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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UBC

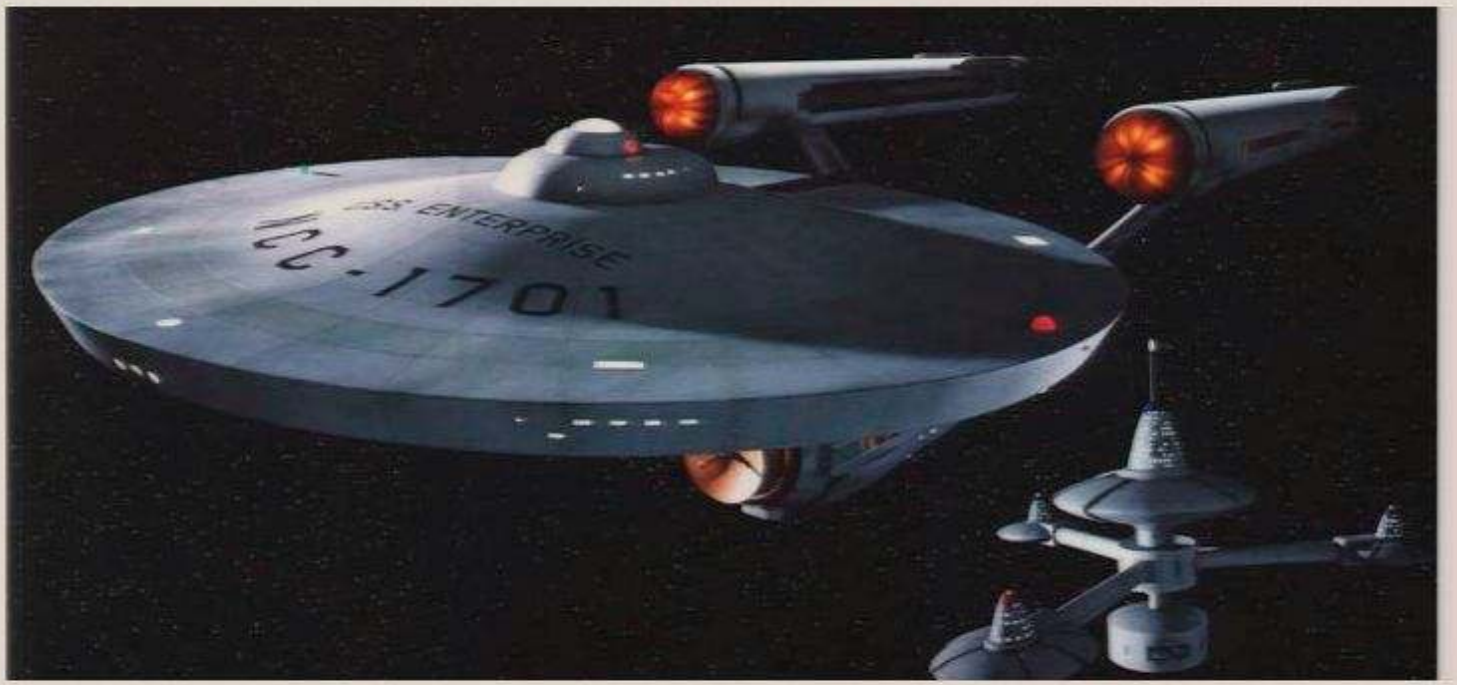
Thanks to NSERC and PI for support
(based on work done in collaboration with D. Witt)

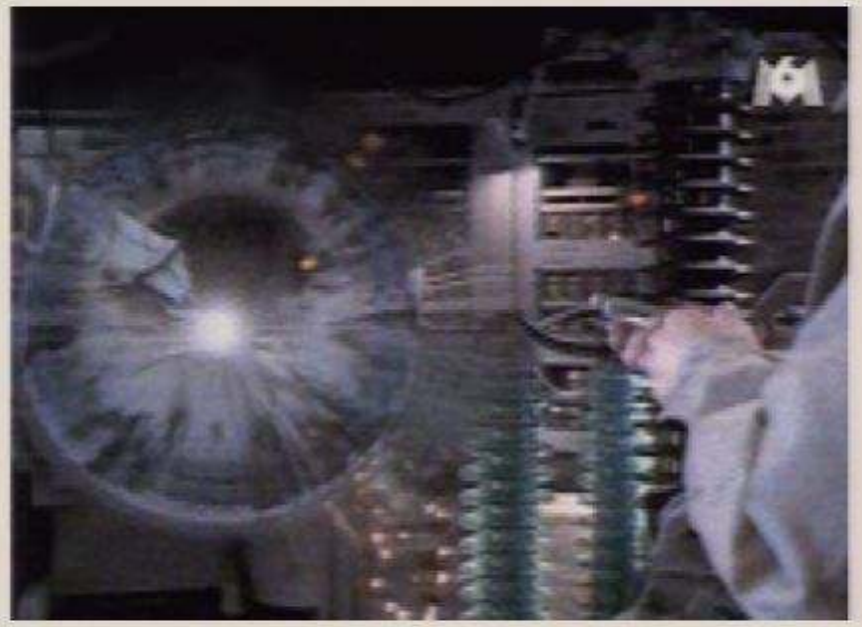
Waterloo, March 2006

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

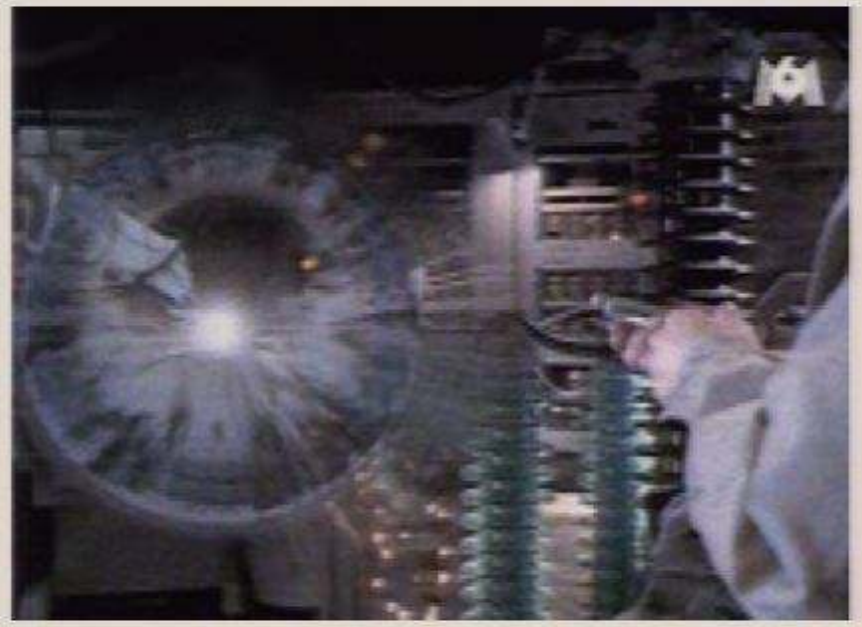
Time Machine: Doctor Who (1963)

Warp Drive: Star Trek (1966)





Wormhole:
Sliders (1995)



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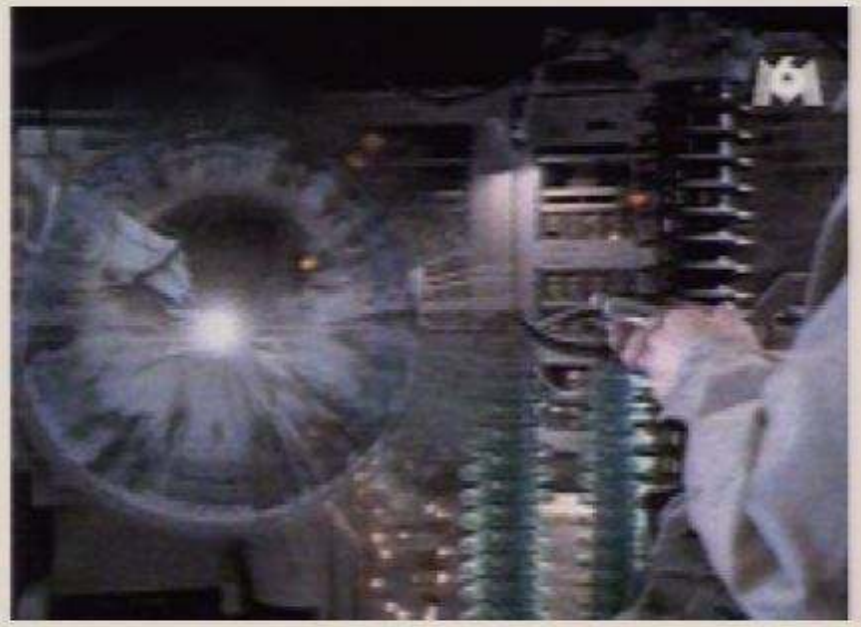


Wormhole:
Sliders (1995)

- 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.

