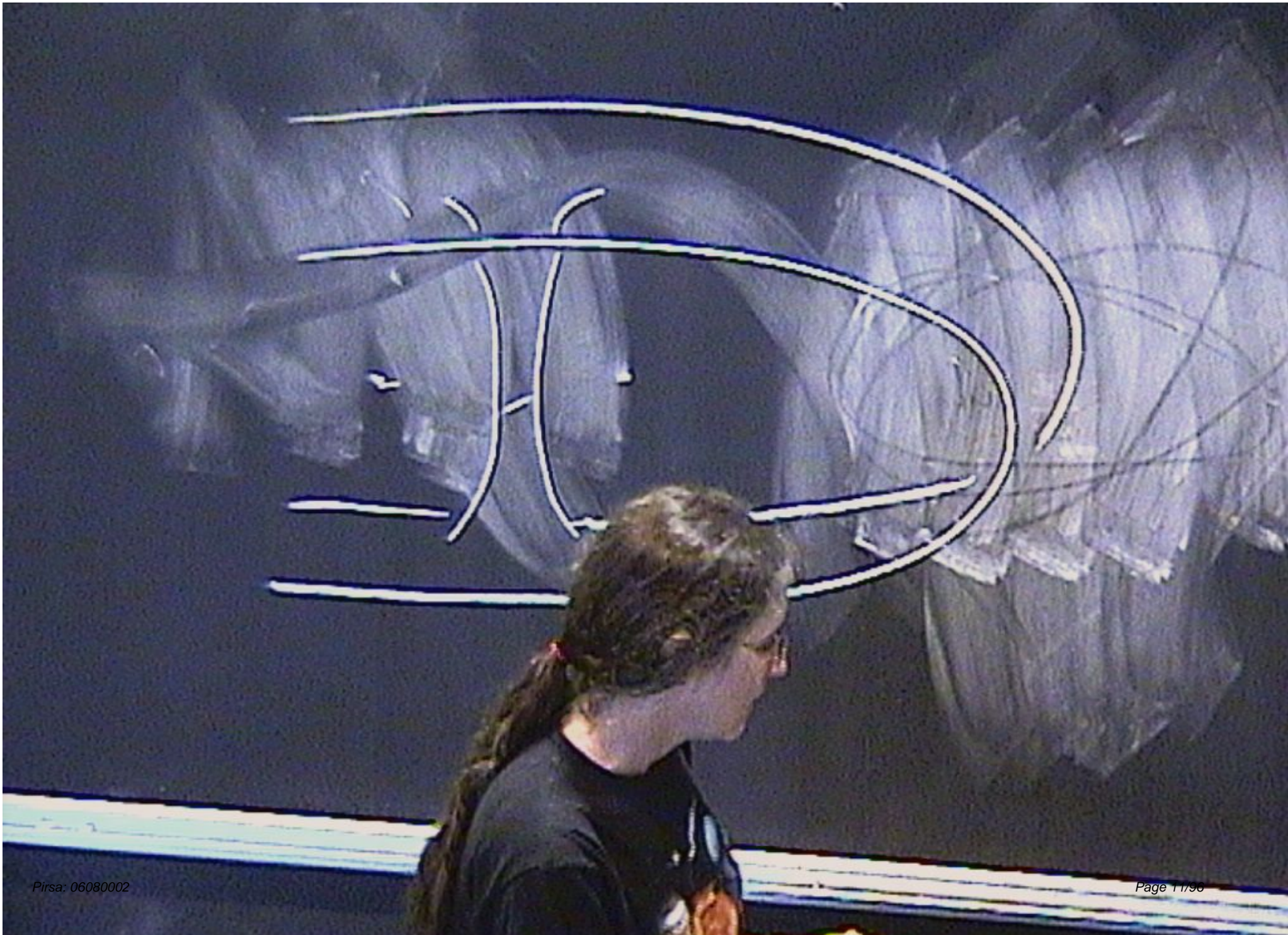
- write down the geometry you want
- compute the Einstein tensor
- Posit matter with a stress energy = this Einstein tensor

Einstein equations:

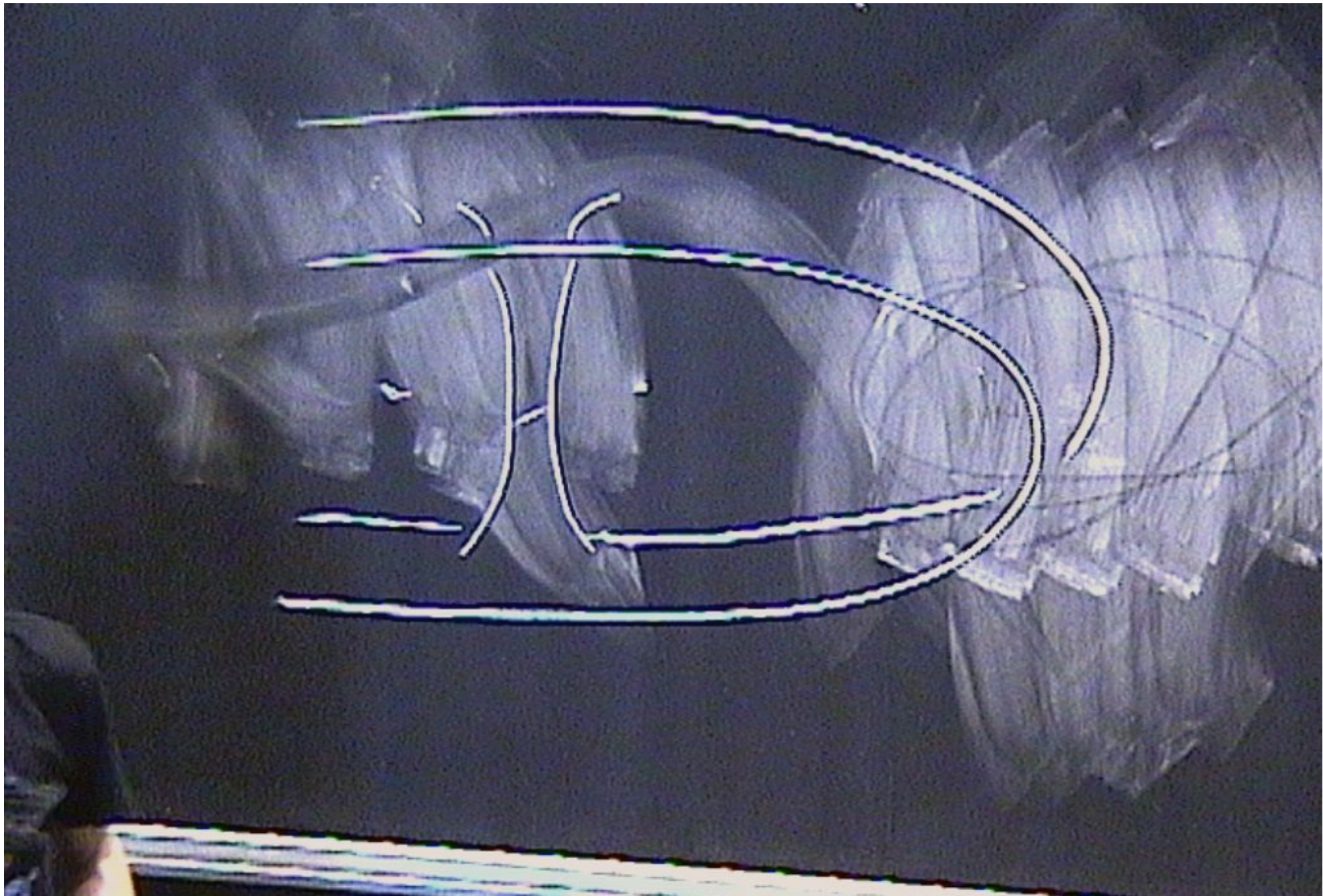
$$R_{ab} - 1/2 R g_{ab} = 8\pi T_{ab}$$

“Curvature” = matter









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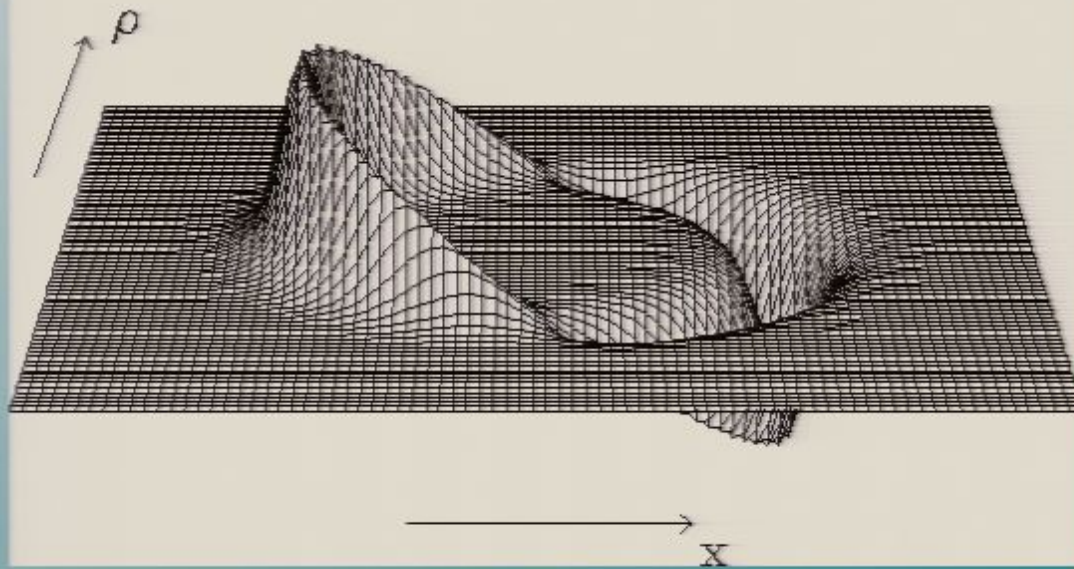
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## Alcubierre warp drive geometry

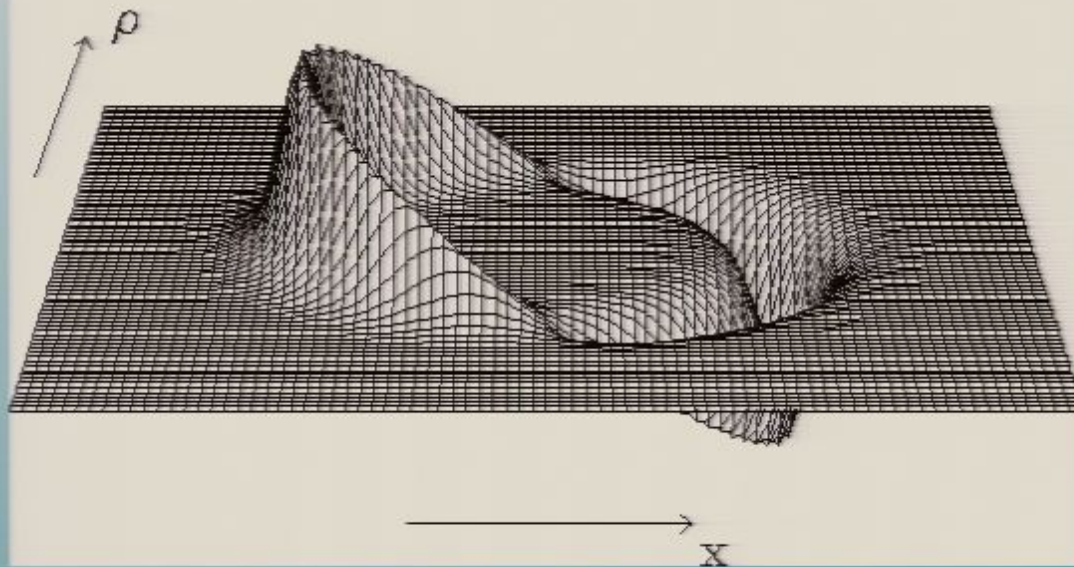
$$\mathcal{V} = -\alpha \text{Tr}(K)$$

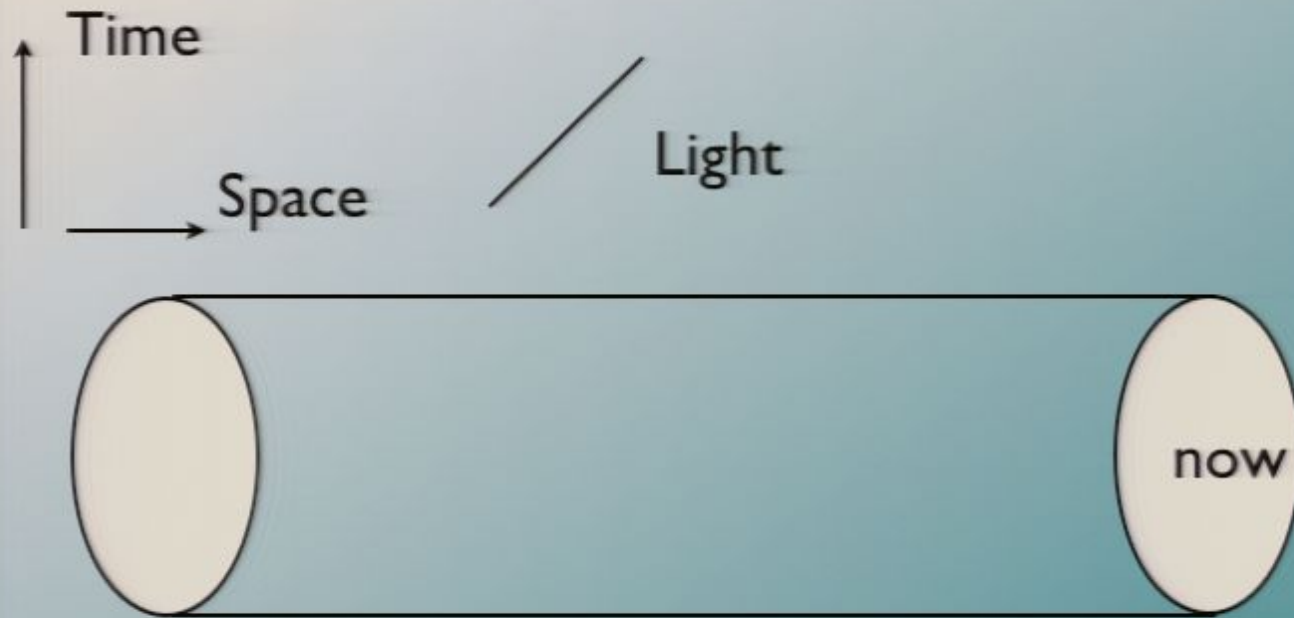




## Alcubierre warp drive geometry

$$\psi = -\alpha \text{Tr}(K)$$





Time machine spacetime geometry

Note: also can make more interesting examples where time machine exists in a localized region of spacetime



So where are the traversable wormholes,  
warp drives and time machines?

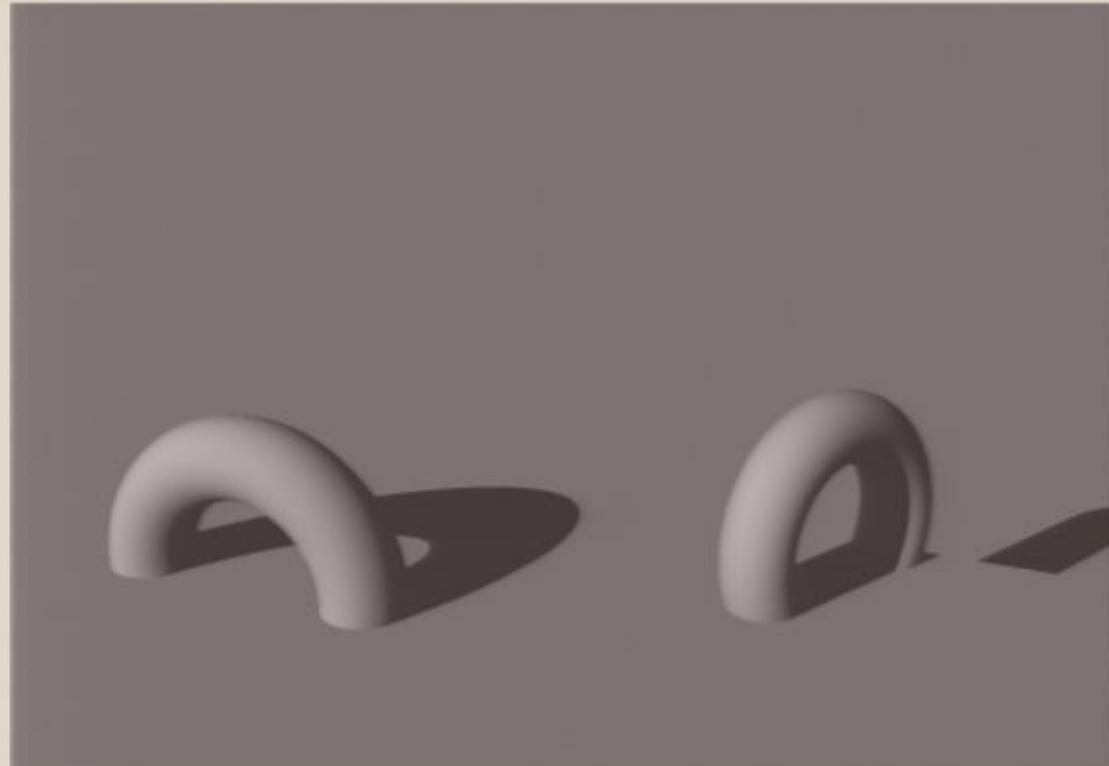
- How would we see them?

Lets consider wormholes.