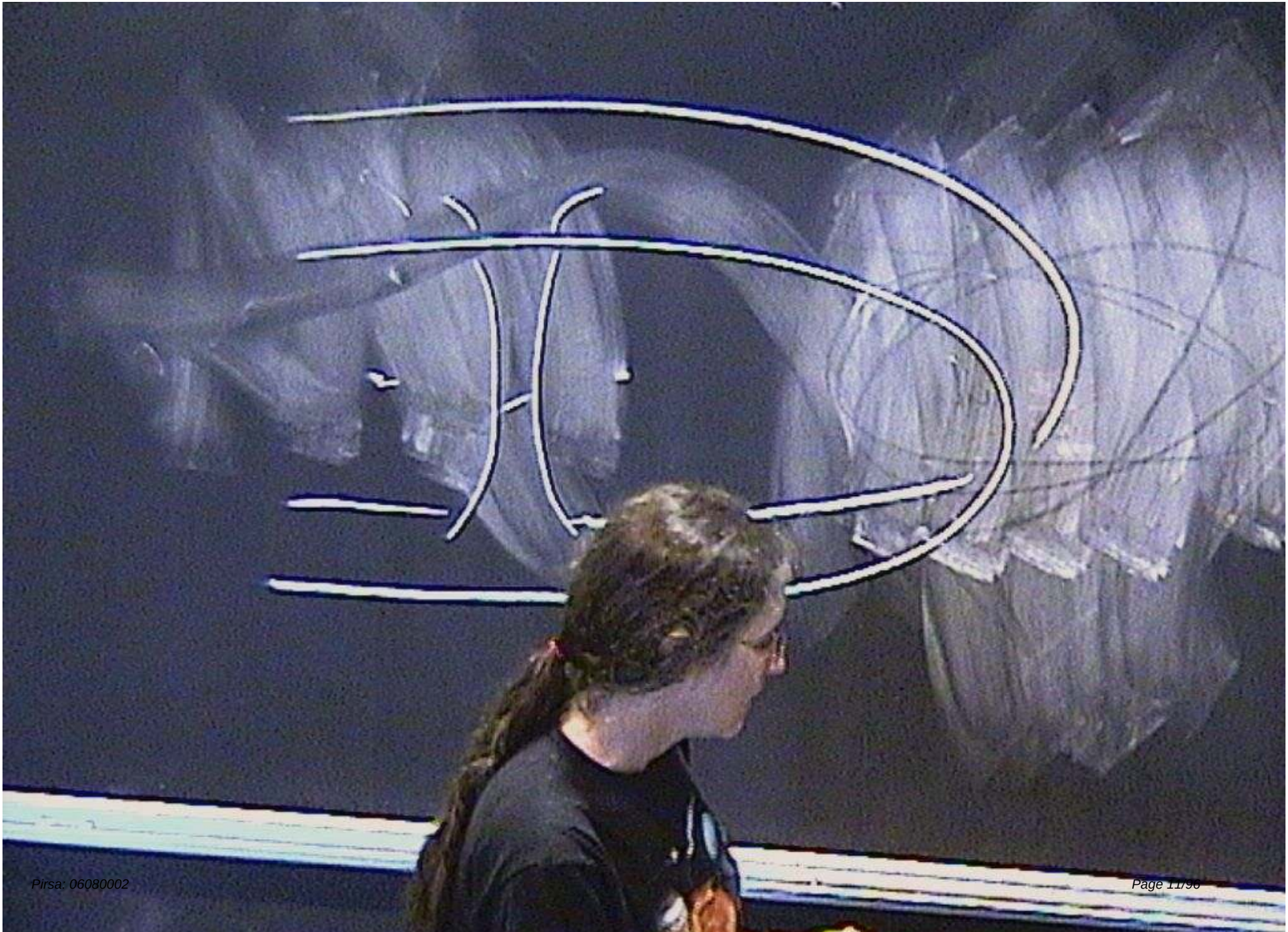
How to build a warp drive, traversable wormhole or time machine in three easy steps

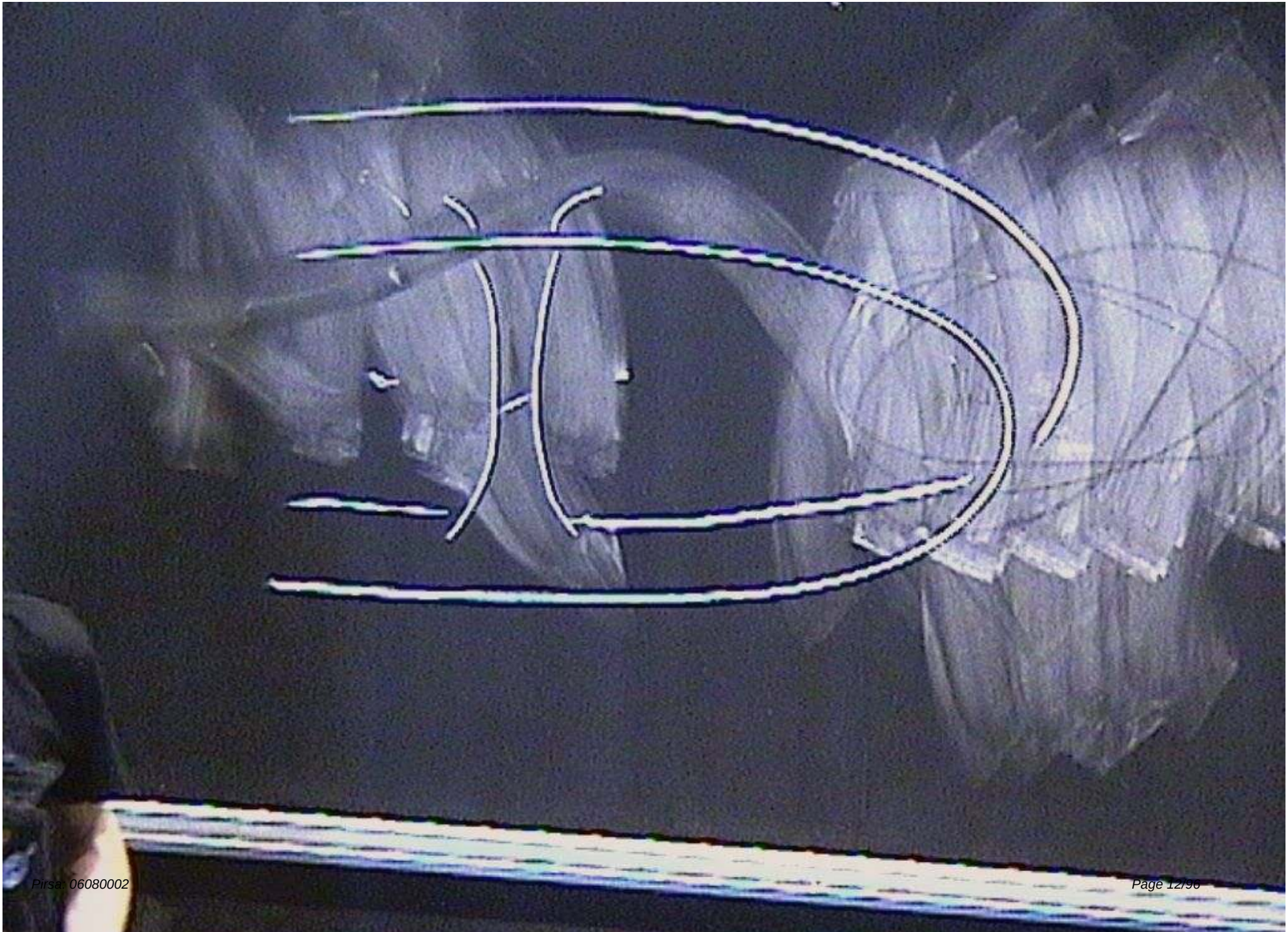
- write down the geometry you want
- compute the Einstein tensor
- Posit matter with a stress energy = this Einstein tensor

Einstein equations:

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

"Curvature" = matter





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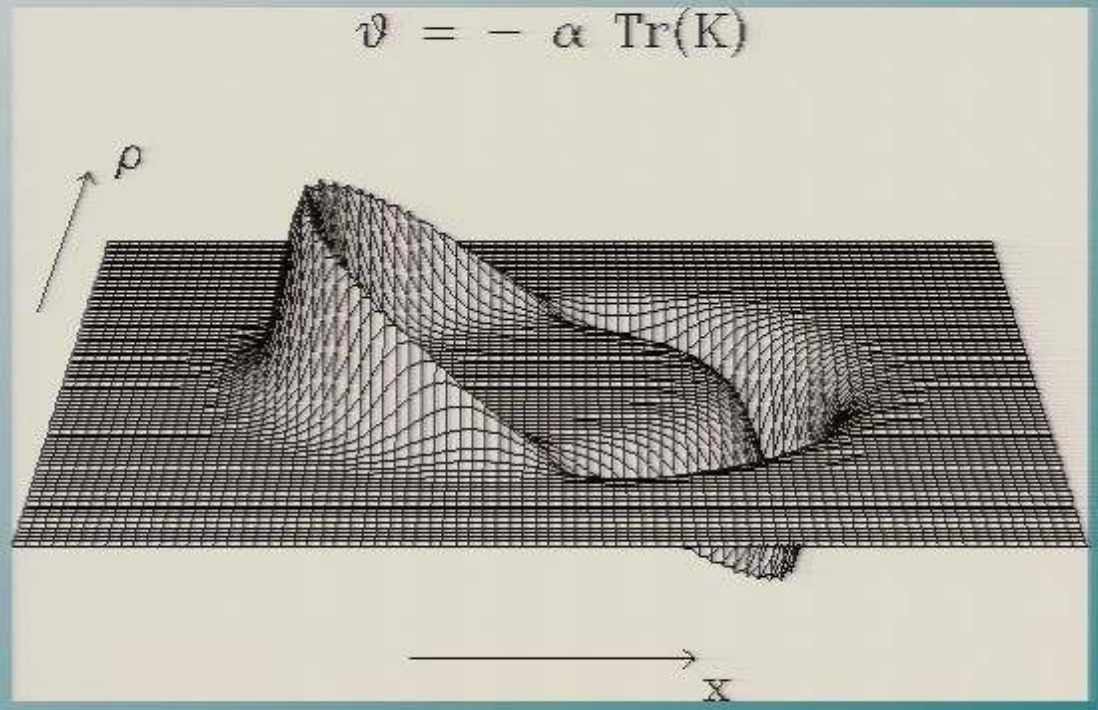
Alcubierre warp drive geometry

$$\vartheta = -\alpha\ \mathrm{Tr(K)}$$



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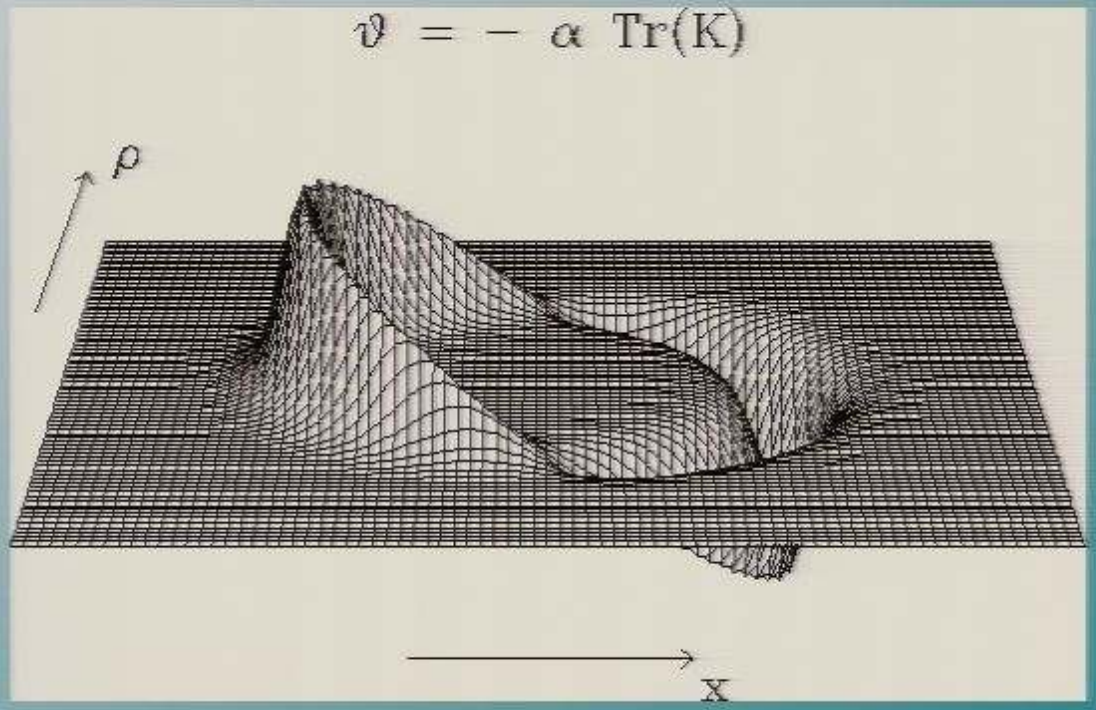

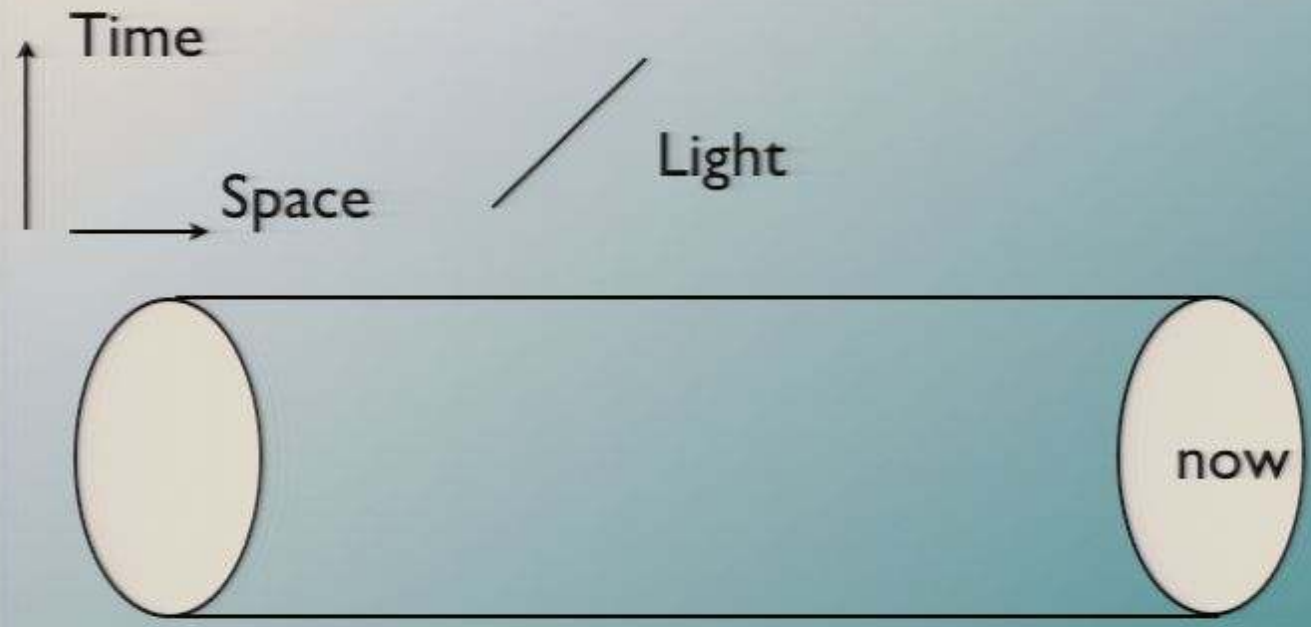

Time machine spacetime geometry

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.

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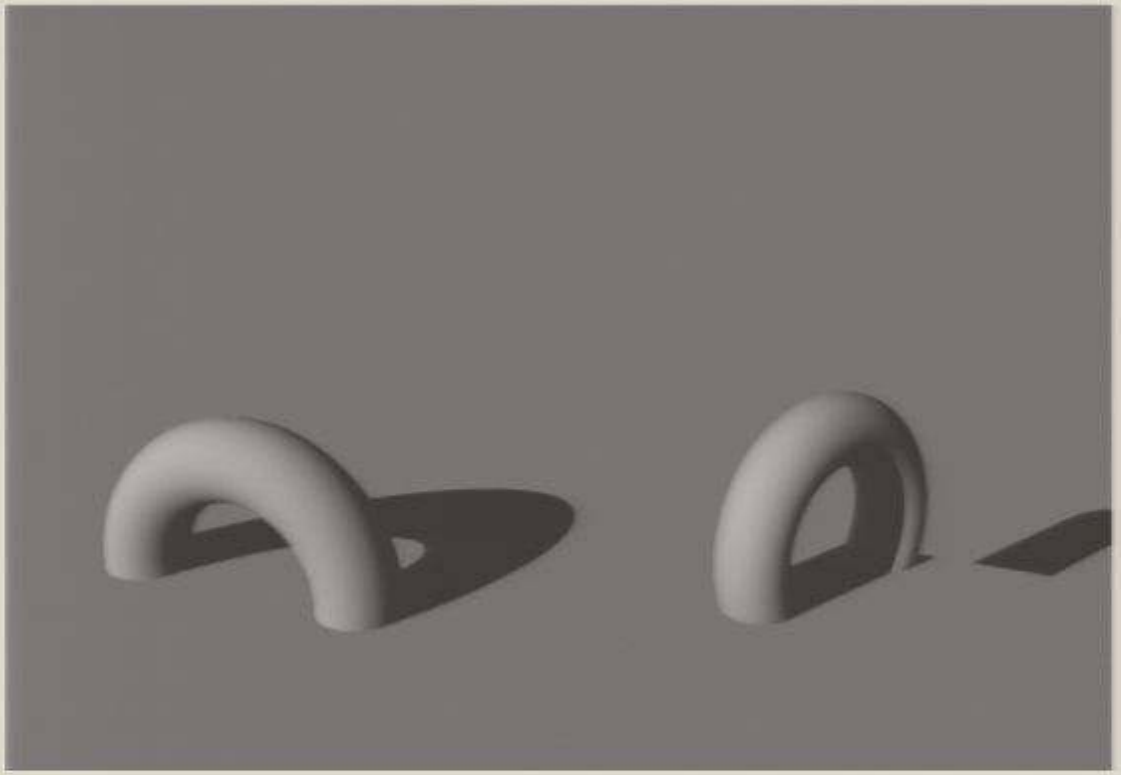
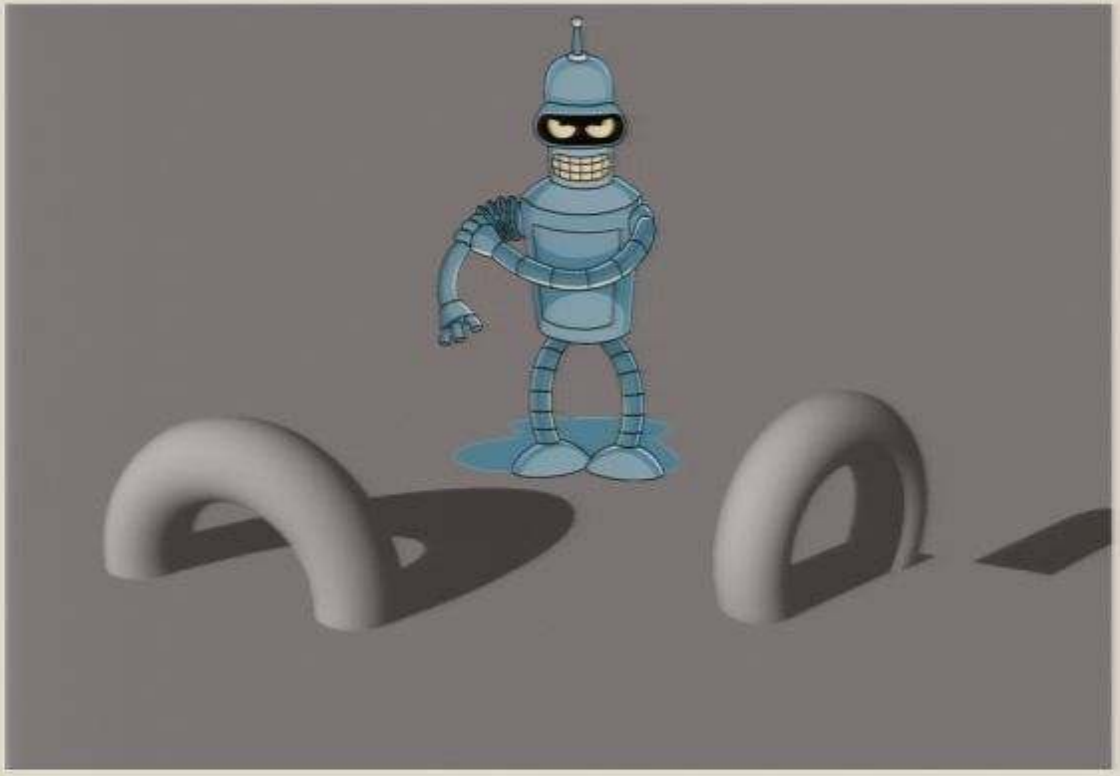
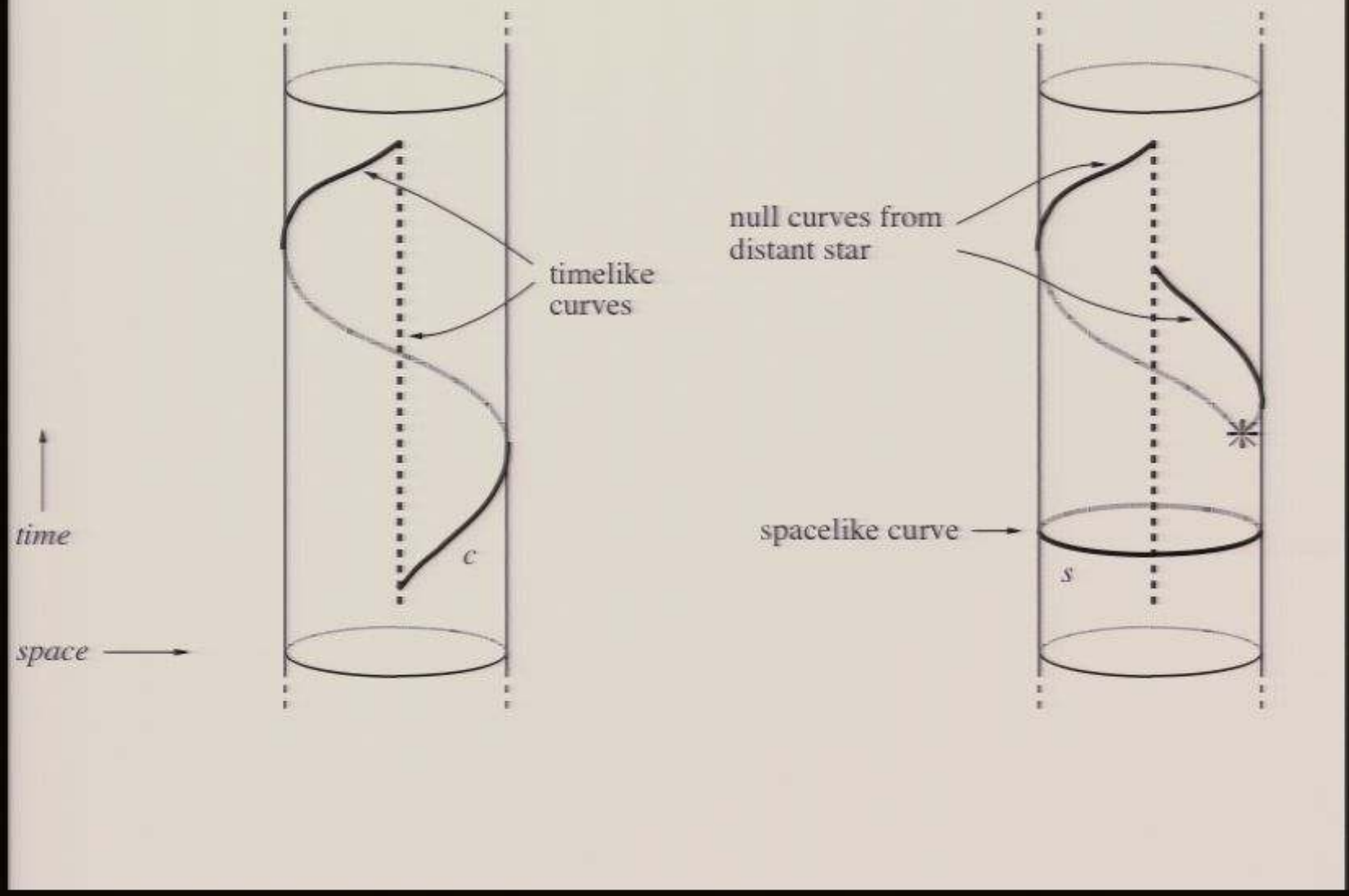
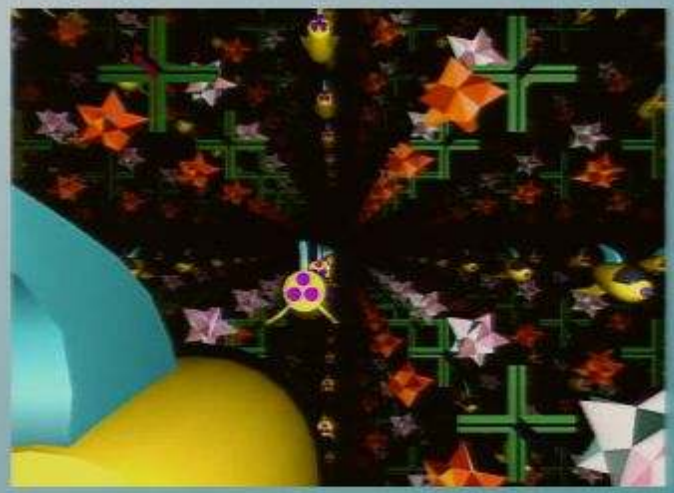