So where are the traversable wormholes,  
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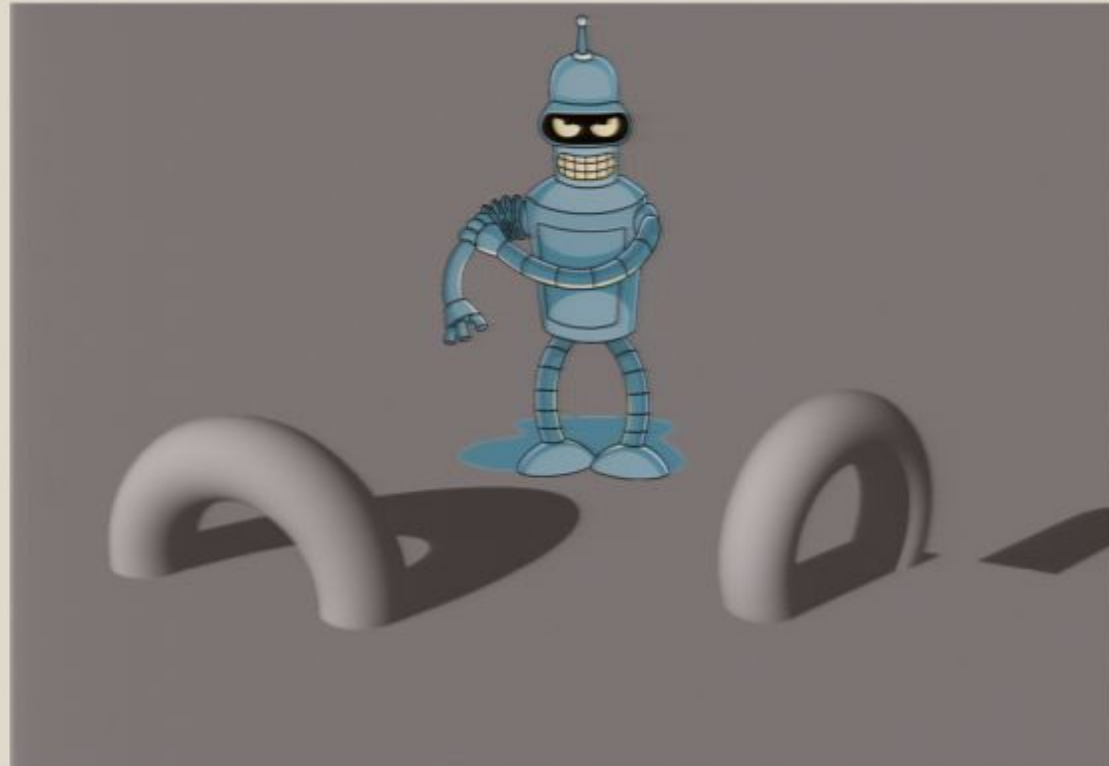
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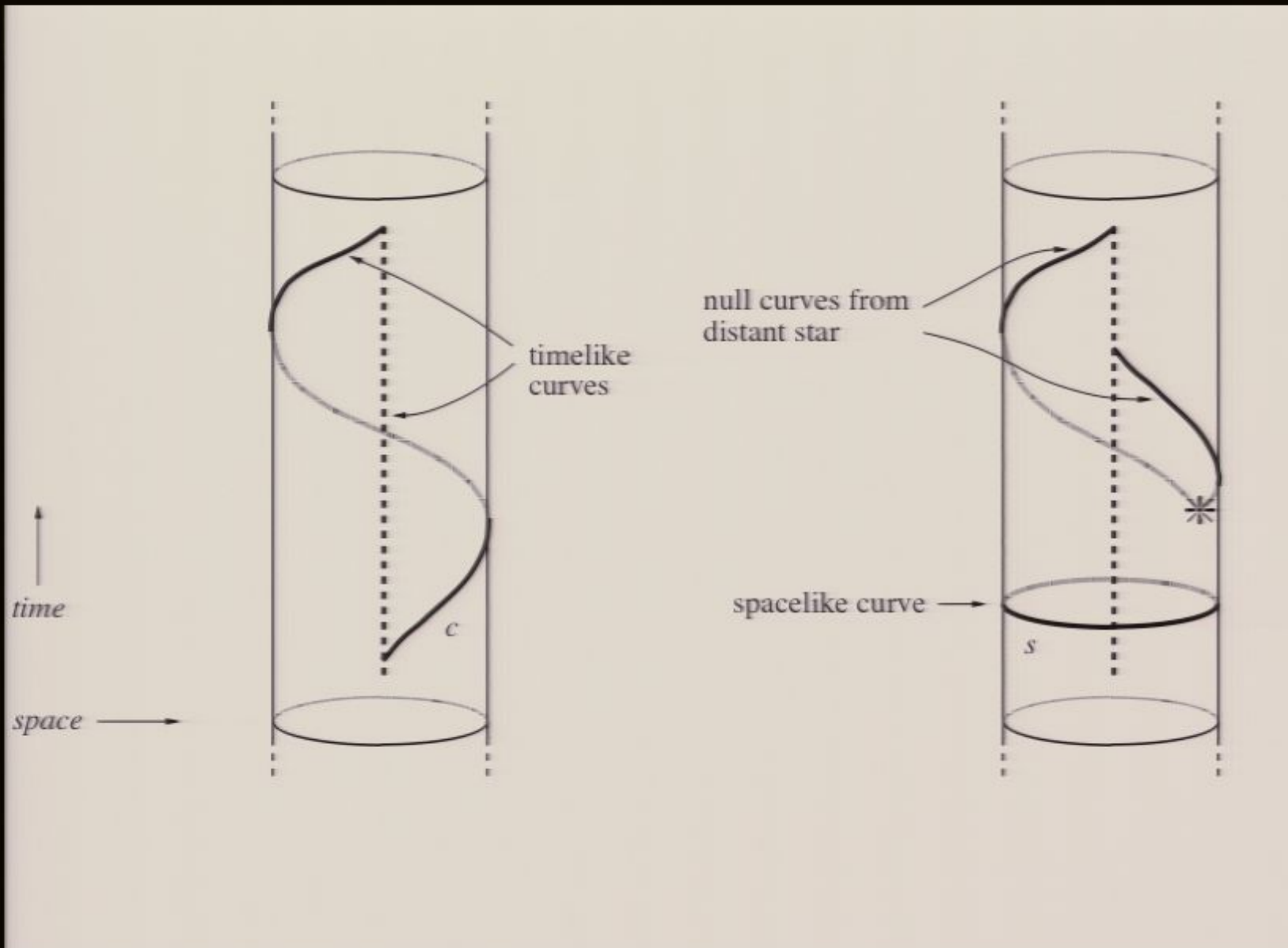


Spatial projection of probing the spacetime  
topology

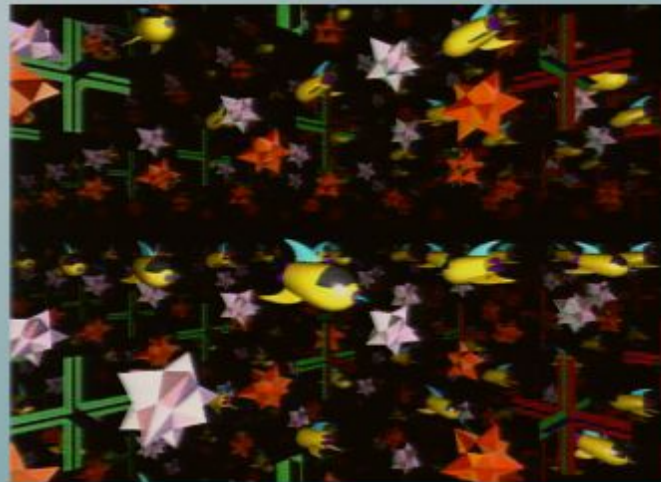




Spatial projection of probing the spacetime topology



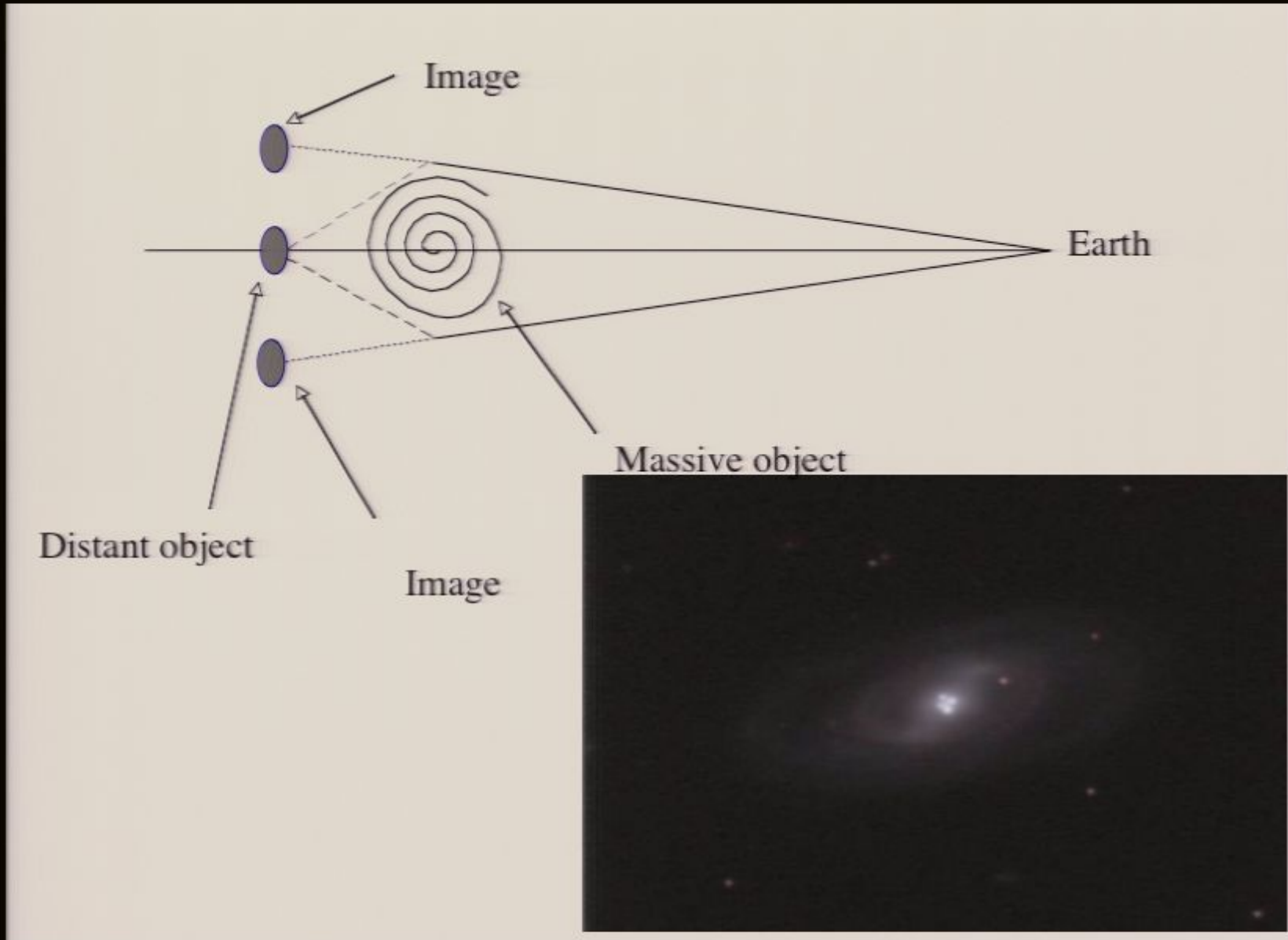












## So what happened to them?

- Stress energy tensor one computes for traversible wormhole has negative energy (negative mass).
- Classical matter (dust, gas, electromagnetic fields, vacuum, Yang-Mills fields, etc) has positive energy
  - Can one find solutions with positive energy on complicated topologies?
  - If so, are some of these solutions traversible wormholes?

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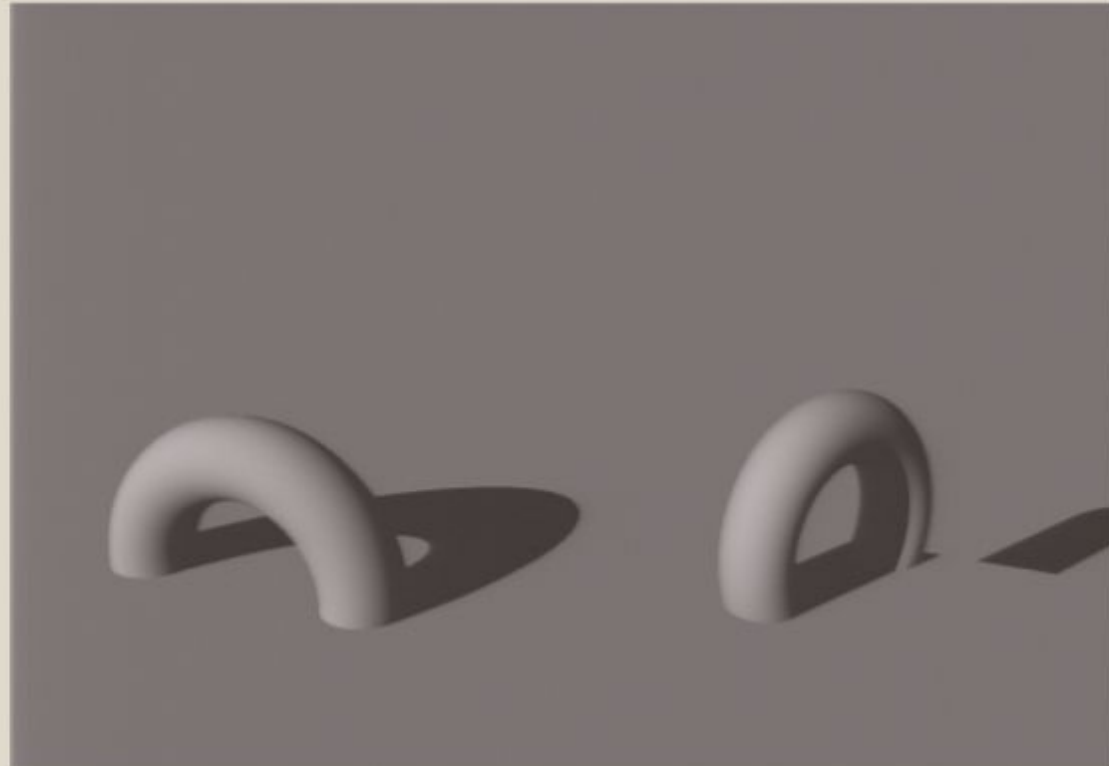
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## Pointers to the answer

- Singularity theorem for topological structures in 4-d spacetime (Gannon)
- Existence of initial data for asymptotically flat spacetimes of arbitrary topology (Witt)
- Examples of non-traversable wormholes
  - Wheeler, Feynman (1960's)
  - Morris, Thorne, Yurtsever (1988)
- Is topology hidden in physically reasonable spacetimes? (Topological censorship conjecture, Witt 1986)

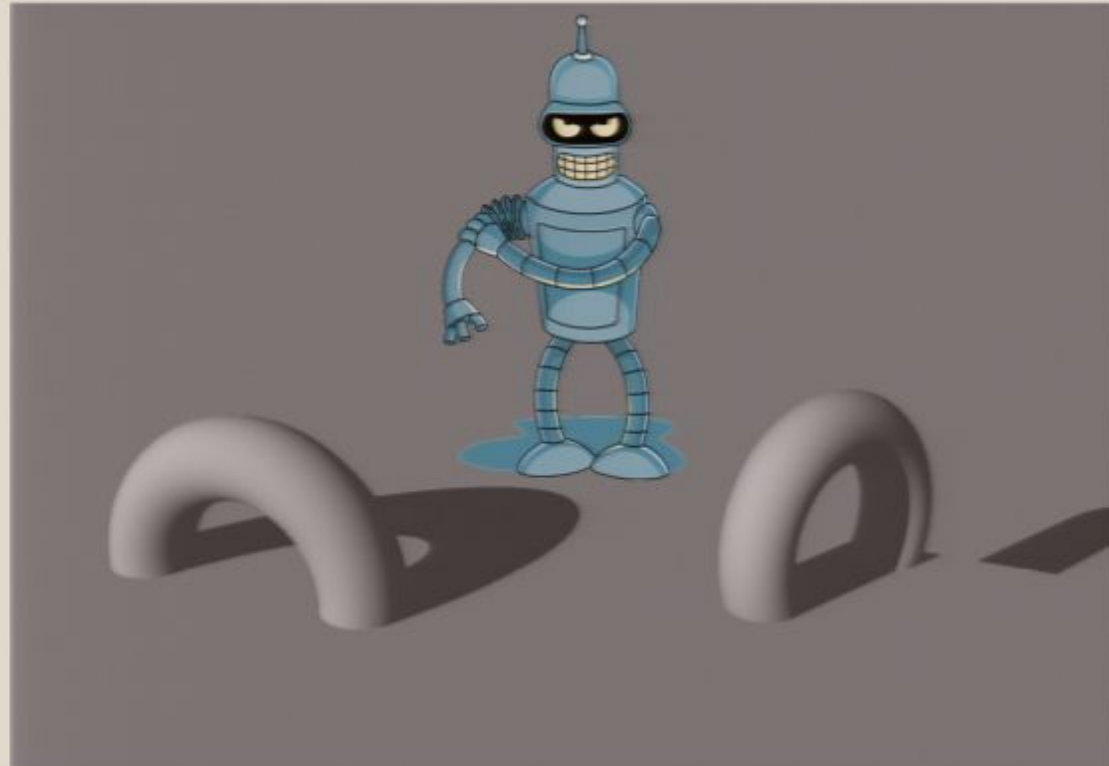
## Active Topological Censorship

- **Active Topological Censorship Conjecture:**  
The topology of any physically reasonable spacetime cannot be actively probed.
- **First proven for the case of asymptotically flat spacetimes (Friedman, Schleich, Witt 1993)**  
Theorem: Given any asymptotically flat, globally hyperbolic spacetime,  $M$ , which obeys ANEC, every causal curve which starts at  $\mathcal{I}^-$  and ends on  $\mathcal{I}^+$  is homotopic to a causal curve in a simply connected neighborhood of  $\mathcal{I}$ .



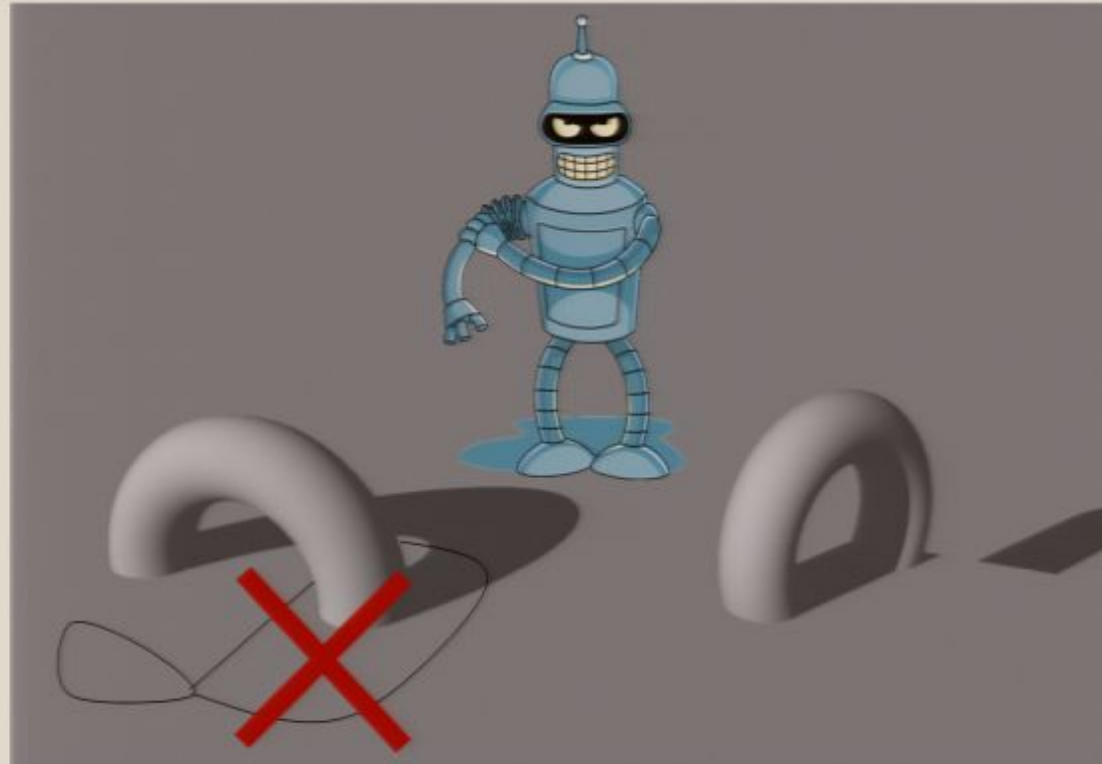
Translation: you can't hook a causal curve  
through a wormhole





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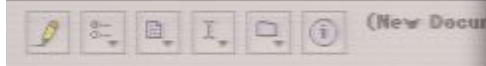




Translation: you can't hook a causal curve through a wormhole

How does this theorem work?

**In order to traverse topology, you have to be able to see inside a black hole horizon**



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Title & Subtitle

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OK

theorem work?

**In order to traverse topology, you have  
able to see inside a black hole horizon**

- 13
- 14
- 15
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- 19



# General Relativity

- Add to the postulates of special relativity

## **Principle of Equivalence**

- Physics is the same in a uniformly accelerated frame as in a uniform gravitational field

**gravity  $\leftrightarrow$  acceleration**

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## **Principle of Equivalence**

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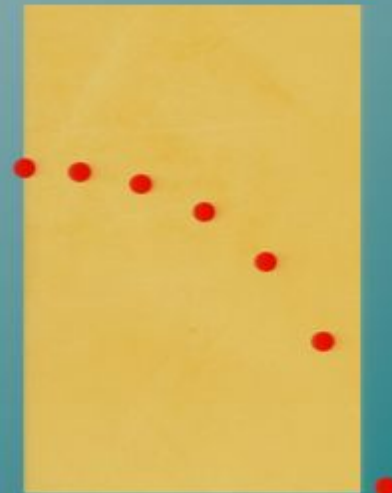


## Consequences

- Gravitational redshift
- Gravitational bending of light

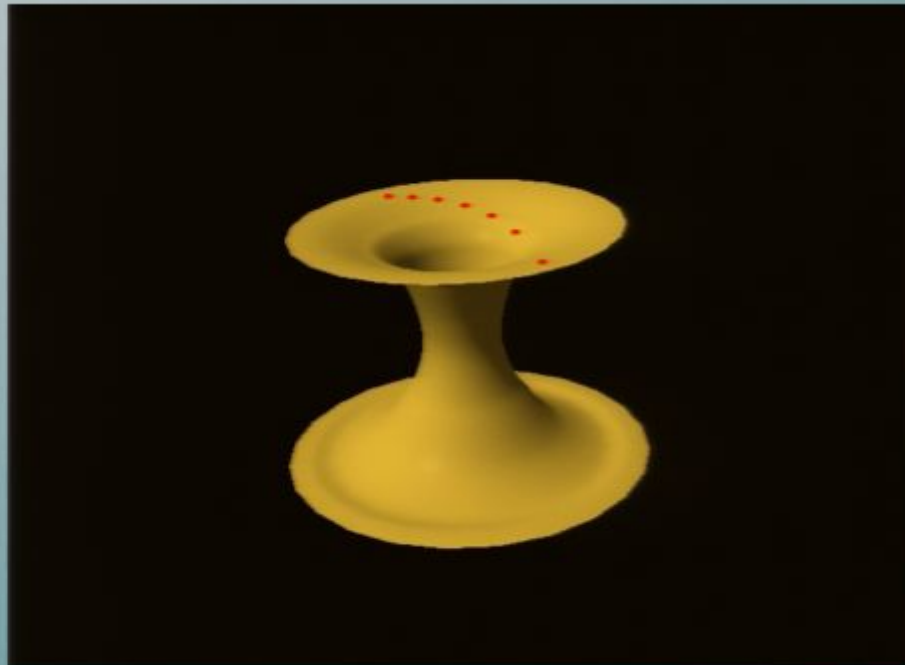
light viewed by accelerated observer

light in flat spacetime



## Gravity = Geometry

- freely falling light travels locally straight line - a geodesic - curved path due to curvature of spacetime









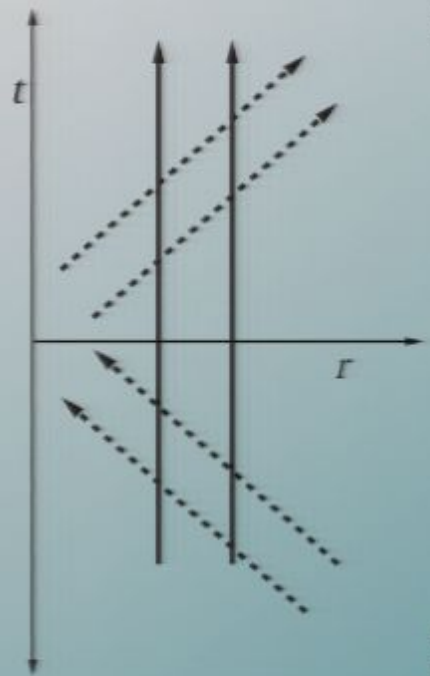






# Tracing the path of light in spacetime

future timelike infinity

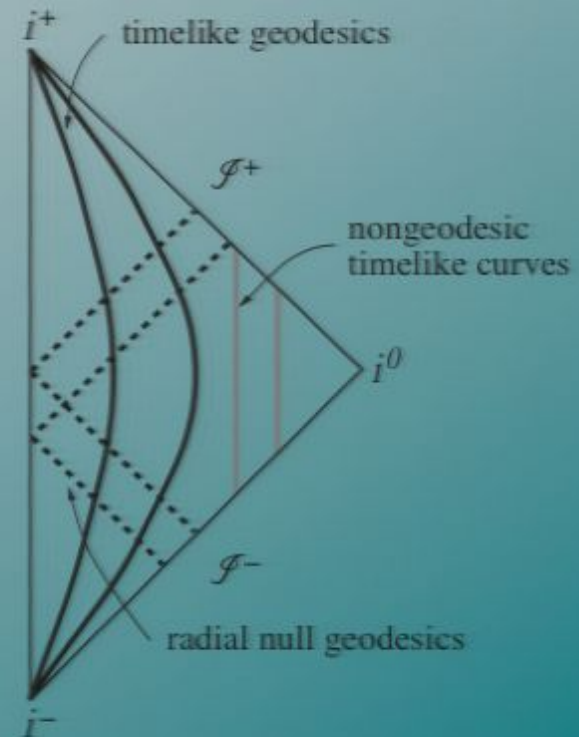


future null infinity

spatial infinity

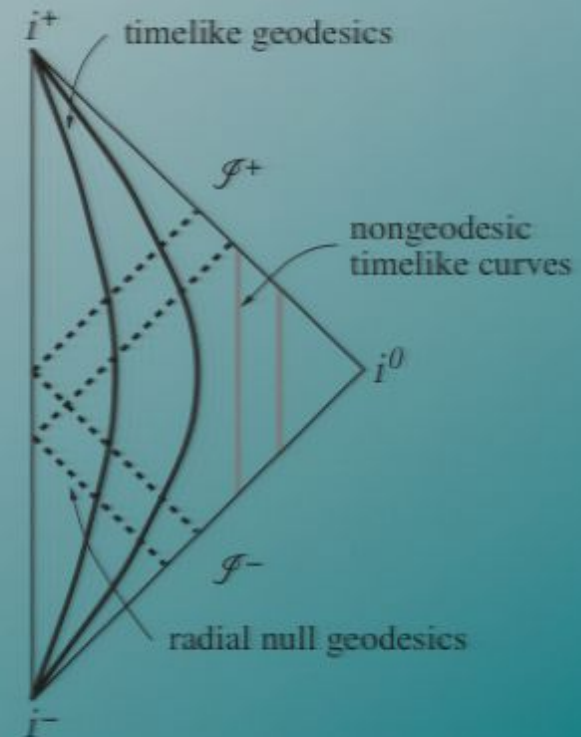
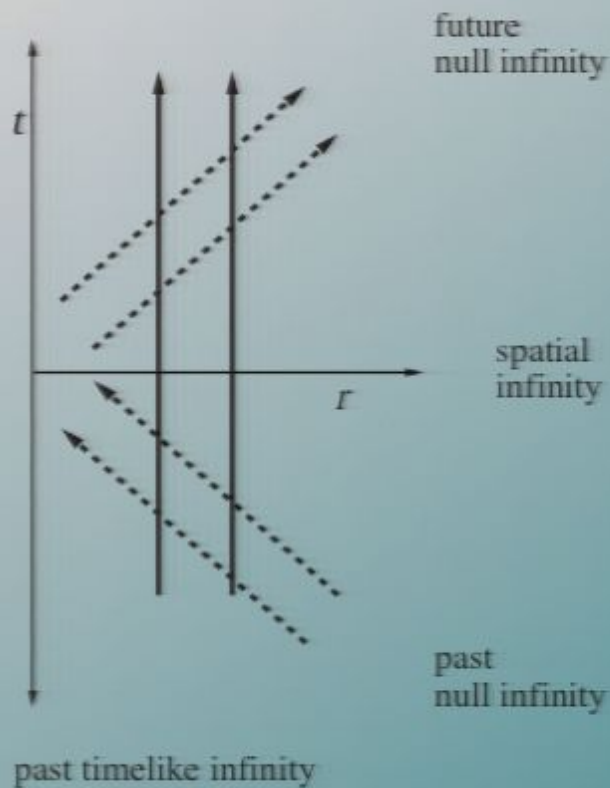
past null infinity

past timelike infinity



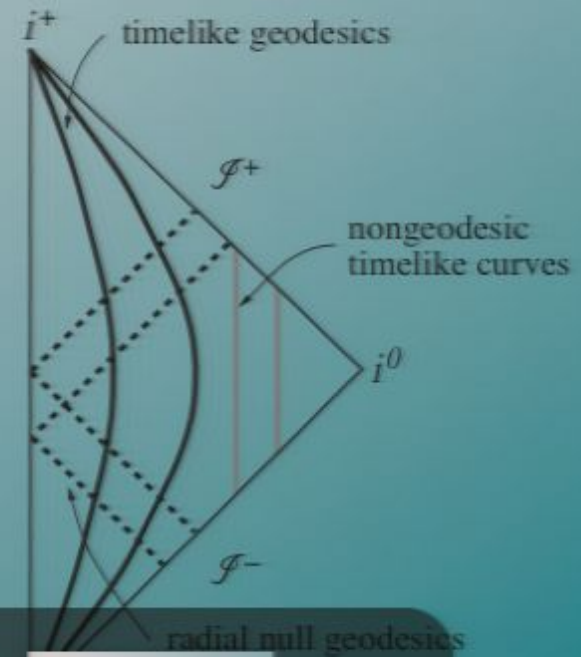
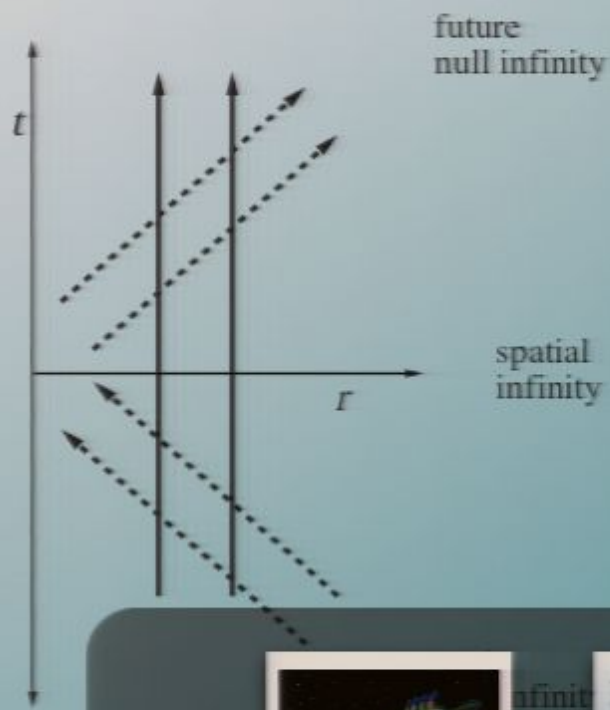
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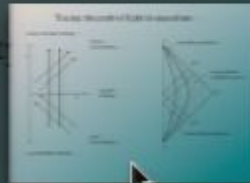


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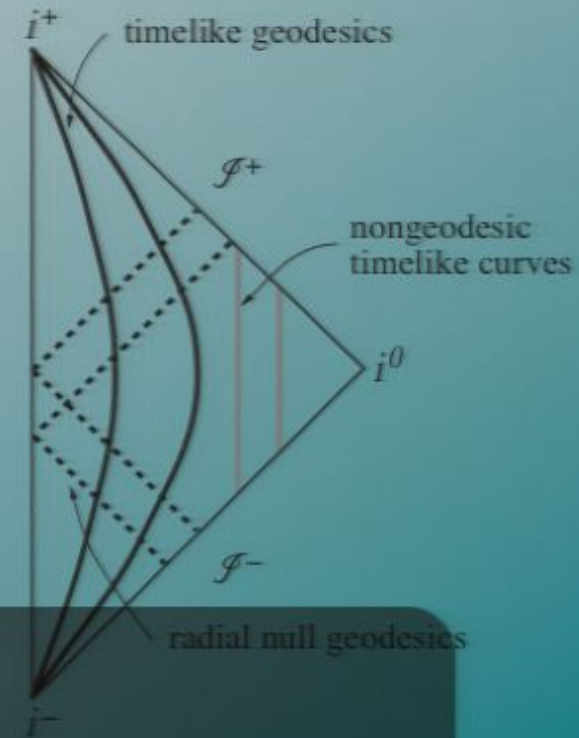
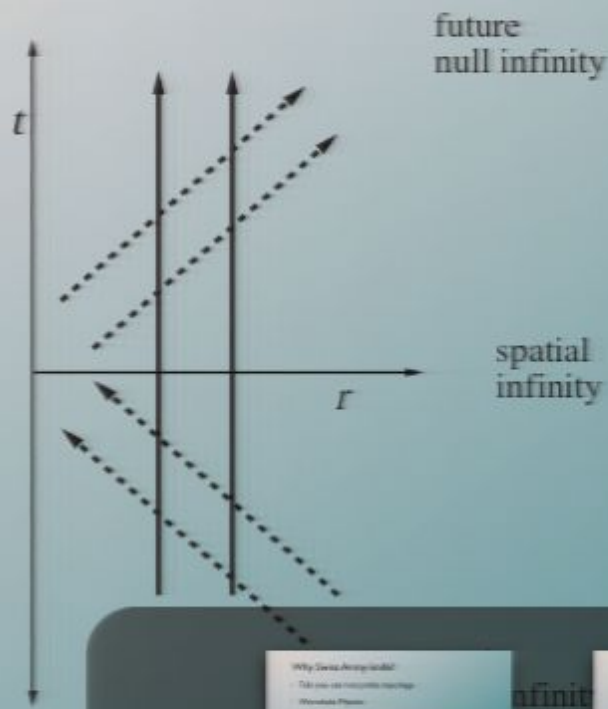
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# Tracing the path of light in spacetime

future timelike infinity



Why does it happen?

- Take an arbitrary mapping
- Weyl's Theorem
- Take the global structure of Einstein's Equations
- Discover the Black Hole Singularity in the
- Space and ADM's 3+1 decomposition of the
- Theory
- In 1970s, Penrose's singularity theorem
- Shows that ADM's 3+1 decomposition is not
- Theorem of Penrose and Hawking

Approximately the same time cost?

- The space is allowed to be curved for
- one observer, but the distance is not
- 1/4 the other time

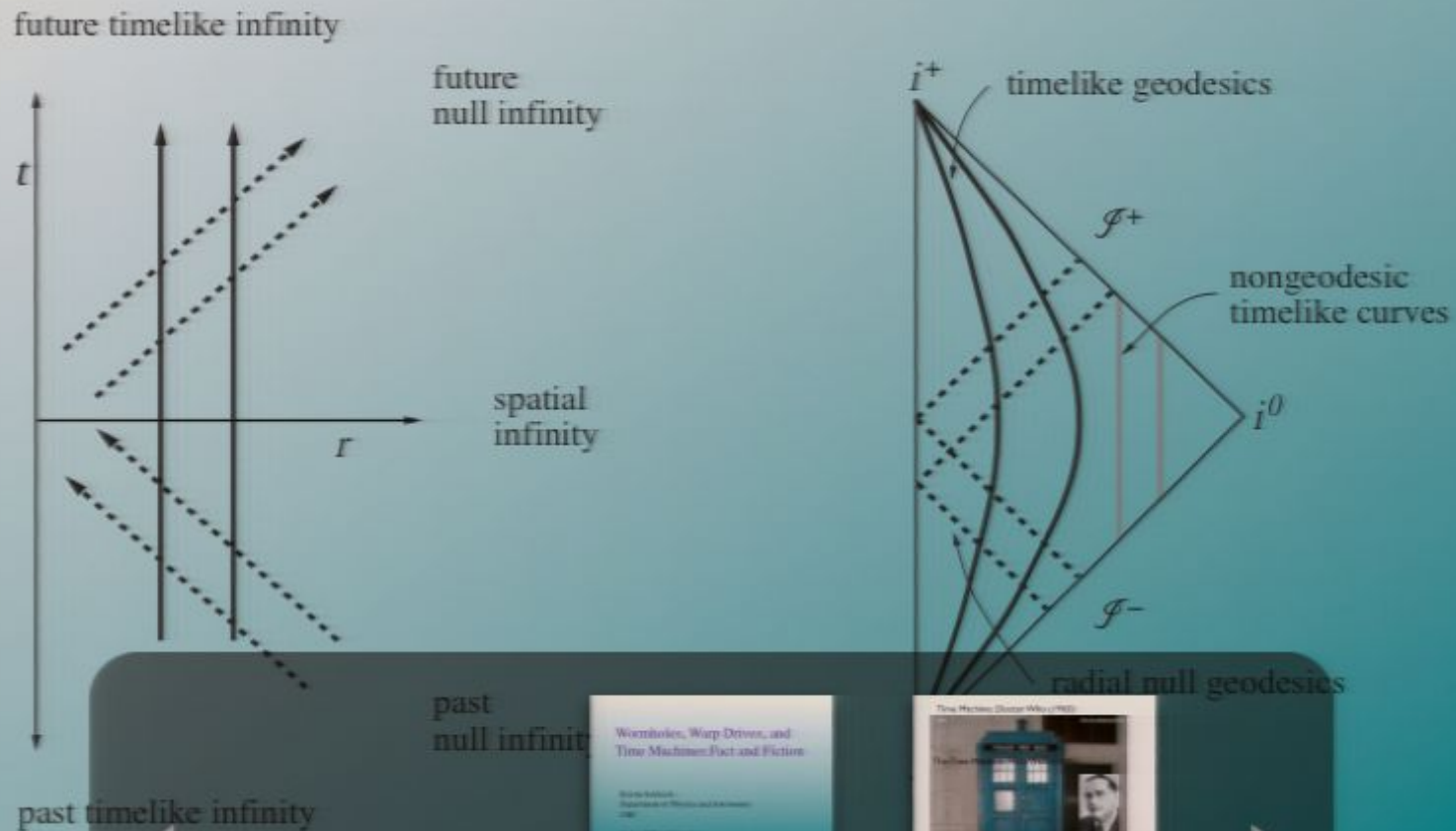
Penrose (1965) and Hawking (1970) singularity theorems

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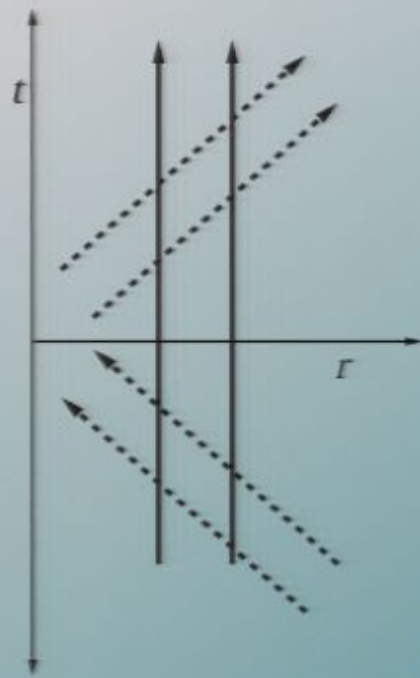
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# Tracing the path of light in spacetime

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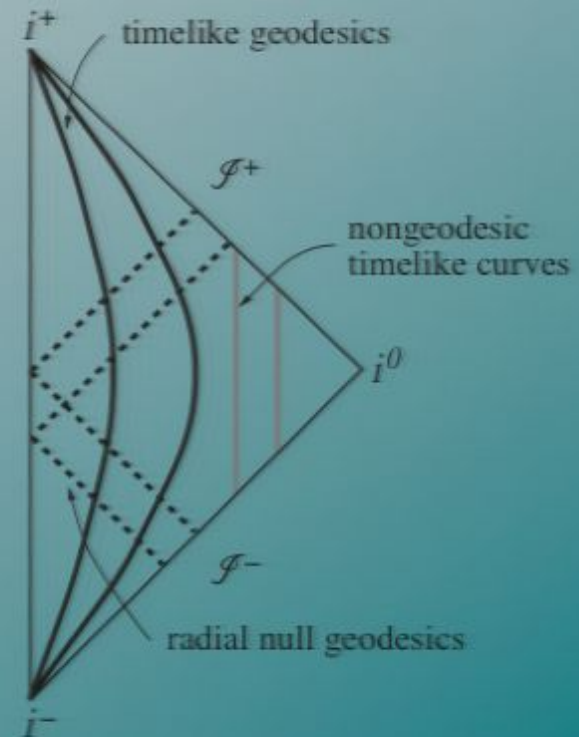