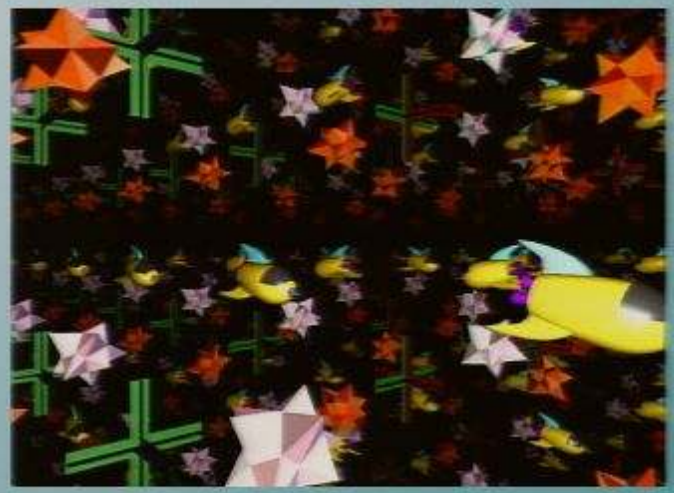
Spatial projection of probing the spacetime topology



Spatial projection of probing the spacetime topology


timelike
curves
c
time
space
null curves from
distant star
spacelike curve
s





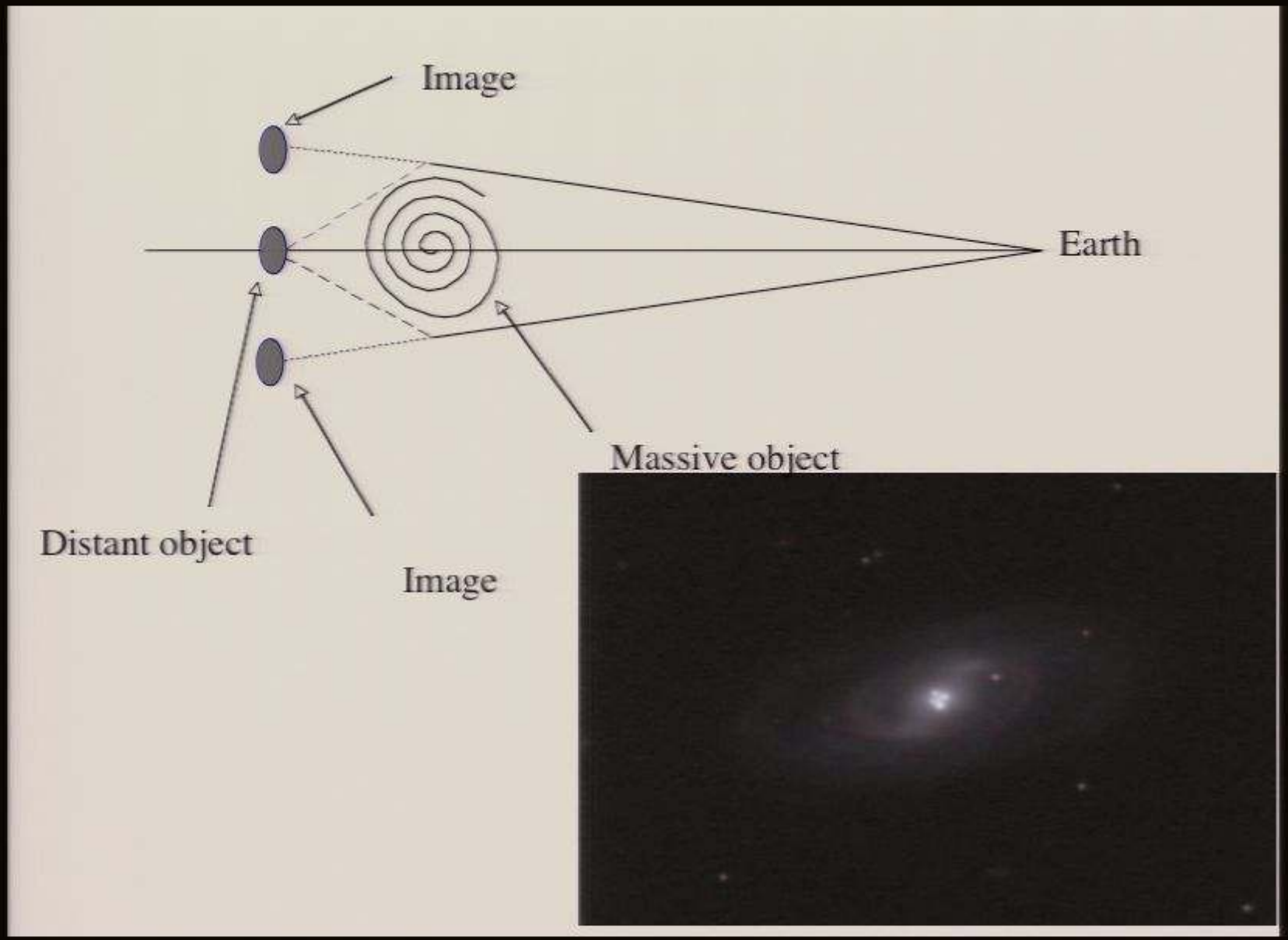


Image
Earth
Massive object
Distant object
Image

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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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-traversible wormholes

  Wheeler, Feynman (1960's)

  Morris, Thorne, Yurtsever (1988)

- Is topology hidden in physically reasonable spacetimes? (Topological censorship conjecture, Witt 1986)