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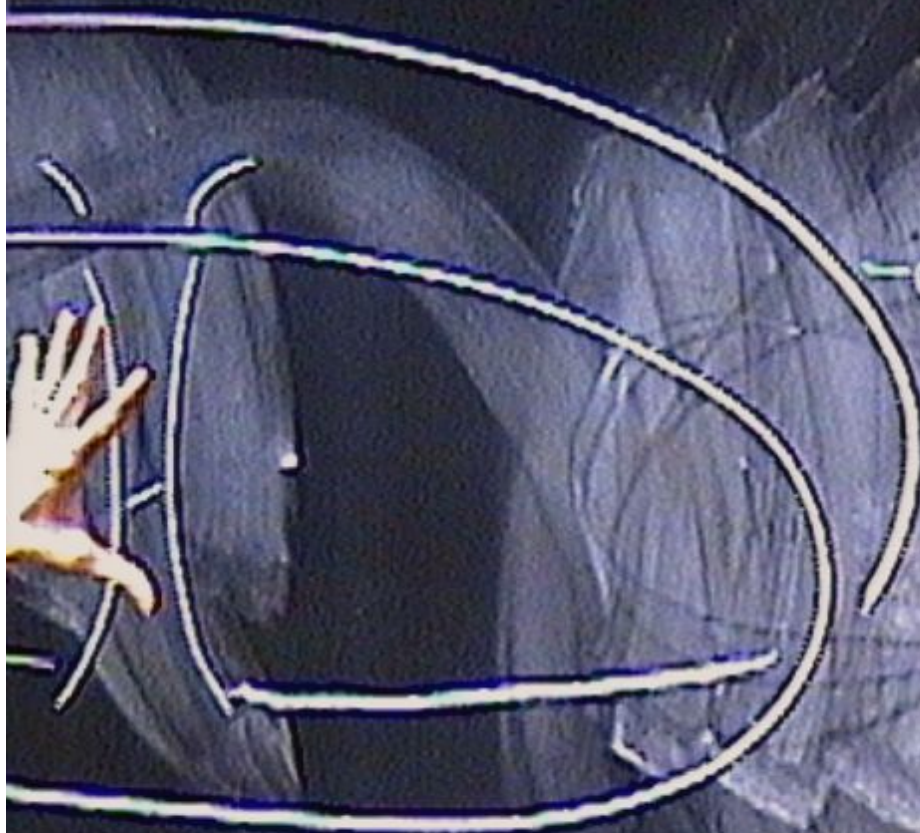


x

$$x = \tan \theta$$



x



$$x = \tan \theta$$

$$-\infty \rightarrow \infty$$

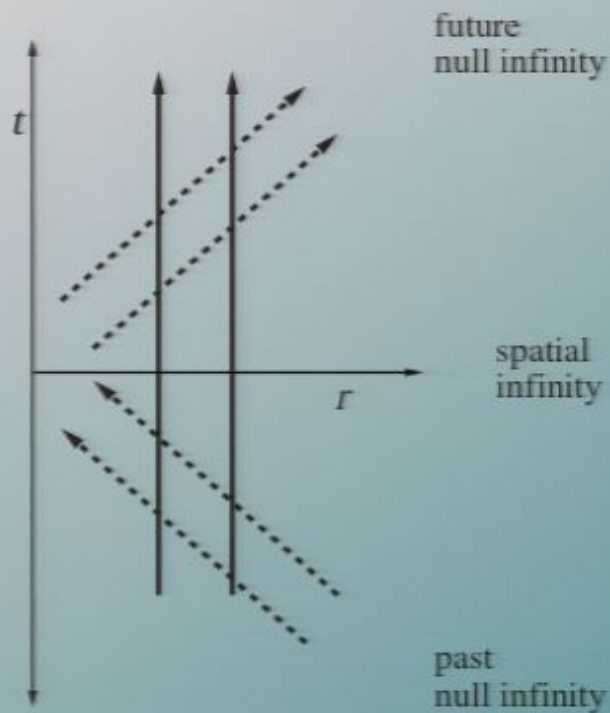
$\Rightarrow$

$$-\frac{\pi}{2} \rightarrow \frac{\pi}{2}$$

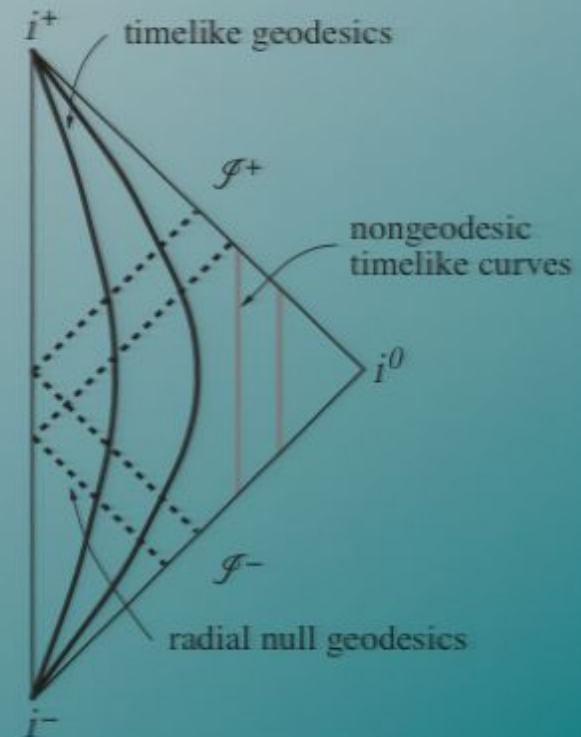


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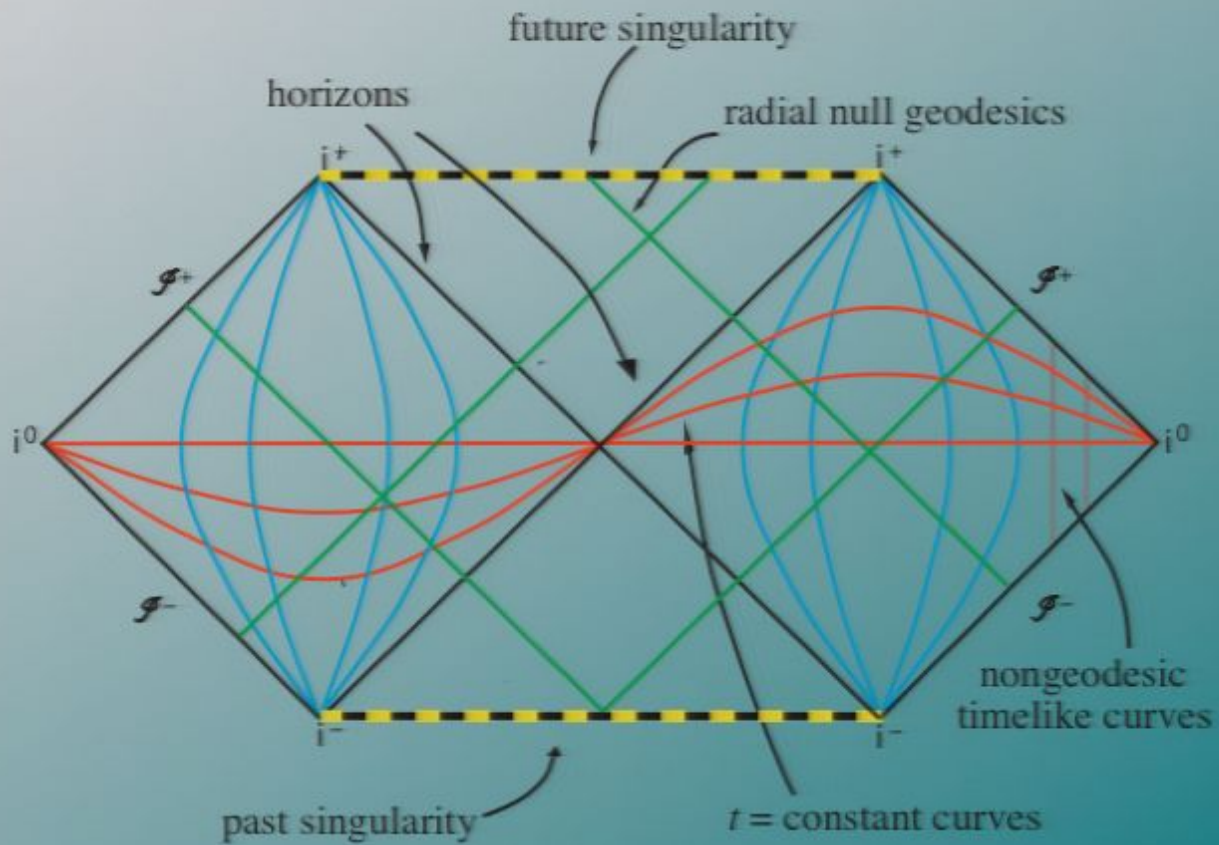
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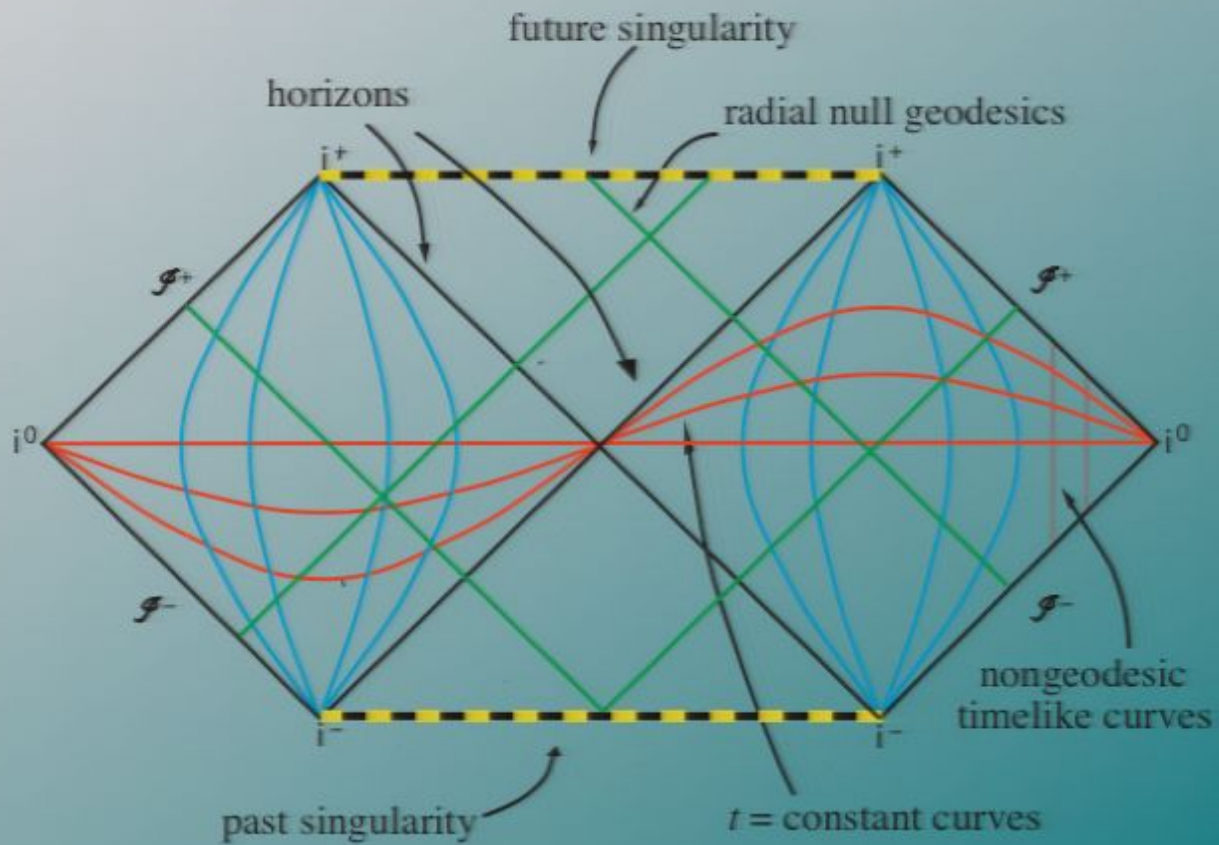
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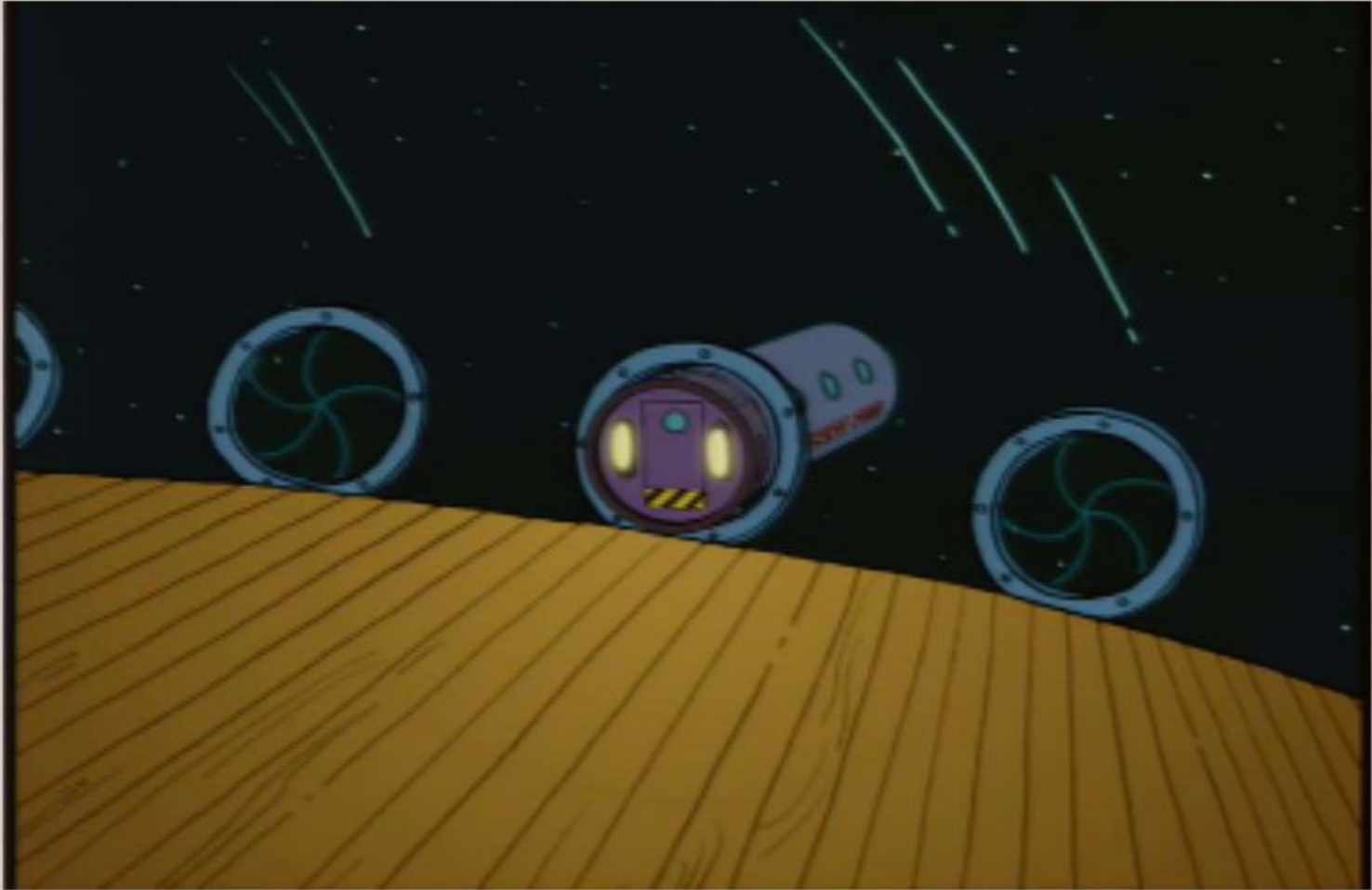


# Schwarzschild Spacetime



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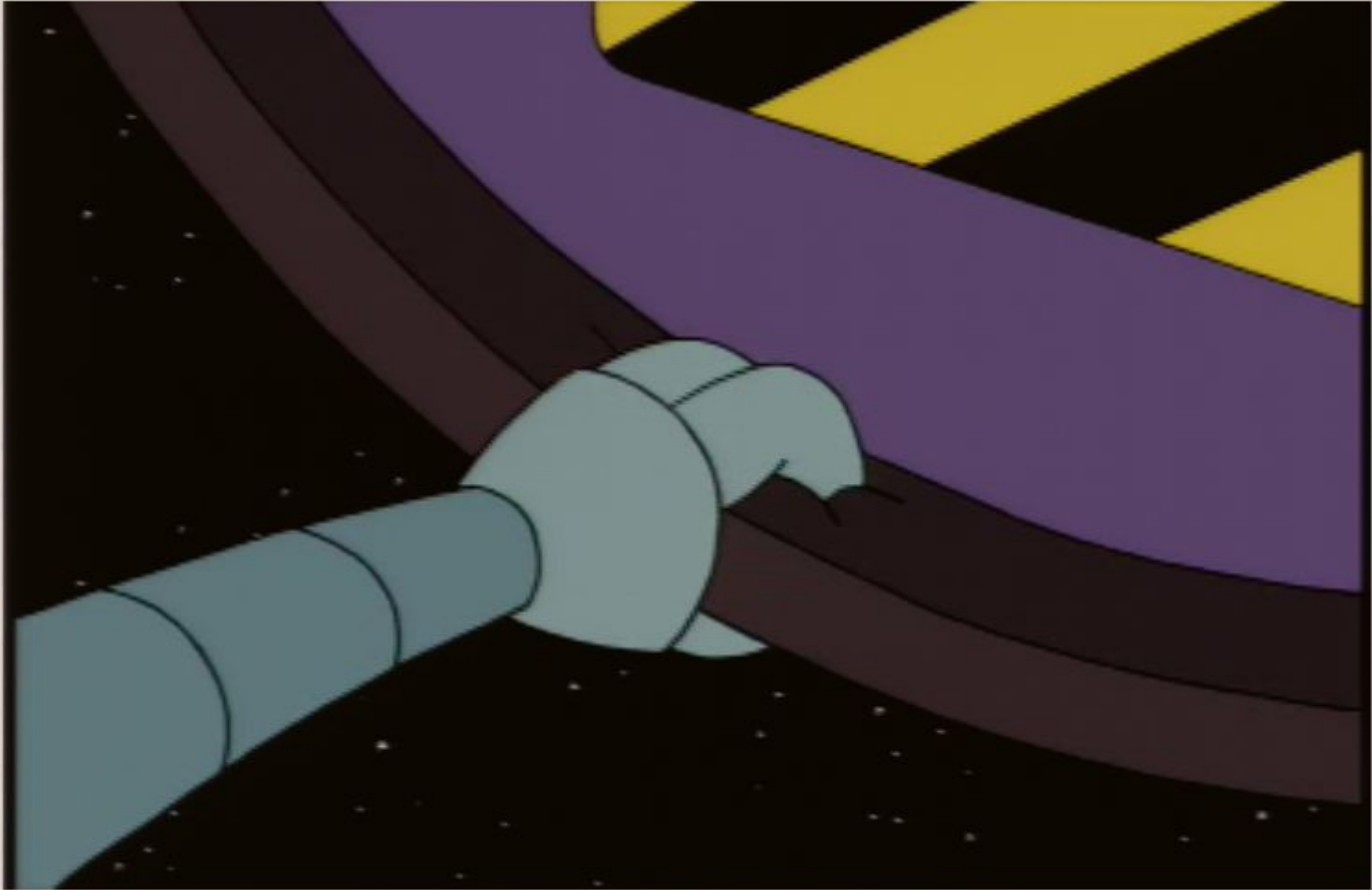