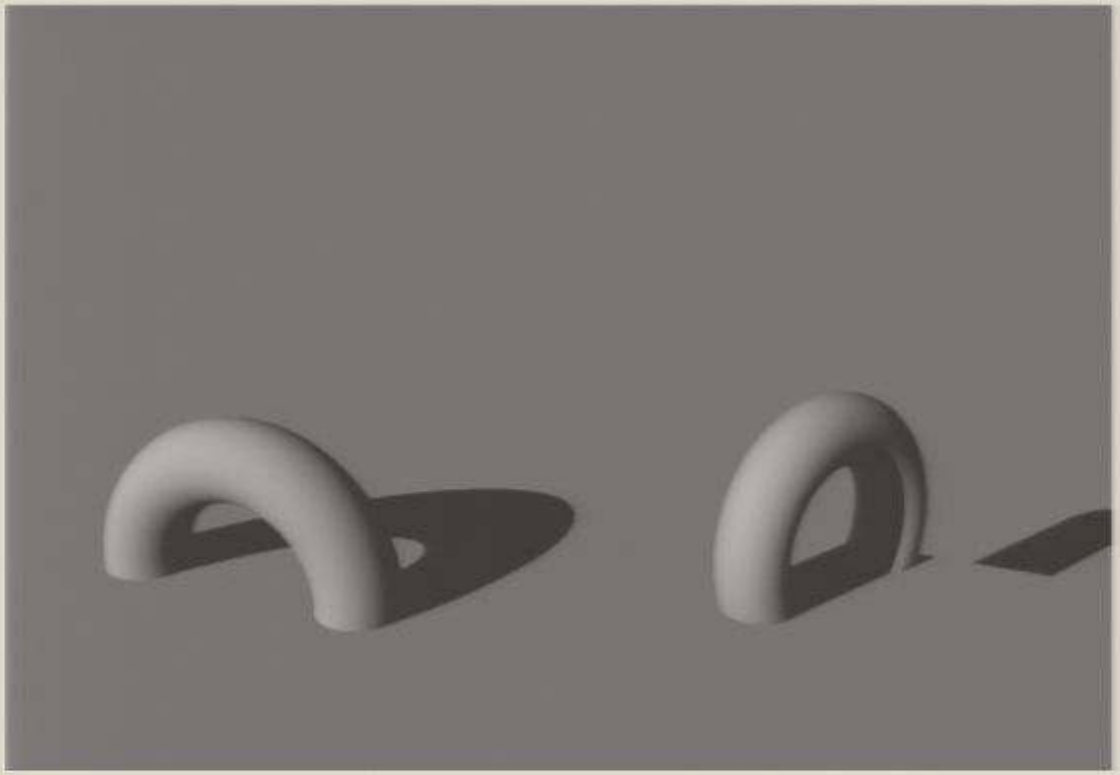
Active Topological Censorship

- **Active Topological Censorship Conjecture:**

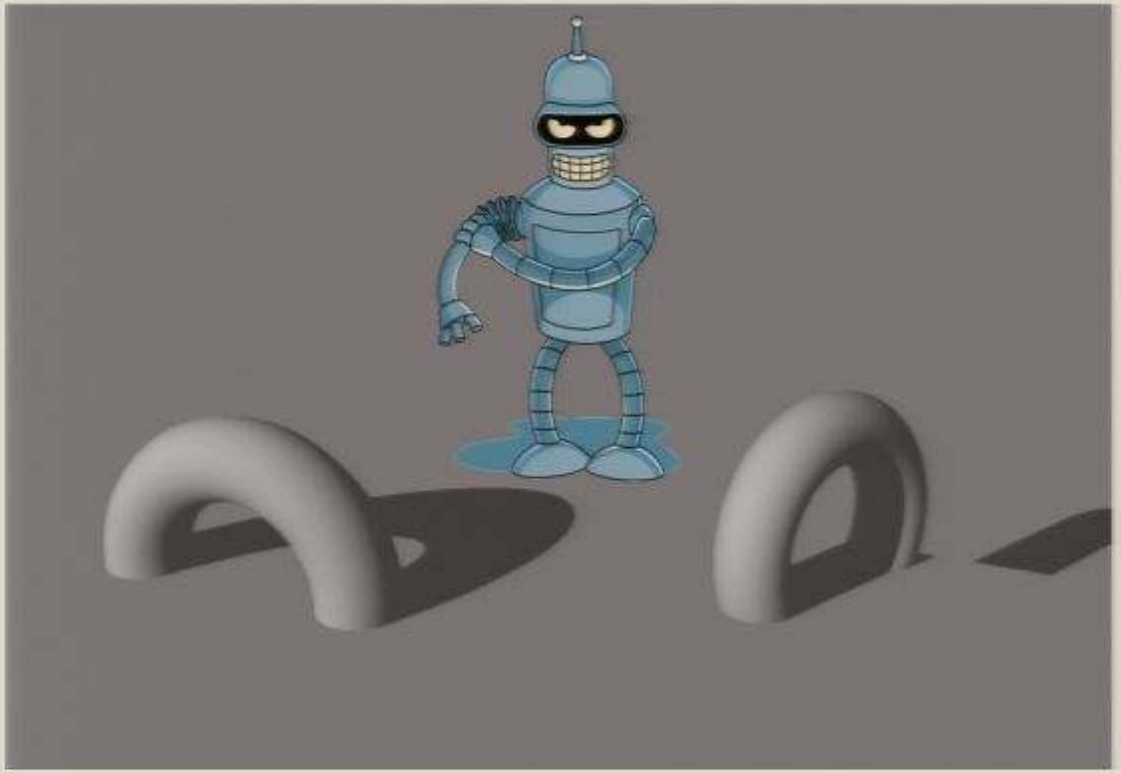
  The topology of any physically reasonable spacetime cannot be actively probed.

- **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 $\mathscr{I}^-$ and ends on $\mathscr{I}^+$ is homotopic to a causal curve in a simply connected neighborhood of $\mathscr{I}$.



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



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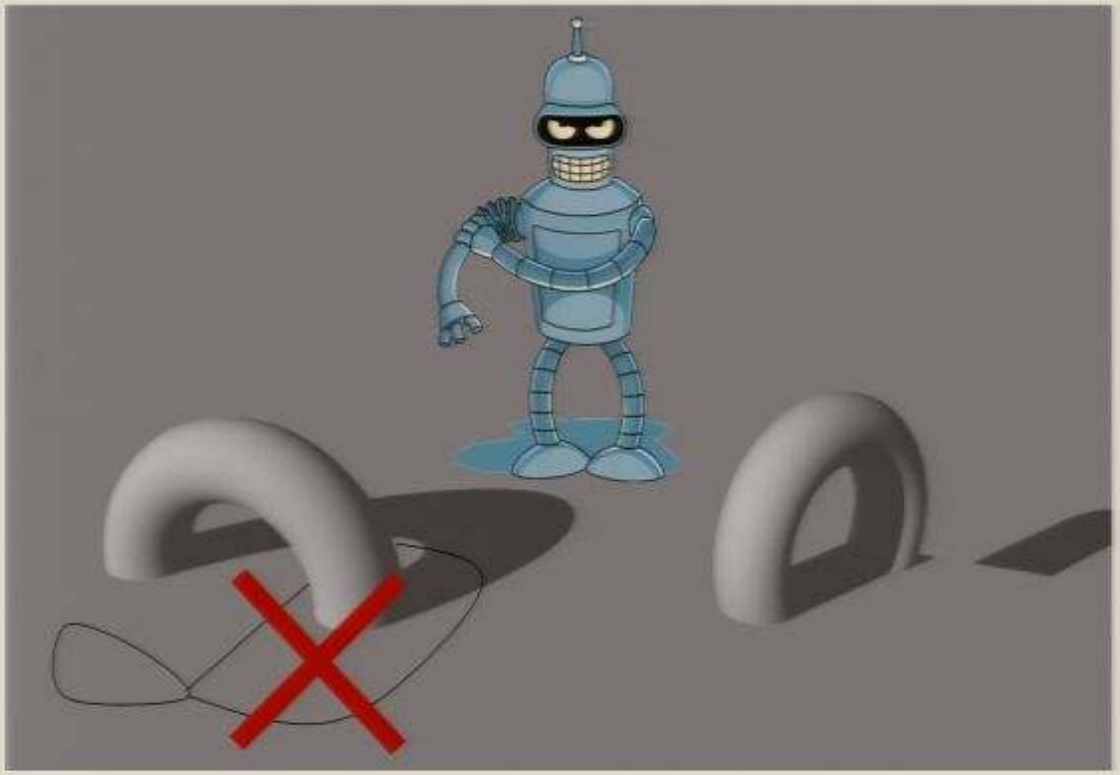
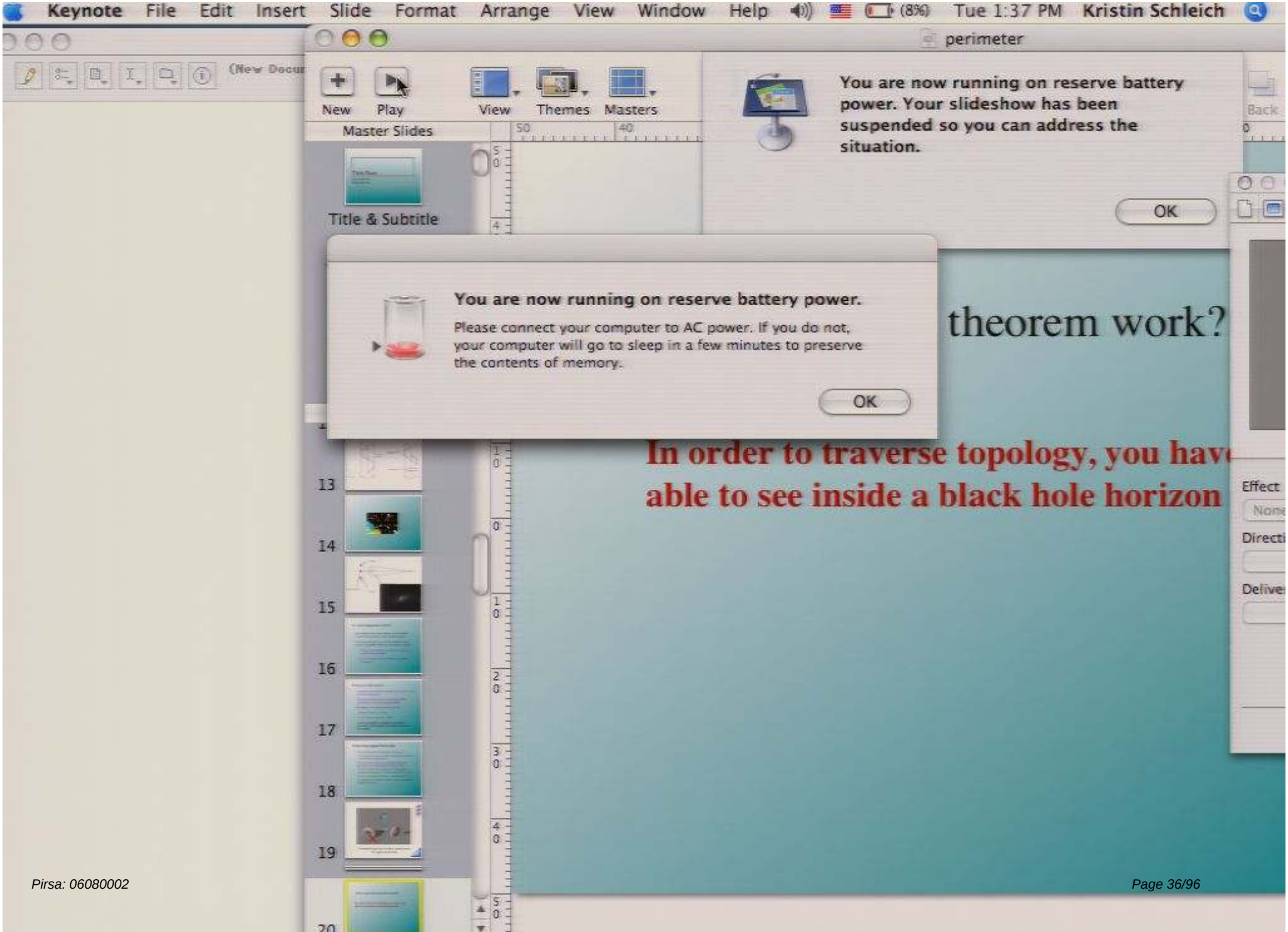


Translation: you can't hook a causal curve through a wormhole

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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OK
You are now running on reserve battery power.
Please connect your computer to AC power. If you do not, your computer will go to sleep in a few minutes to preserve the contents of memory.
OK
theorem work?
In order to traverse topology, you have
able to see inside a black hole horizon
Effect
Back