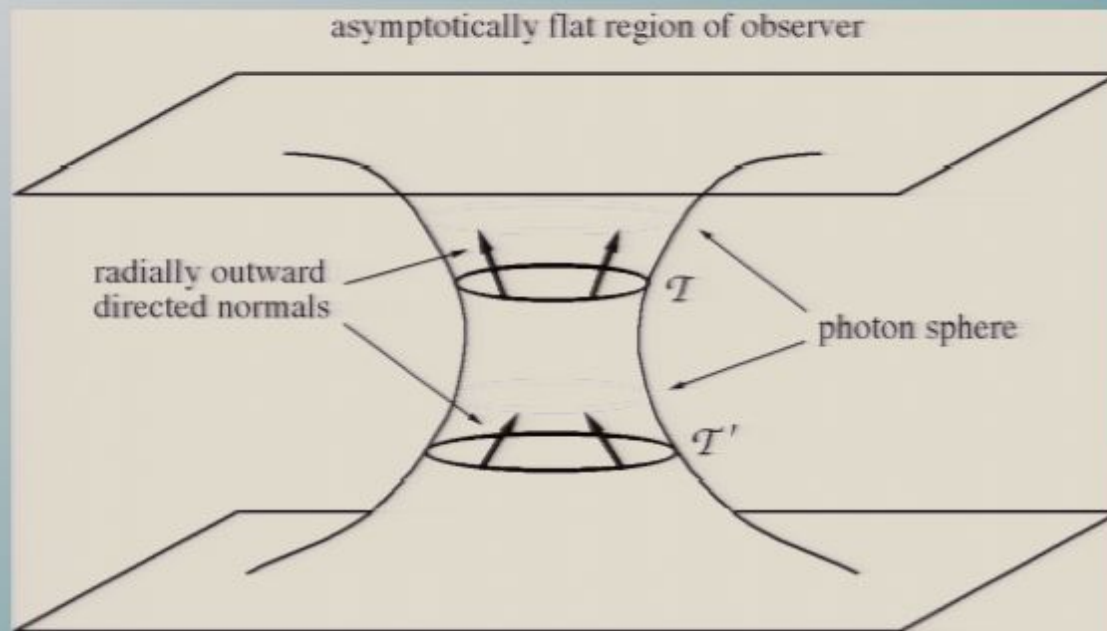






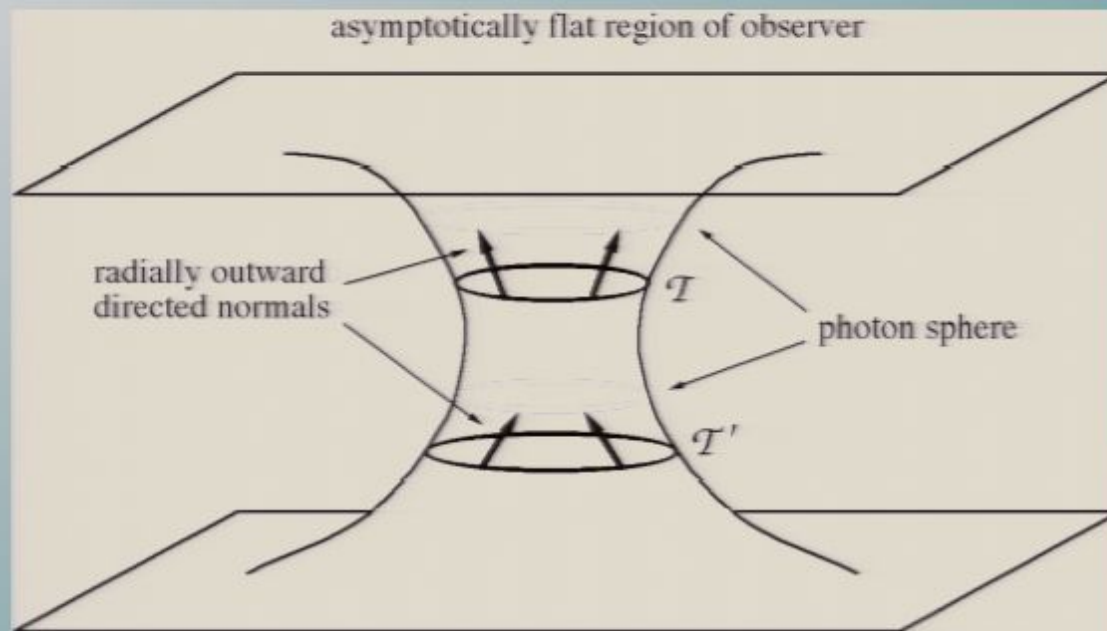


## Schwarzschild throat at $t=0$

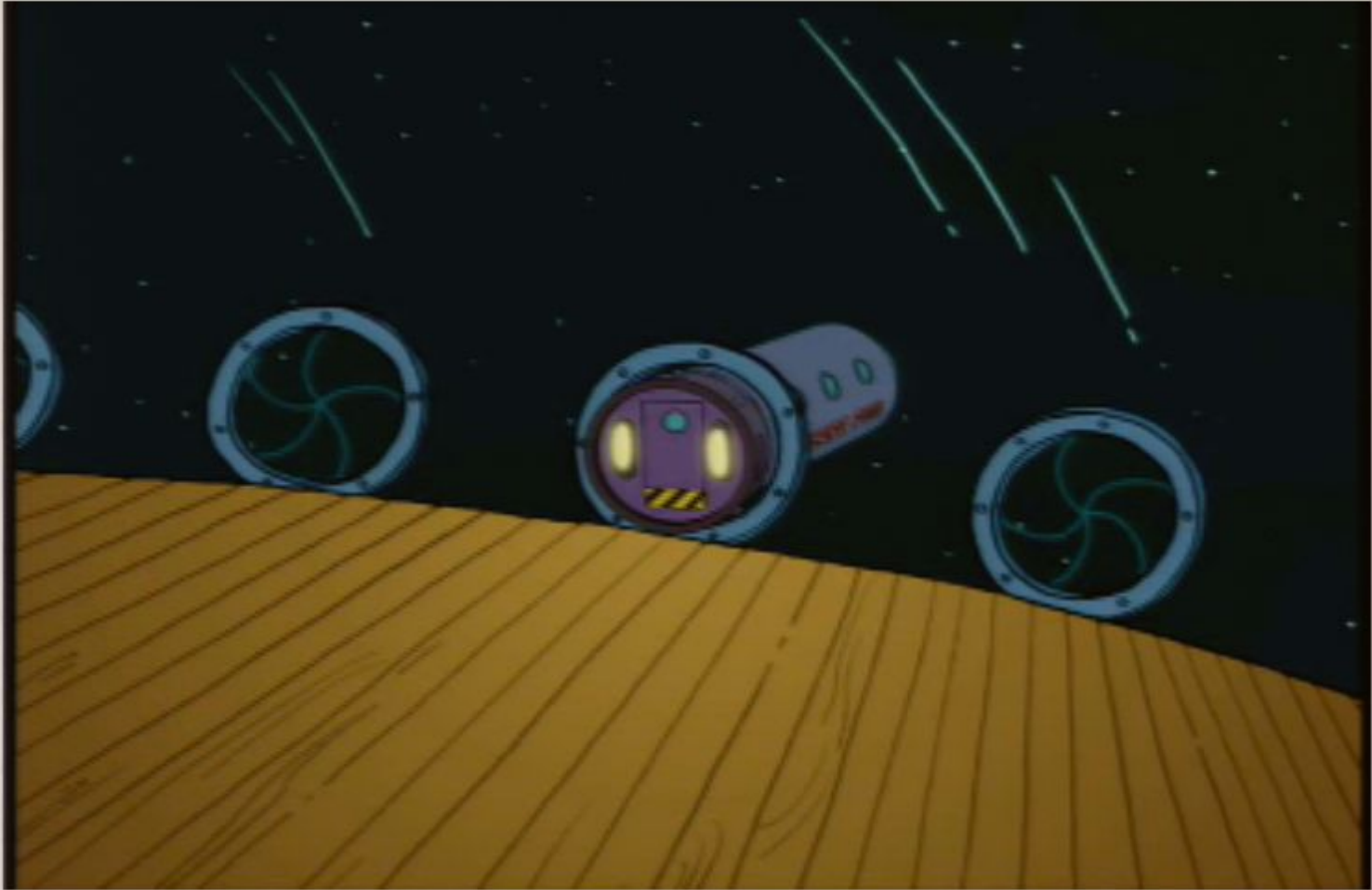


trapped surface  $\tau'$  collapses to zero area in finite affine parameter if ANEC satisfied

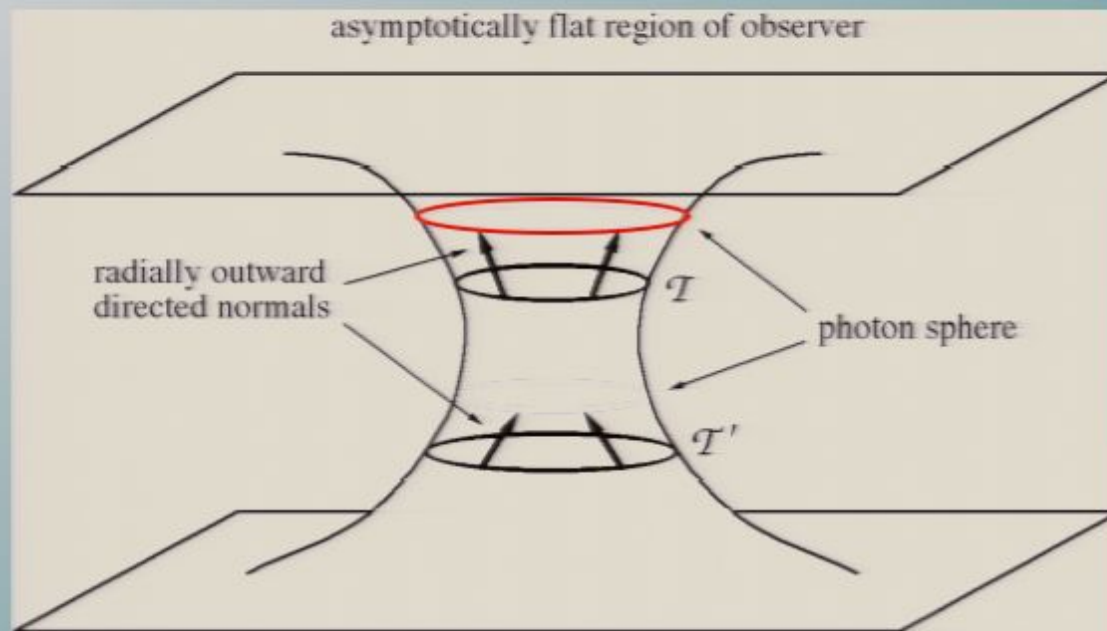
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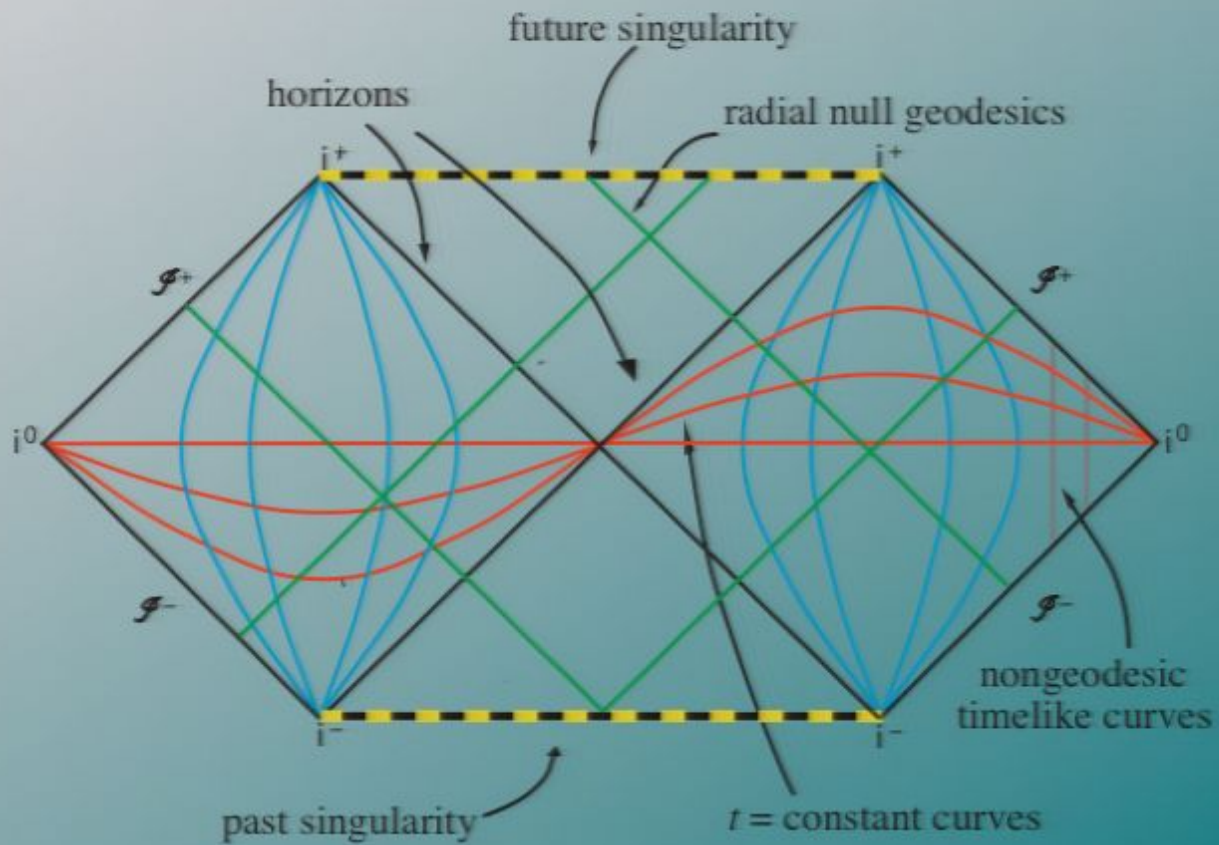
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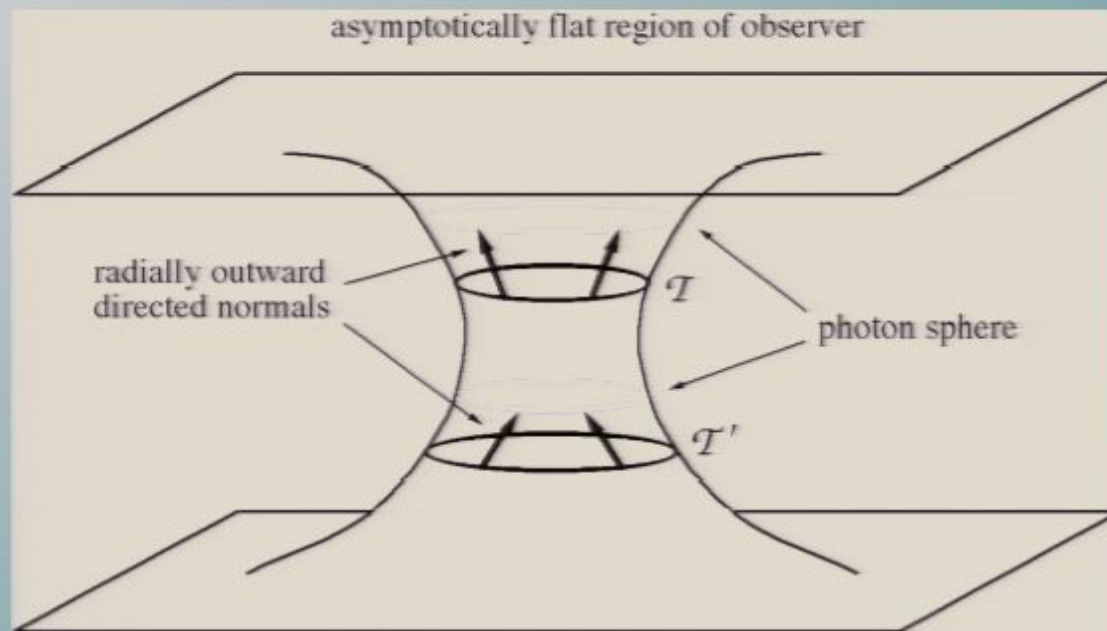
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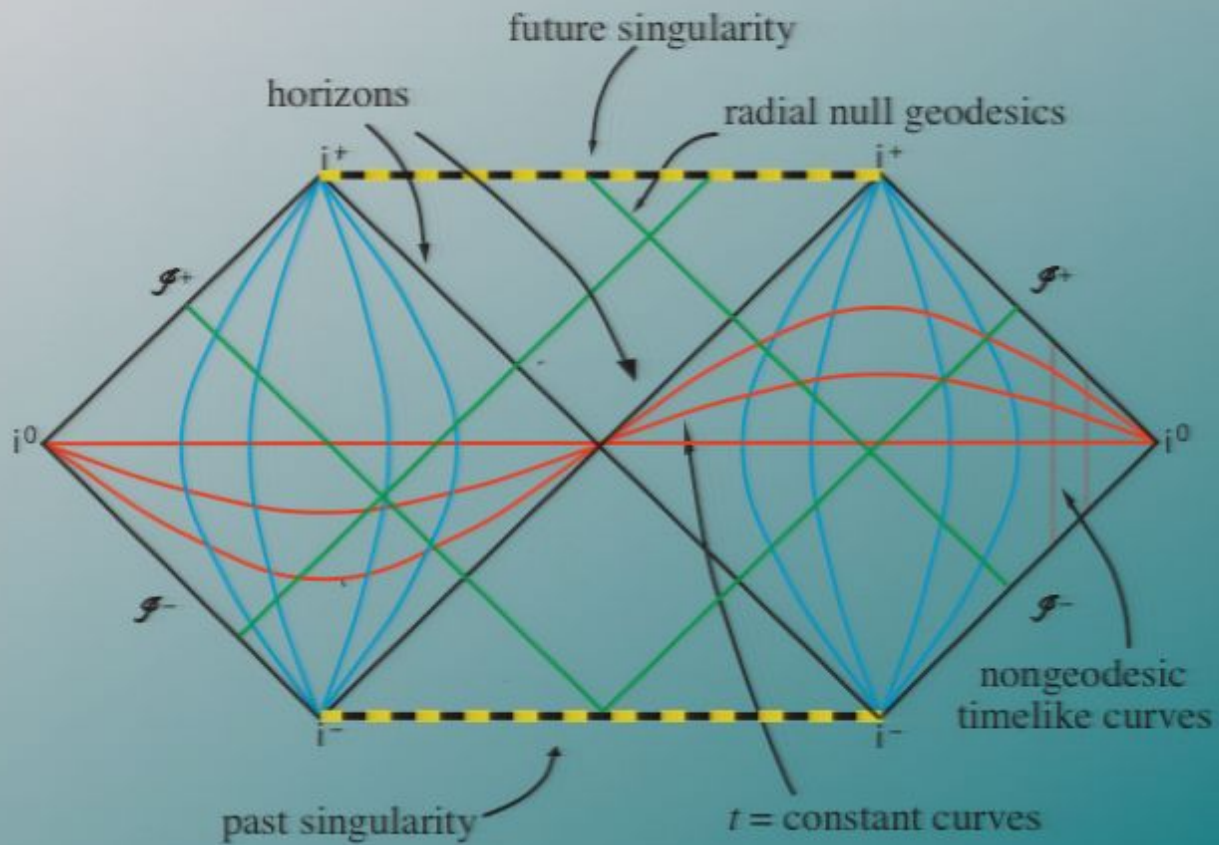


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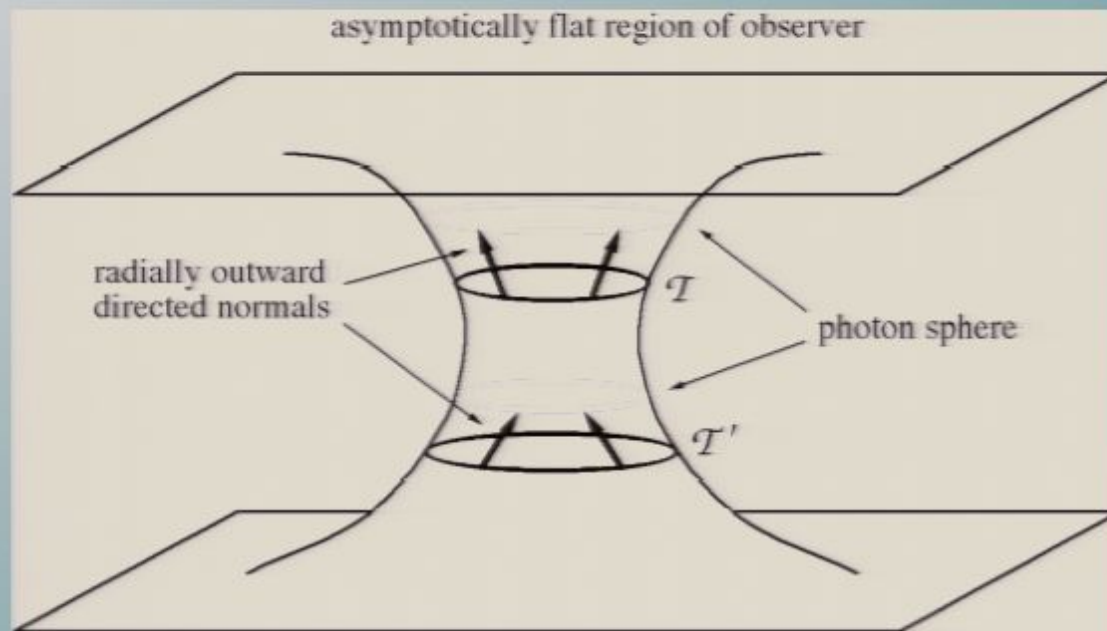