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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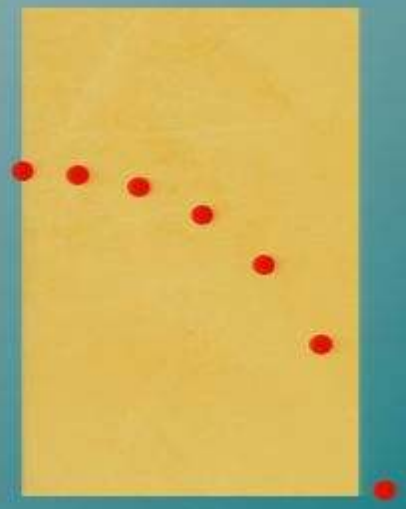
Consequences

- Gravitational redshift
- Gravitational bending of light

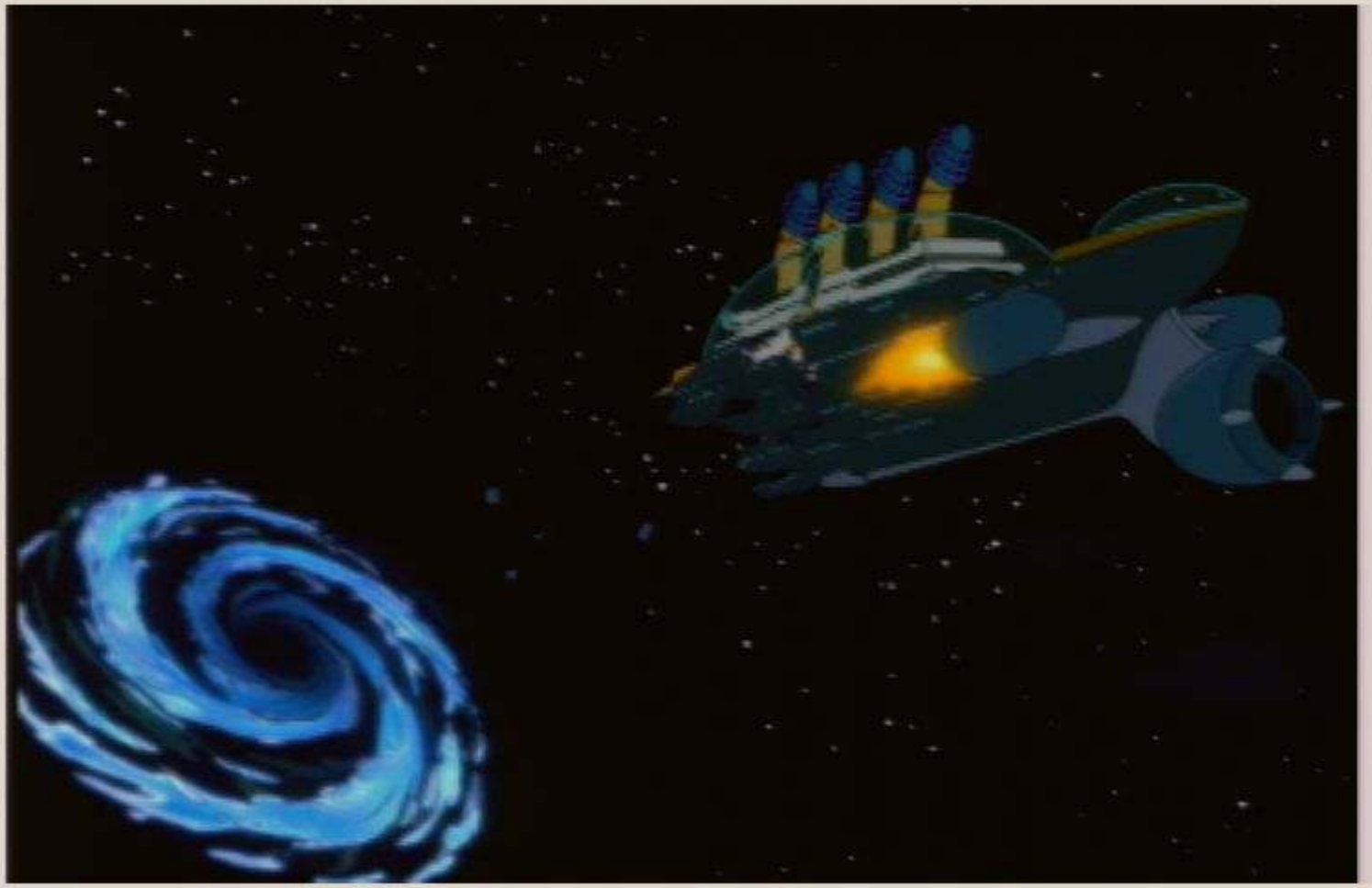
light viewed by accelerated observer

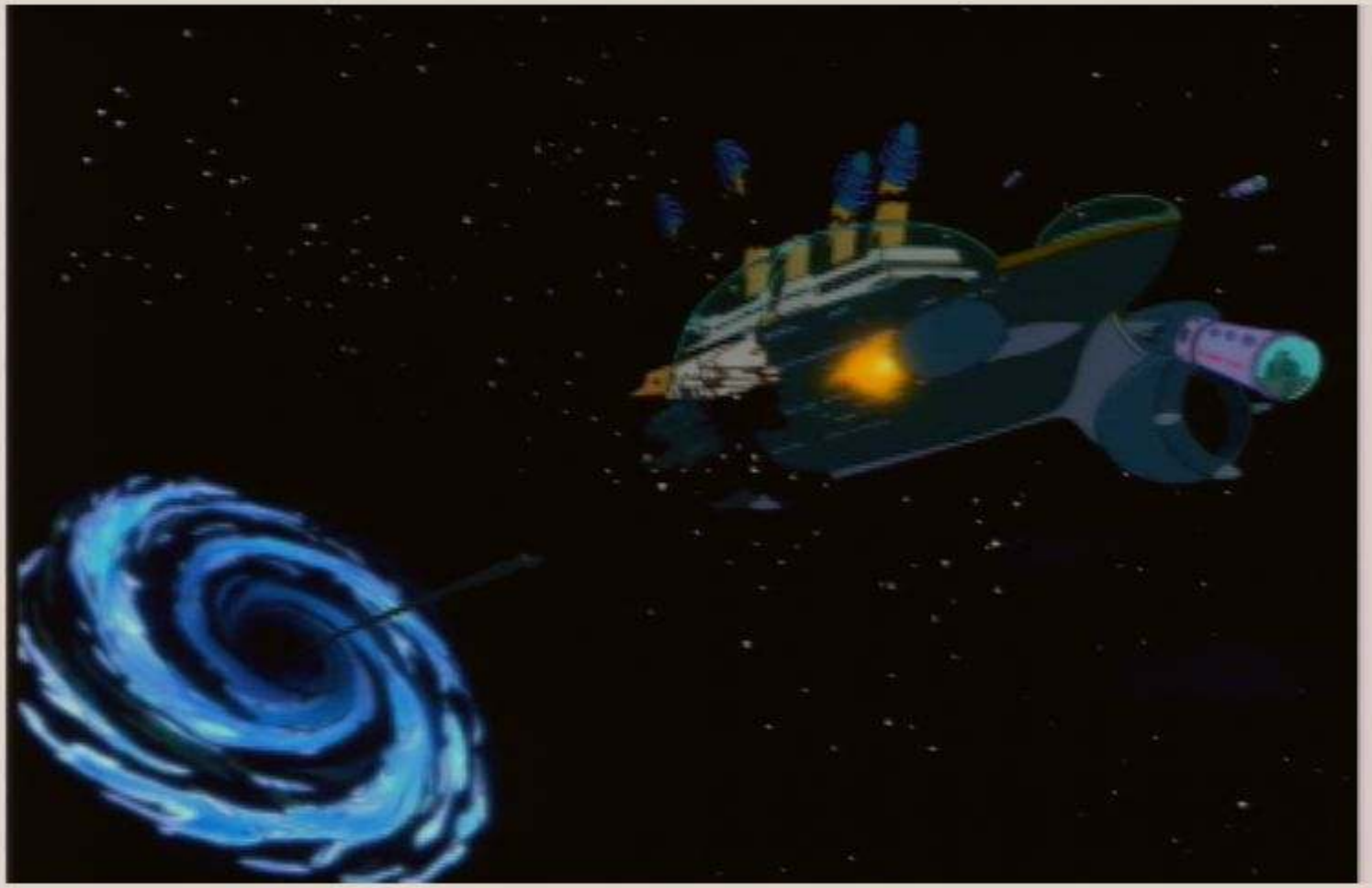
light in flat spacetime

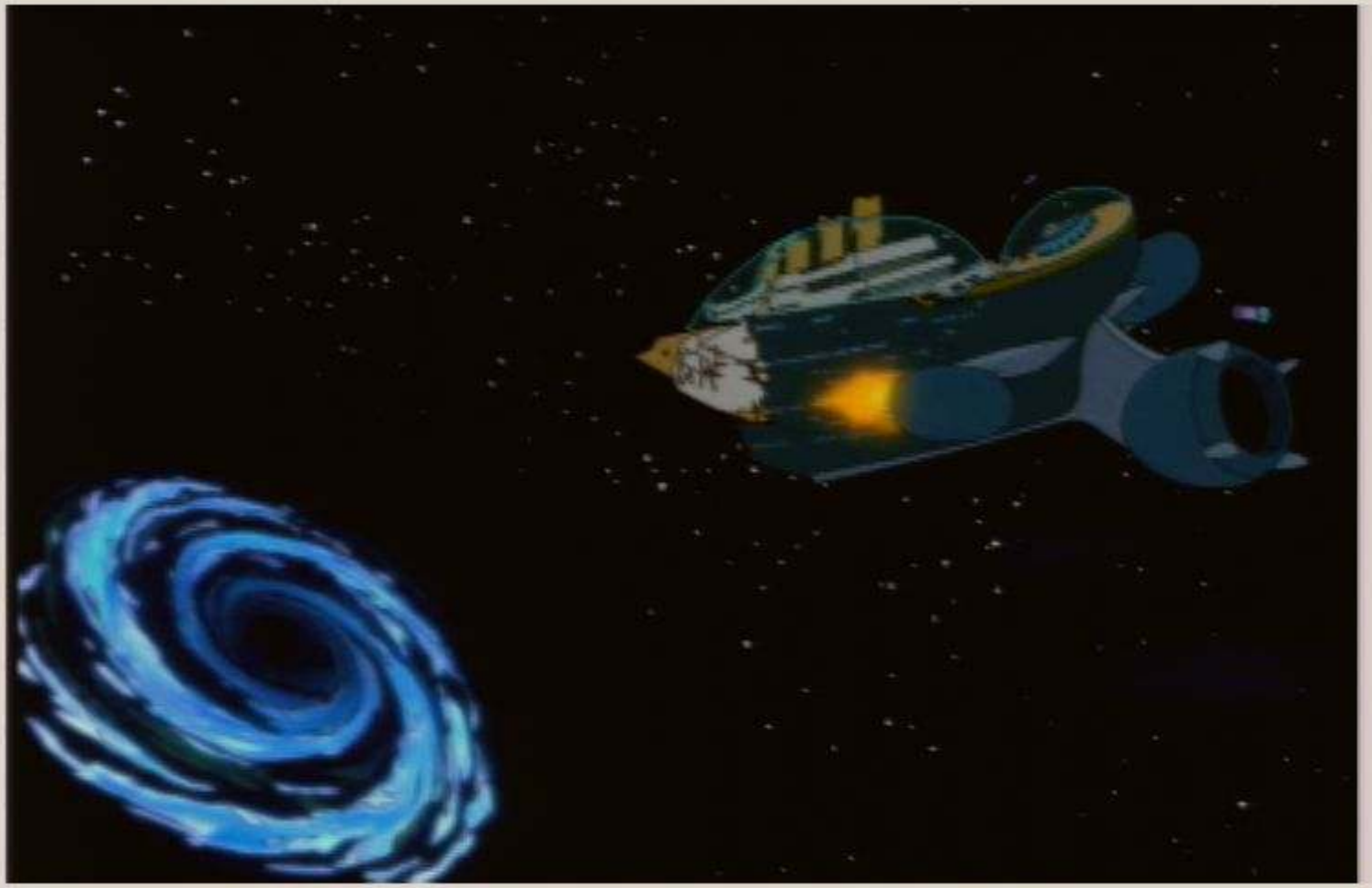


Gravity = Geometry

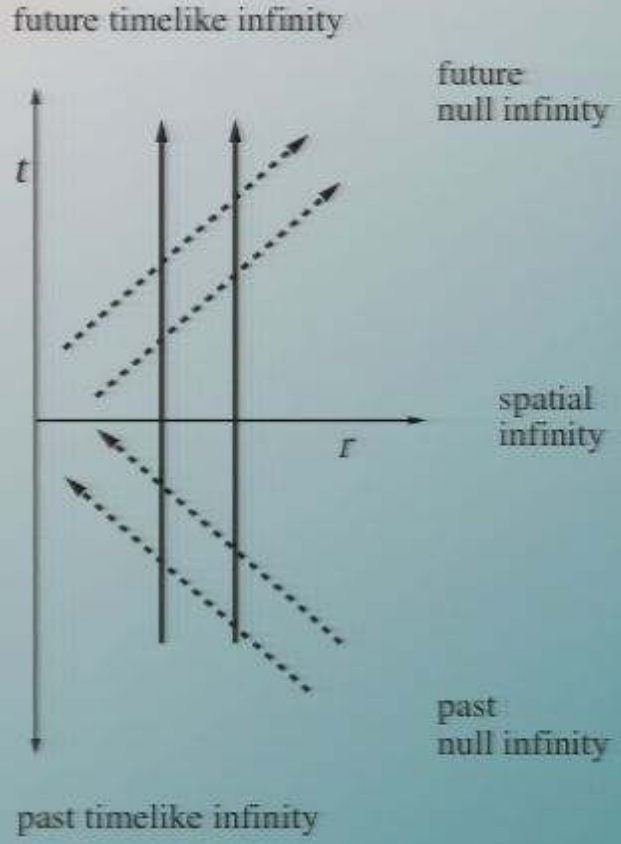