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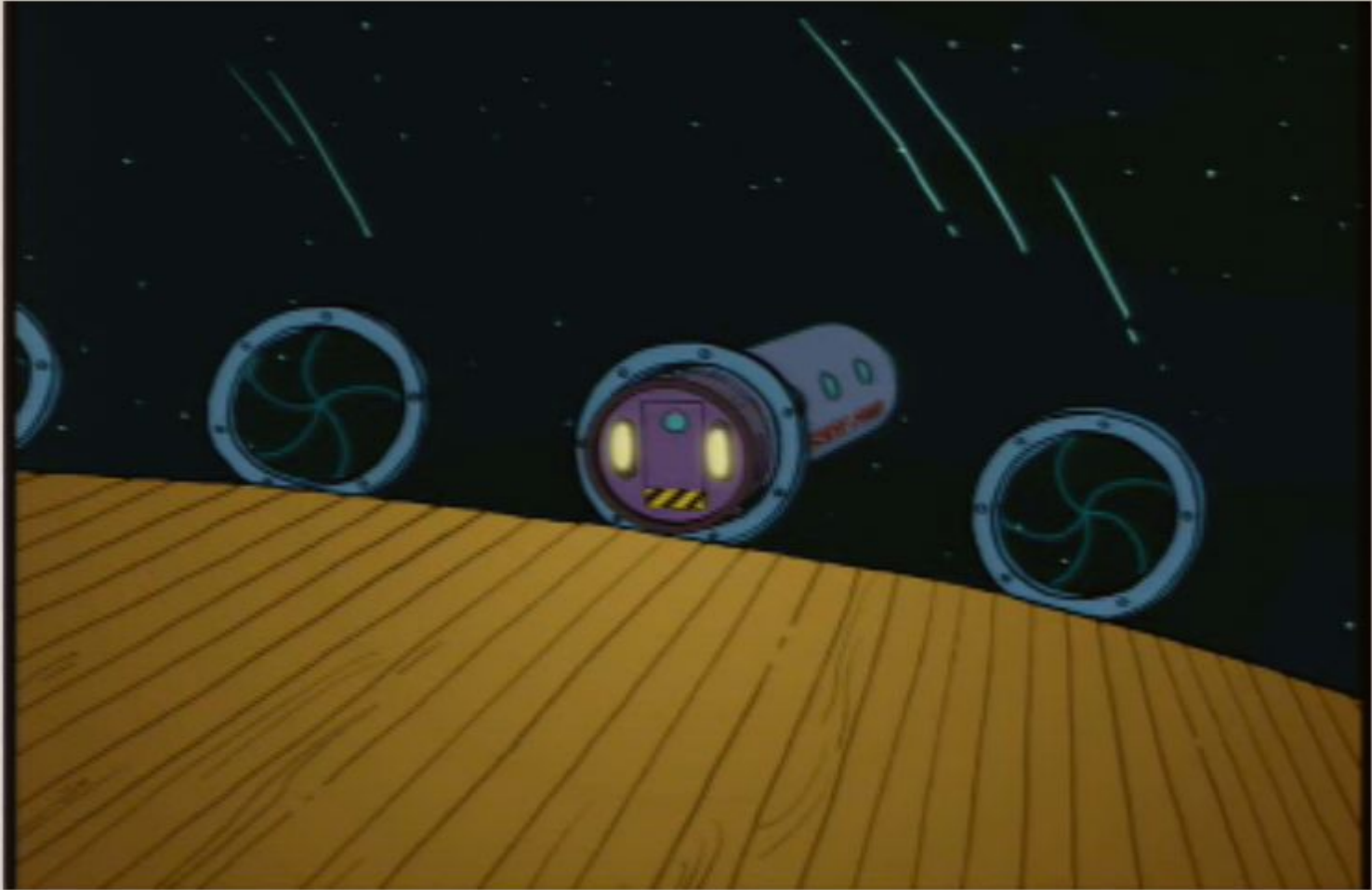
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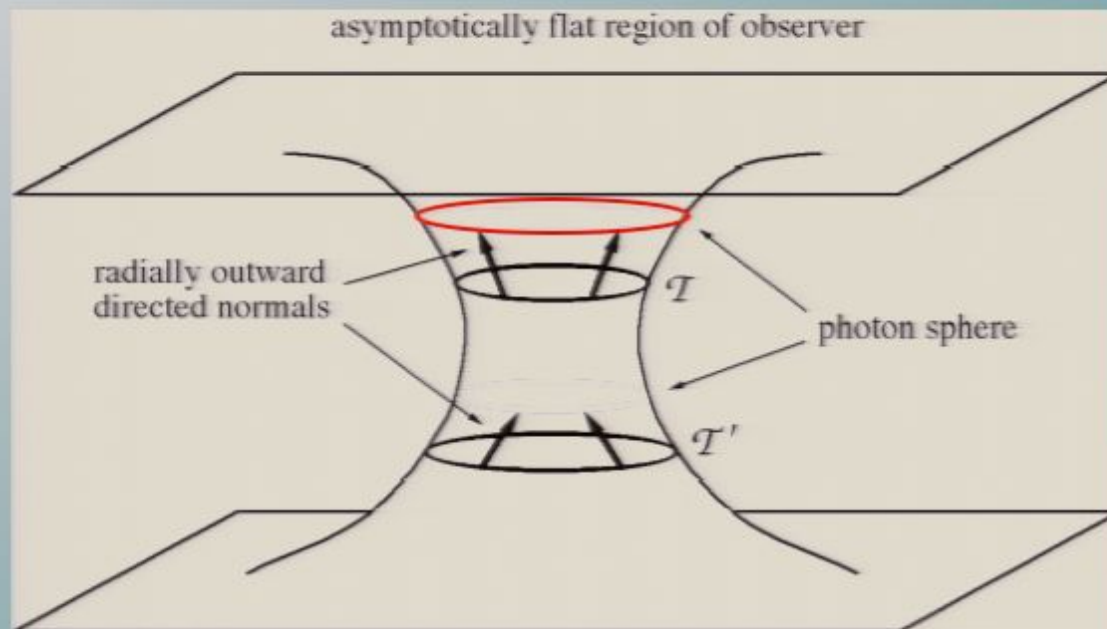


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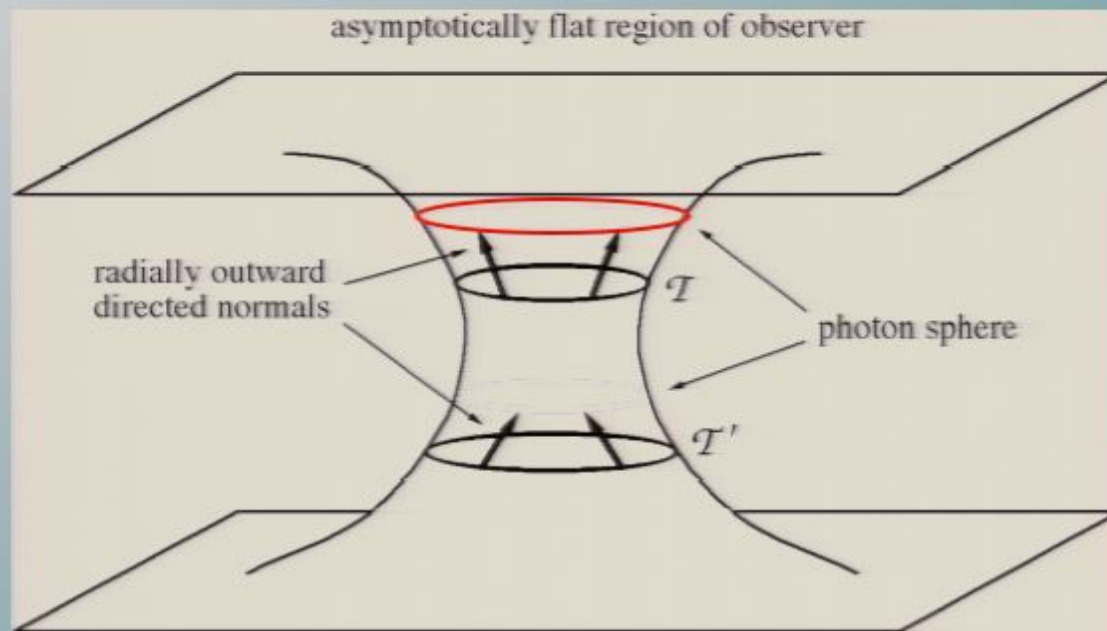


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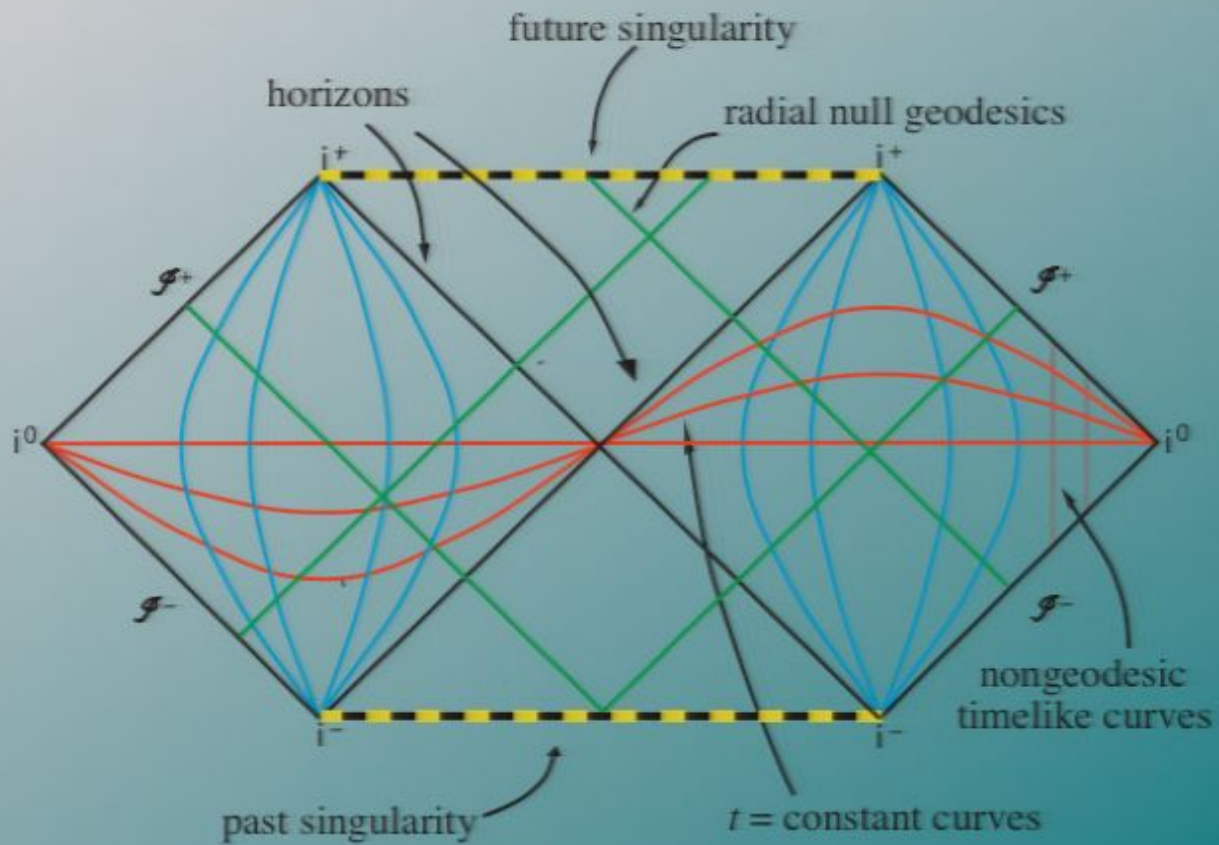
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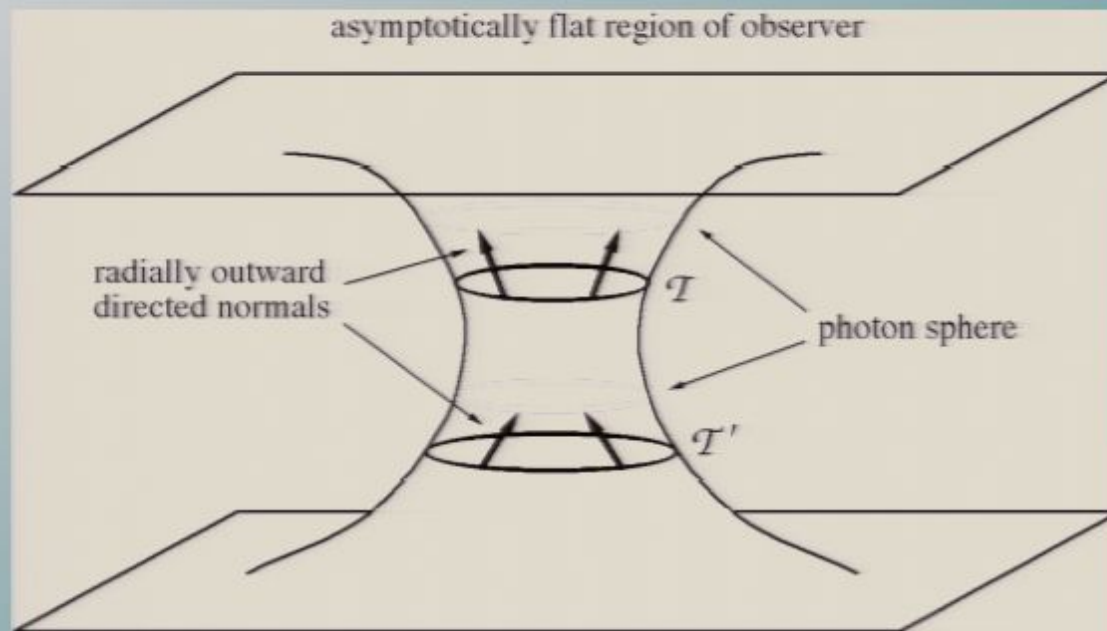


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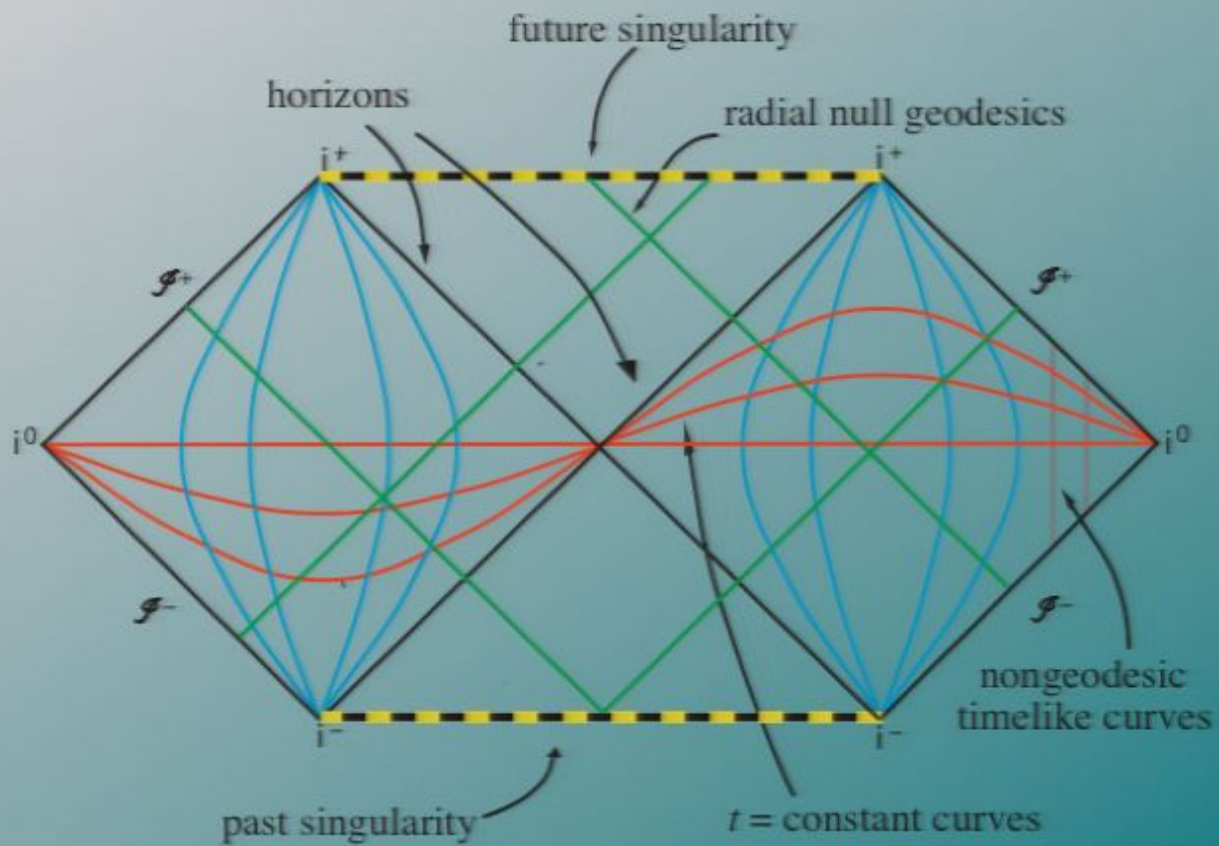


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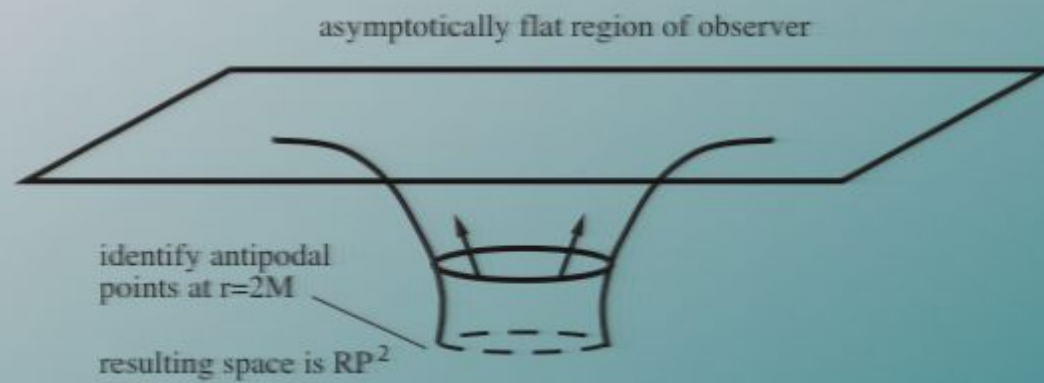
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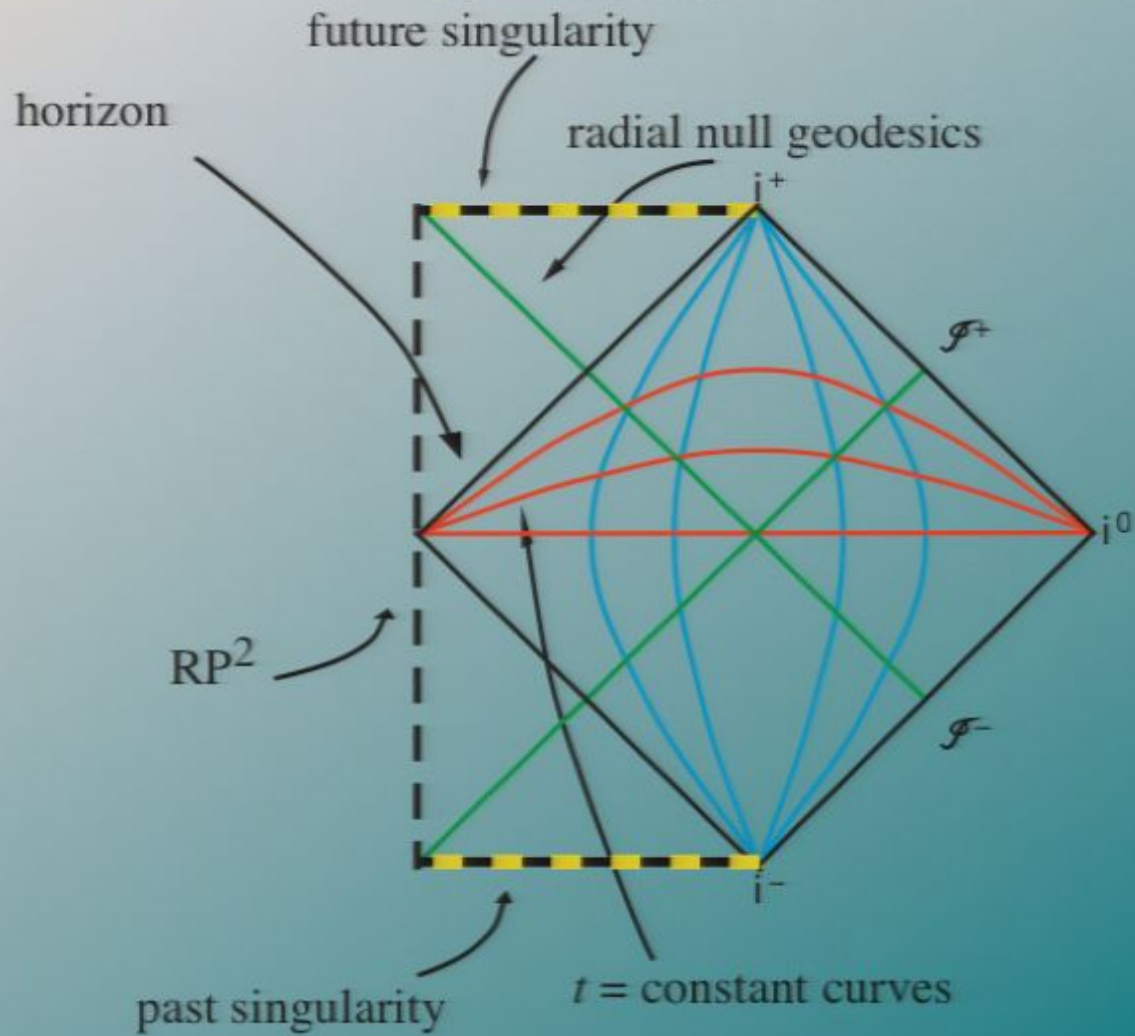