- freely falling light travels locally straight line - a geodesic - curved path due to curvature of spacetime

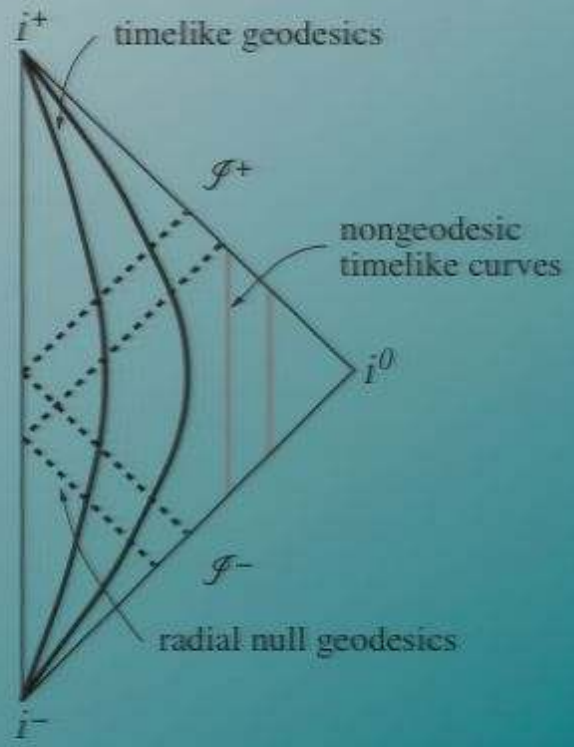






Tracing the path of light in spacetime





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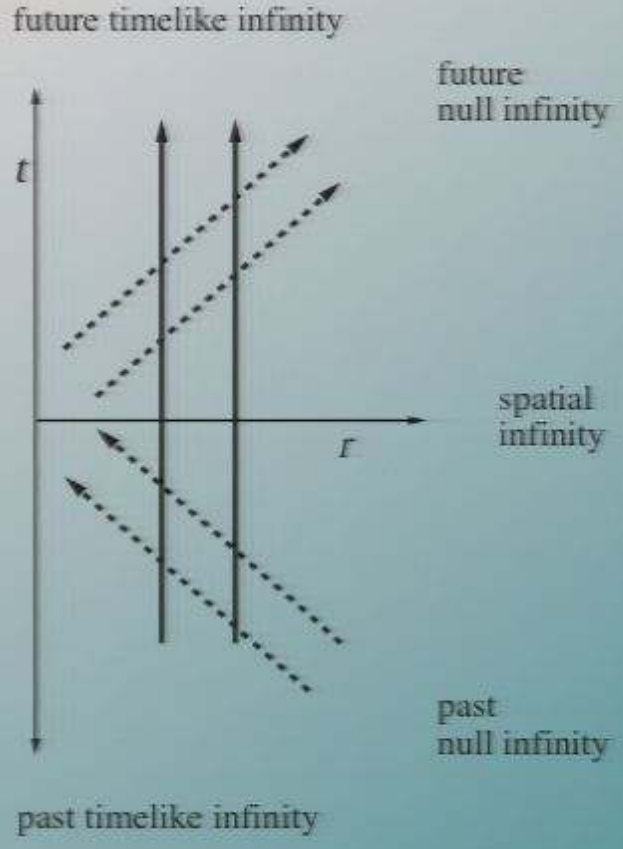

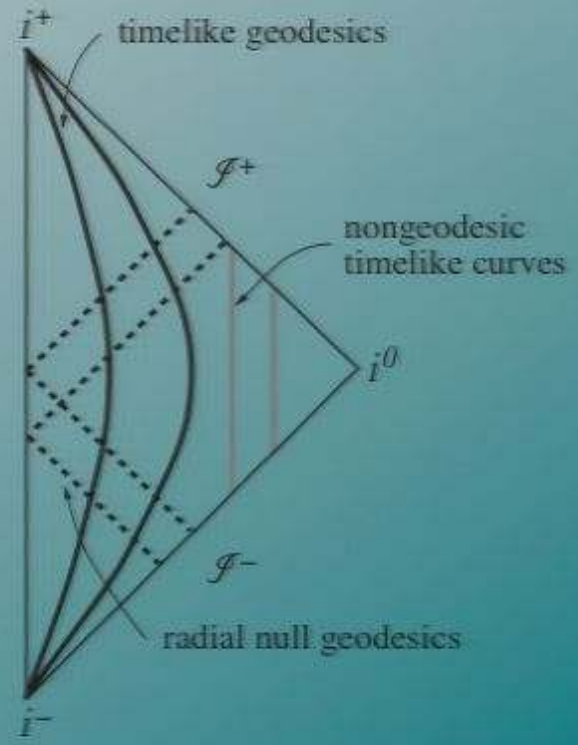

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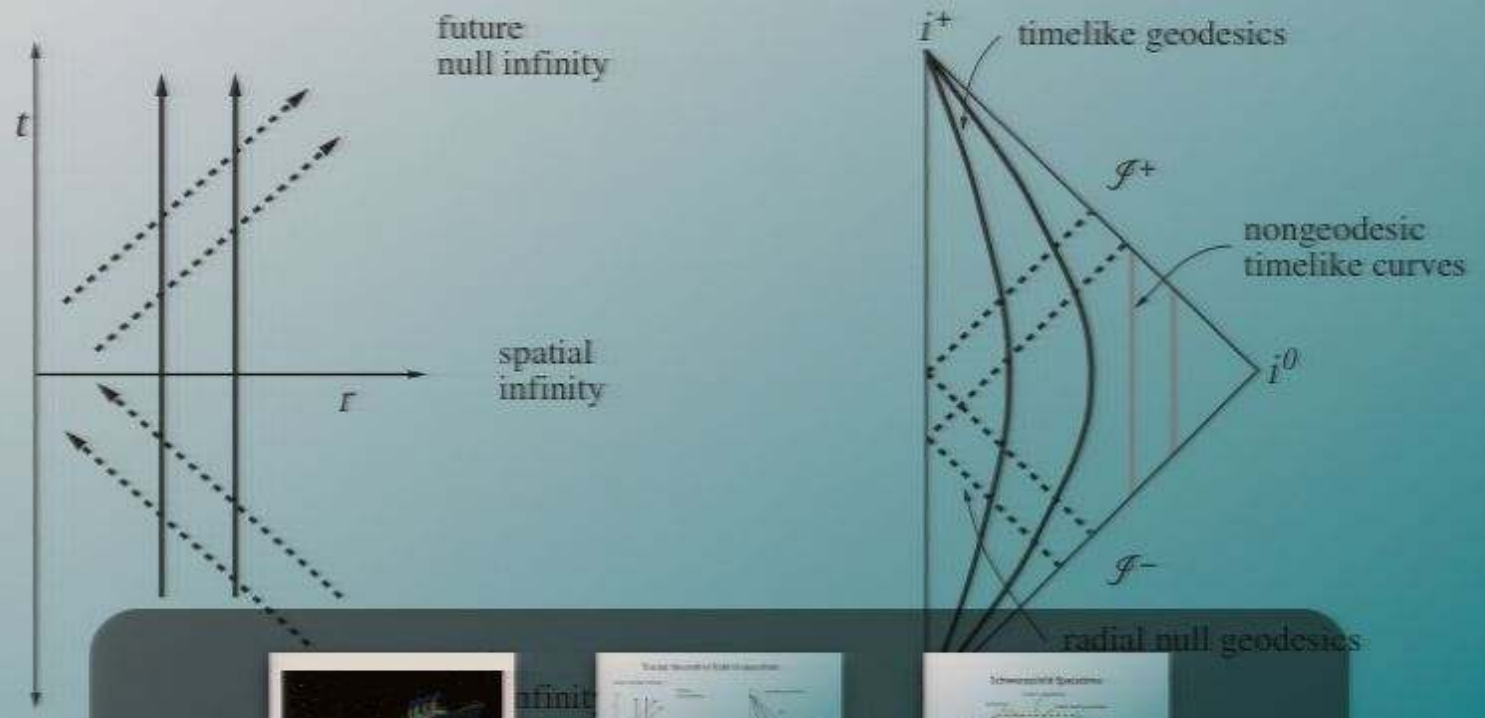