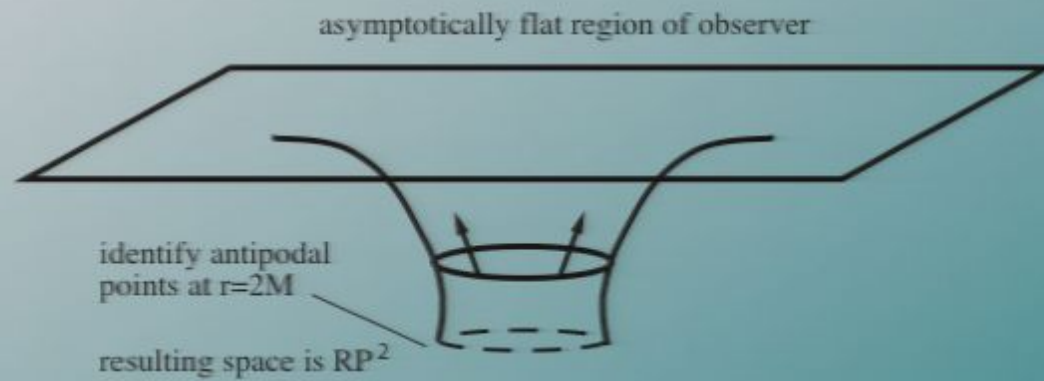
## $RP^3$ throat at $t=0$



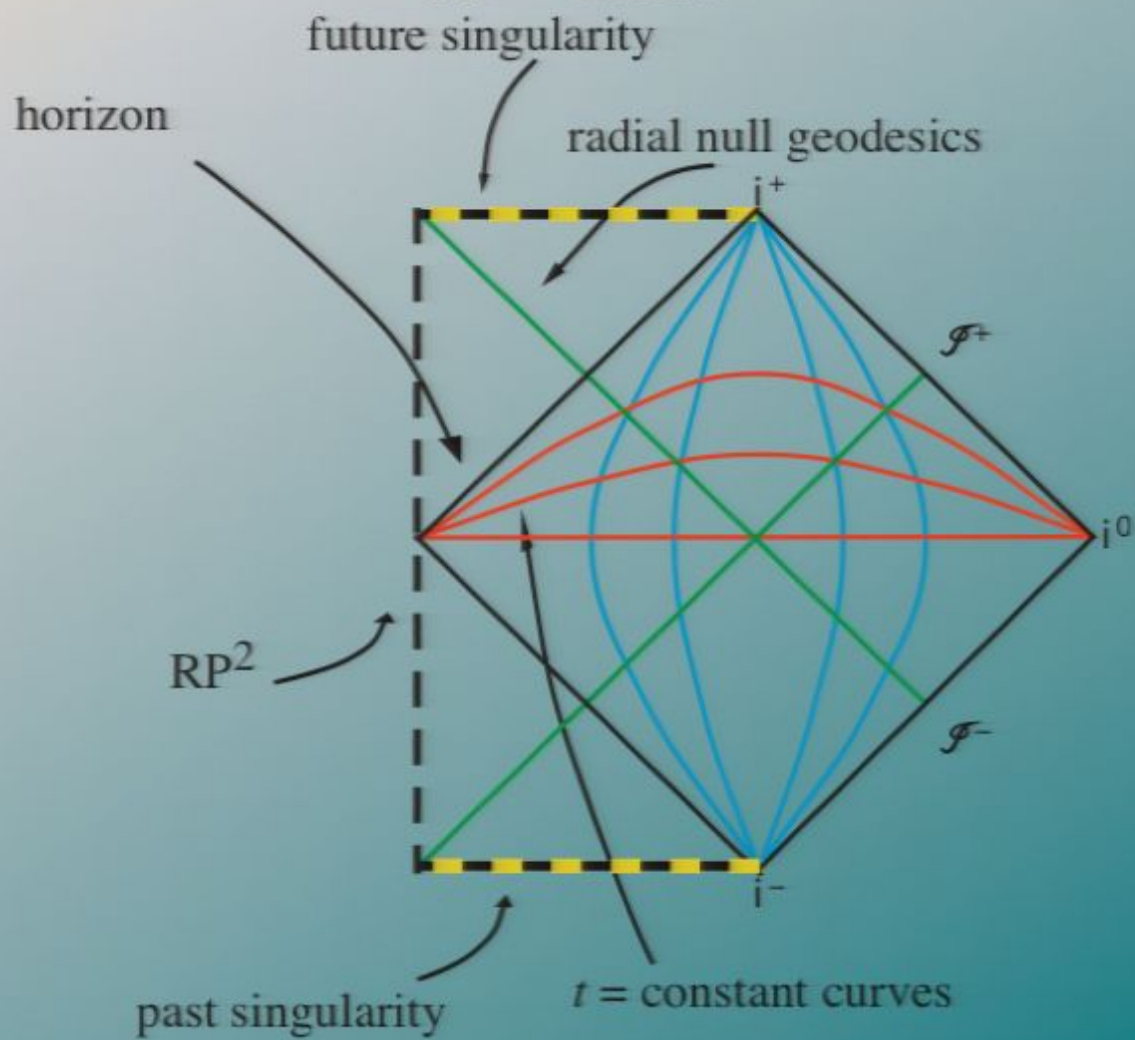
# $RP^3$ Geon



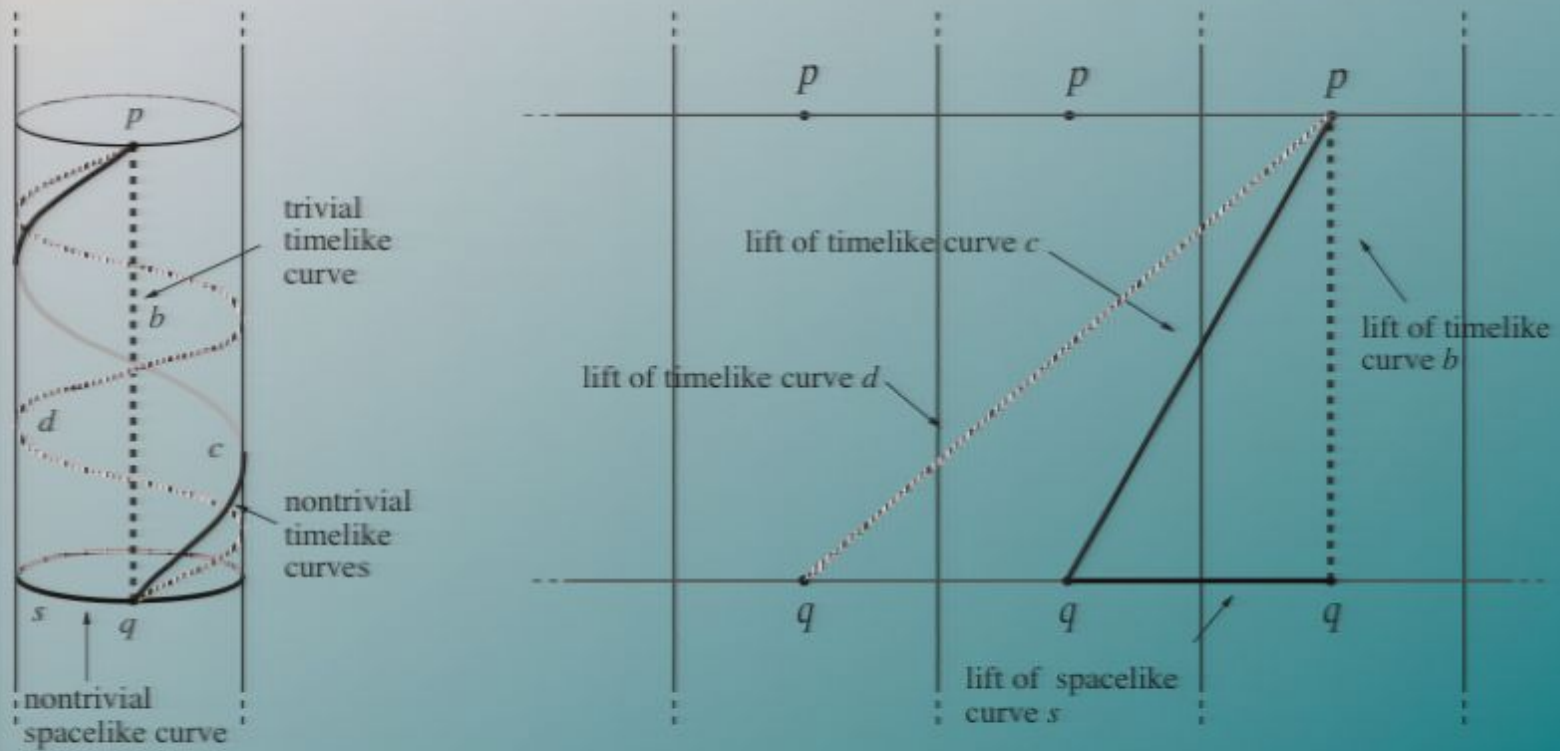
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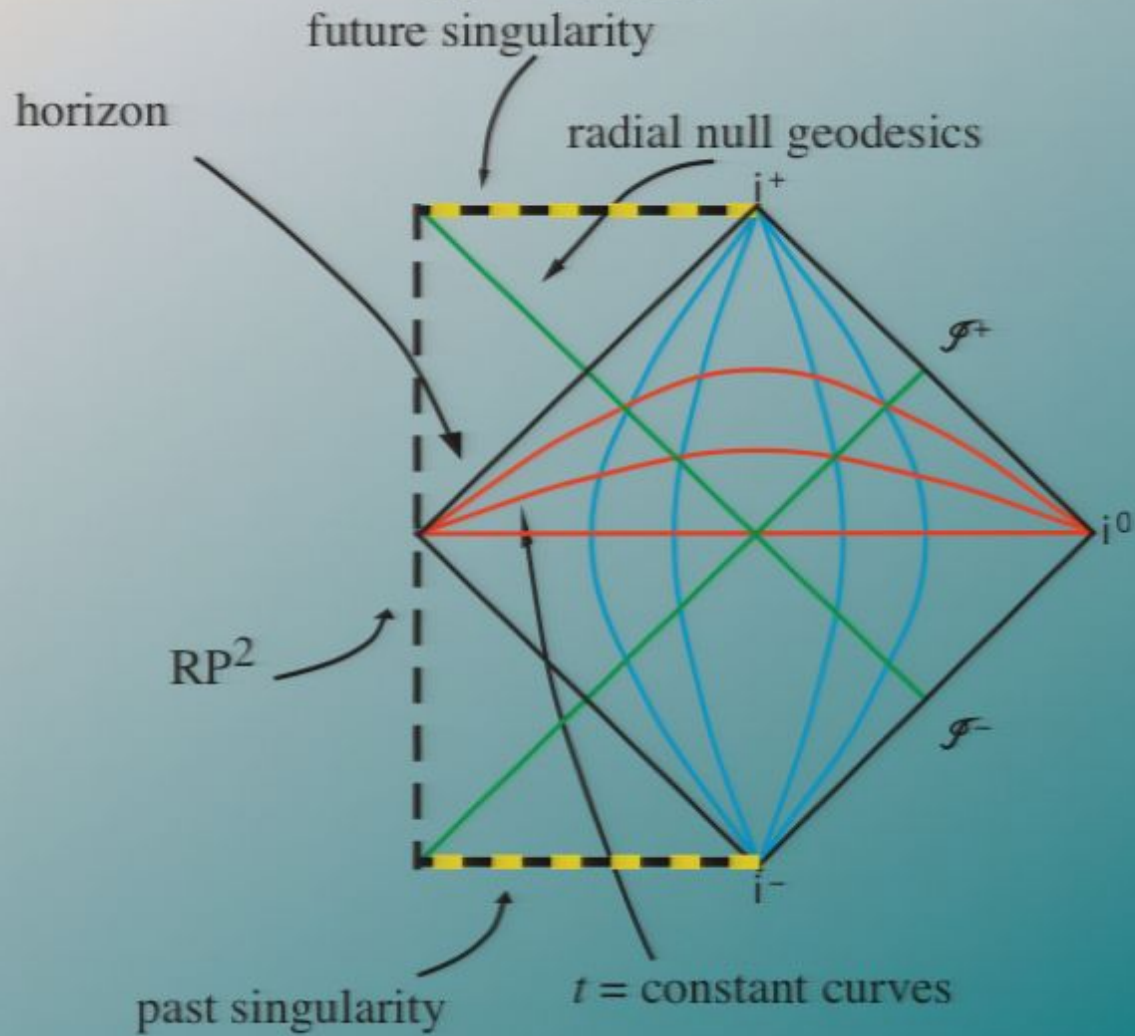


# Covering Space

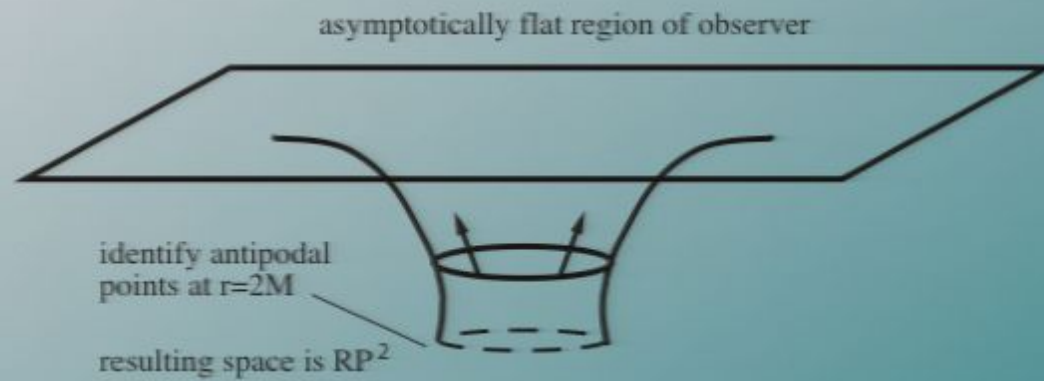




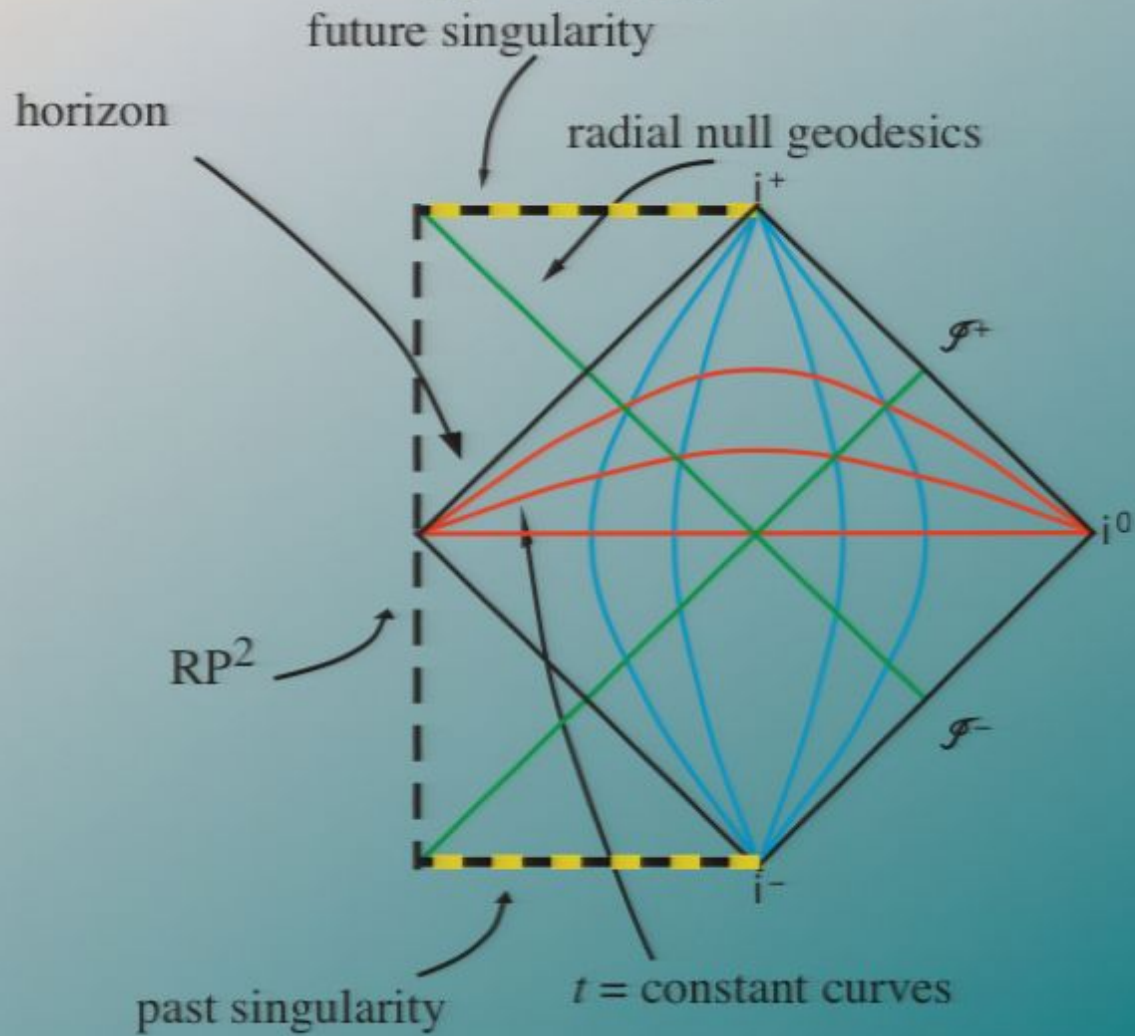
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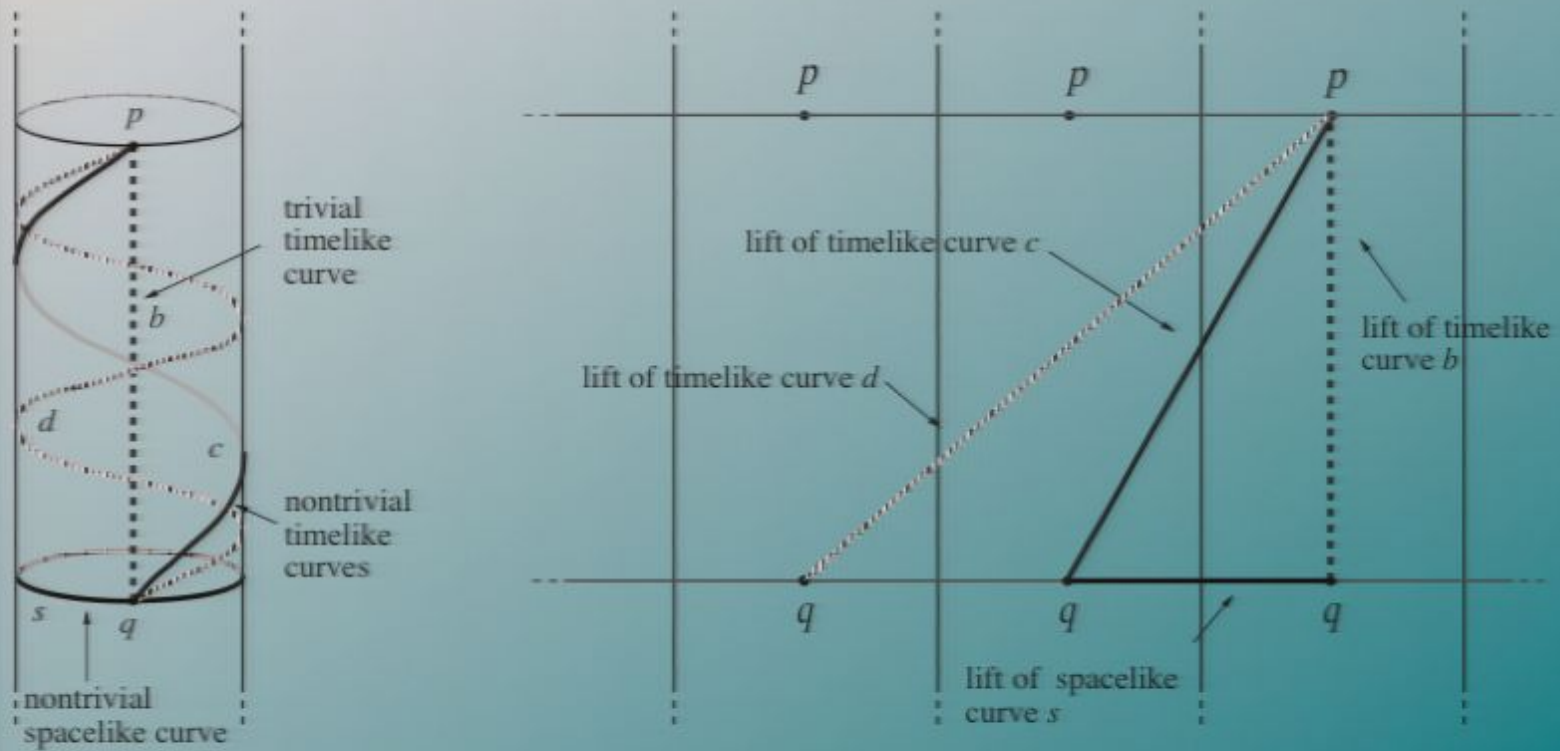
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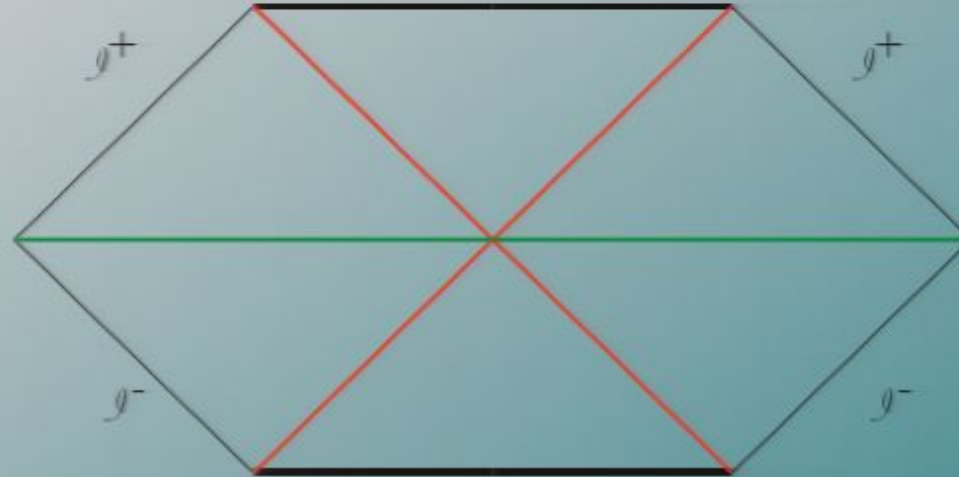
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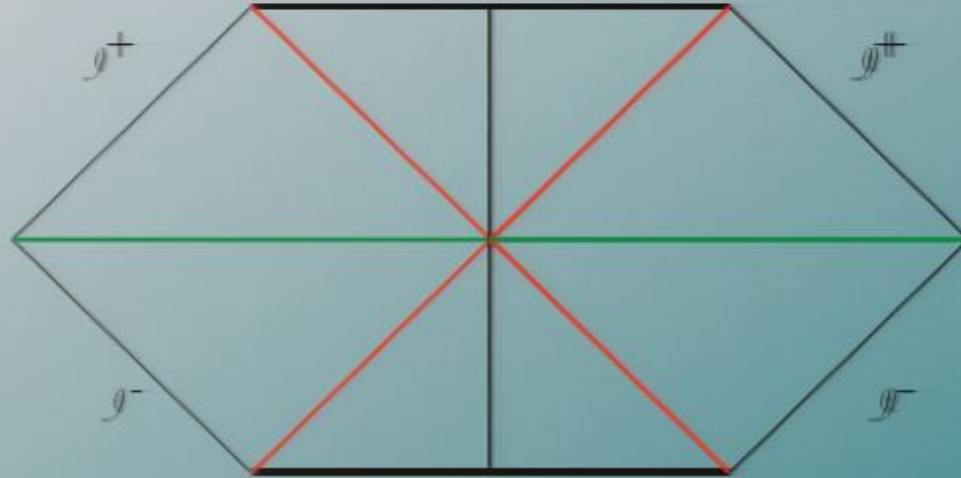
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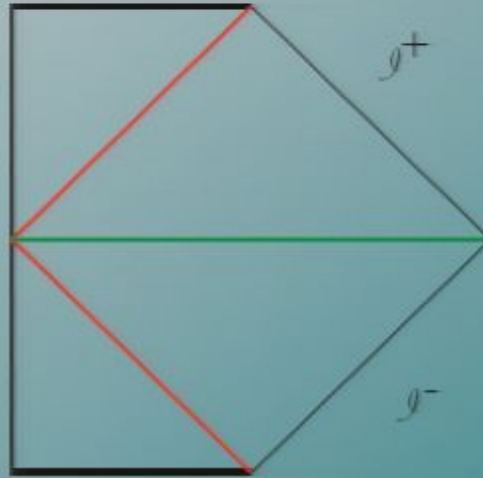


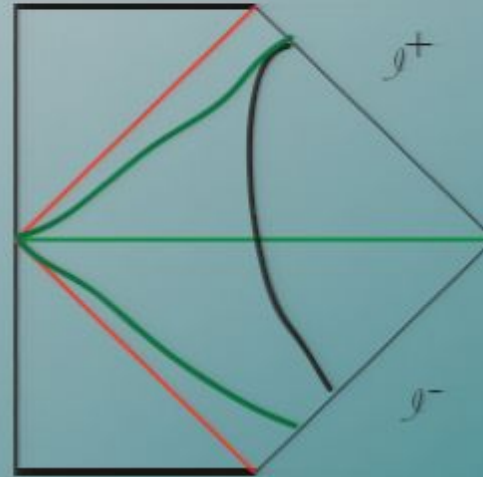
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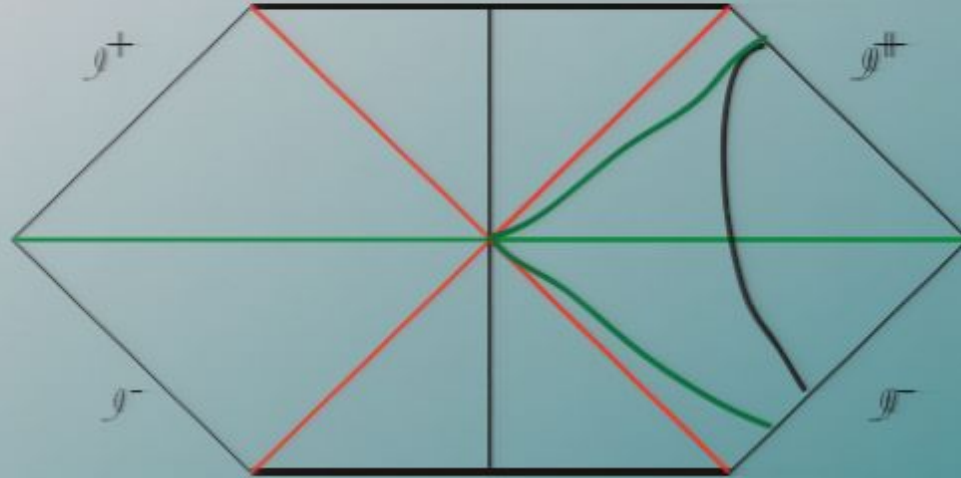






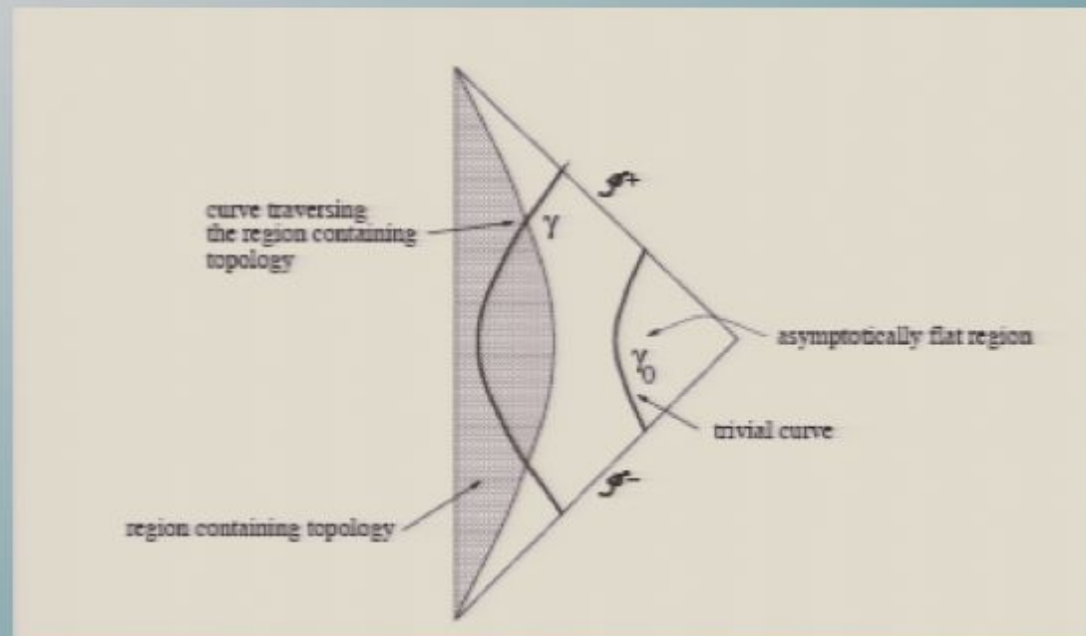


$\mathbb{R}P^3$  Geon



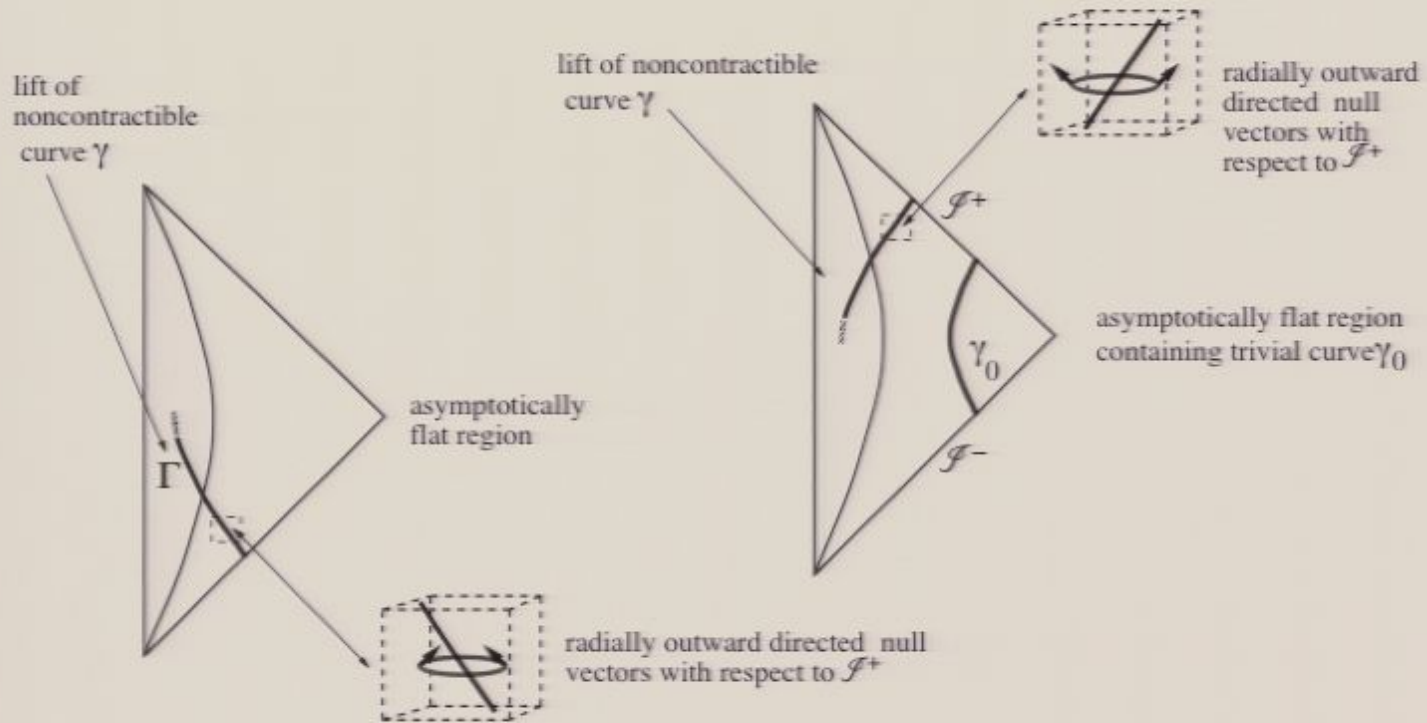
$RP^3$  Geon

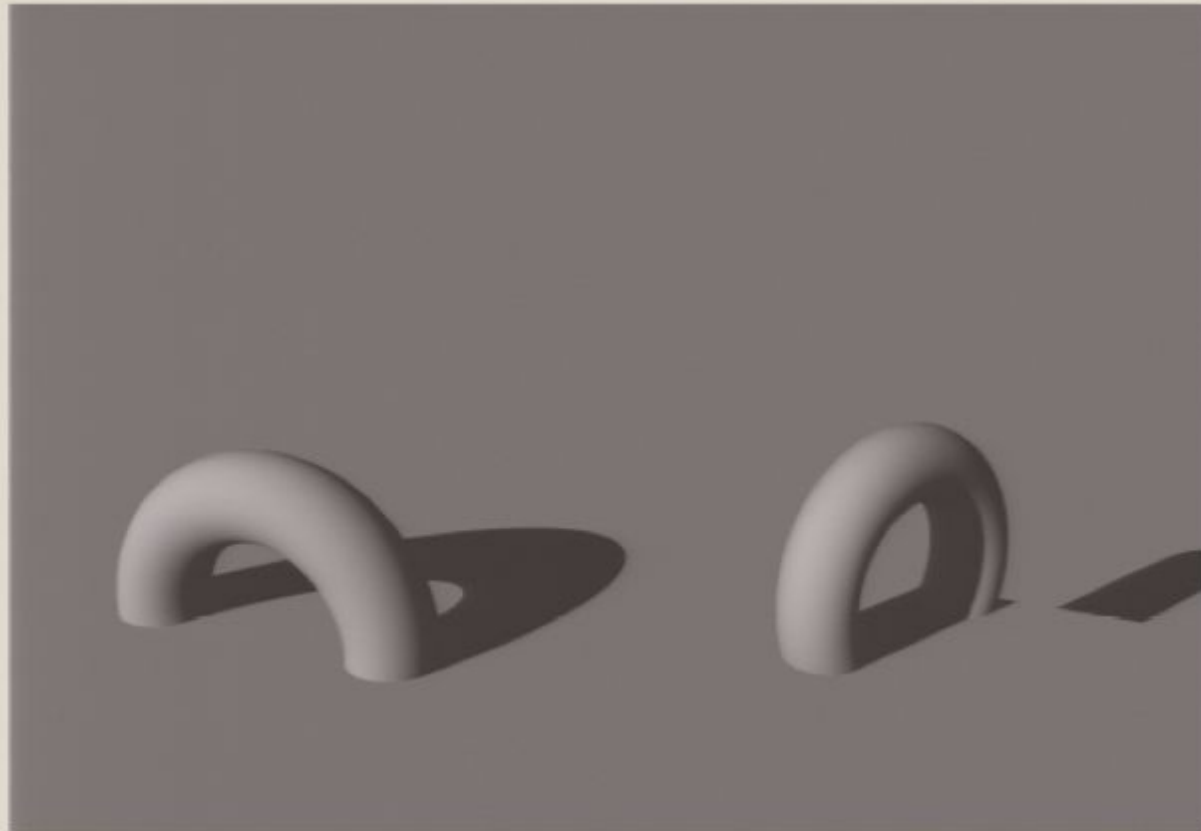
## AF spacetime with non-trivial topology



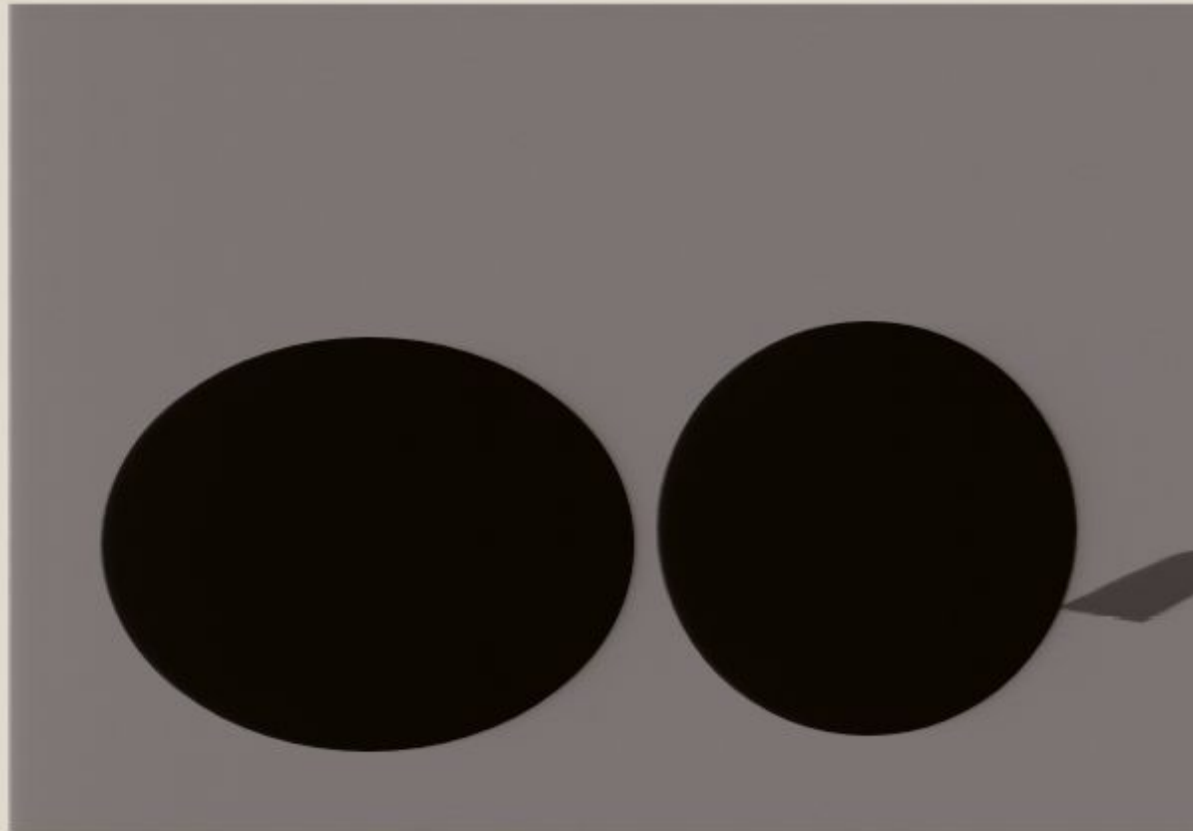


# Simply connected cover





Wormholes collapse to fast to traverse. They are hidden behind black hole horizons.



Wormholes collapse to fast to traverse. They are hidden behind black hole horizons.

## Conclusions

- Wormholes, warp drives and time machines better behaved in fiction than in fact
- General Relativity does not rule them out, but does require negative energy
- If such structures are supported by negative energy, need explain
  - how to build them consistently with the quantum inequalities or
  - why such matter cannot be used nongravitationally