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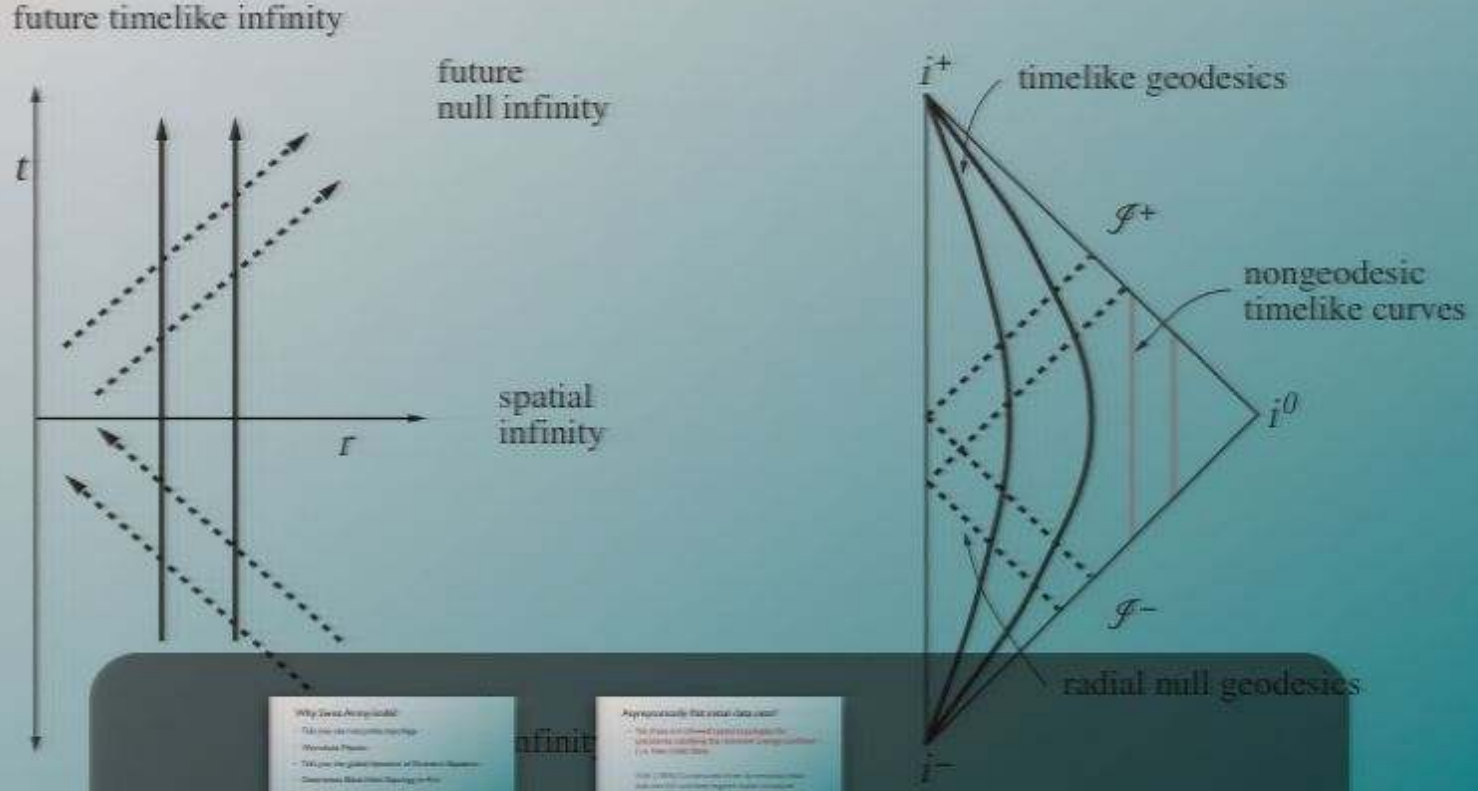

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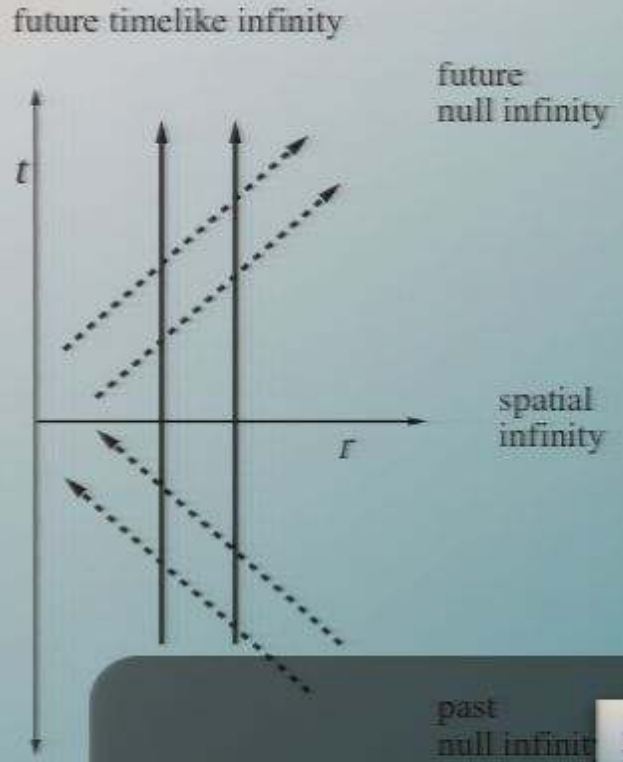

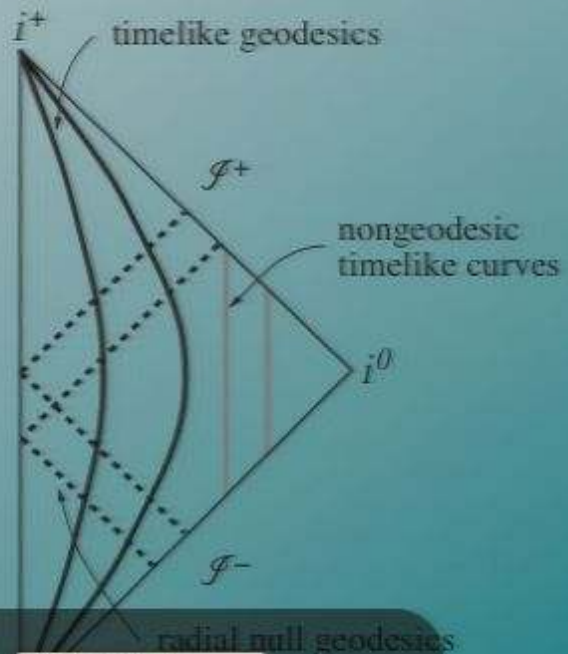

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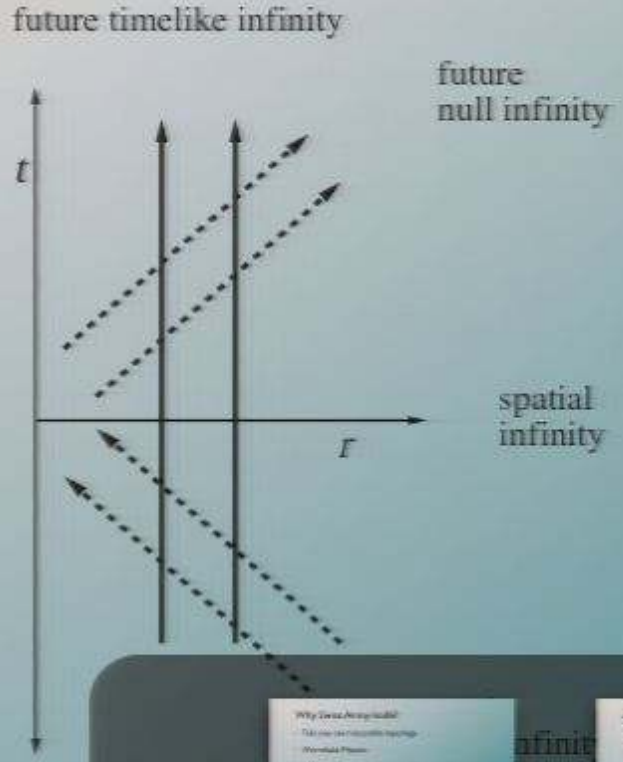

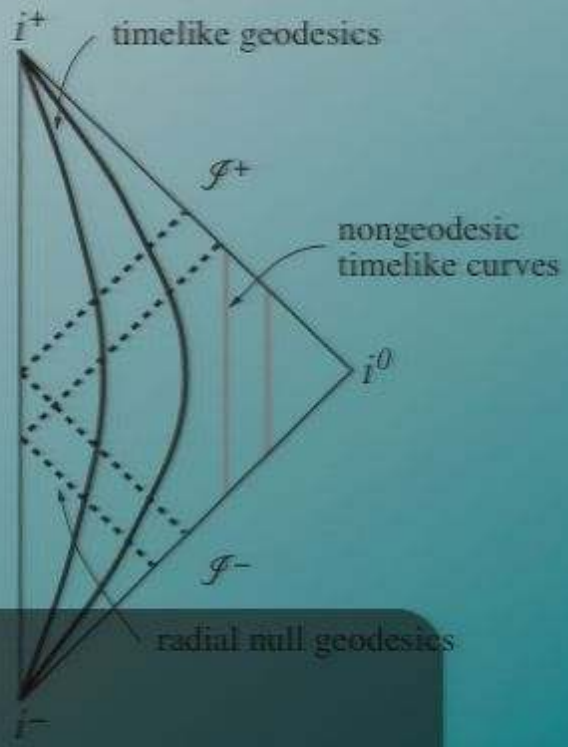

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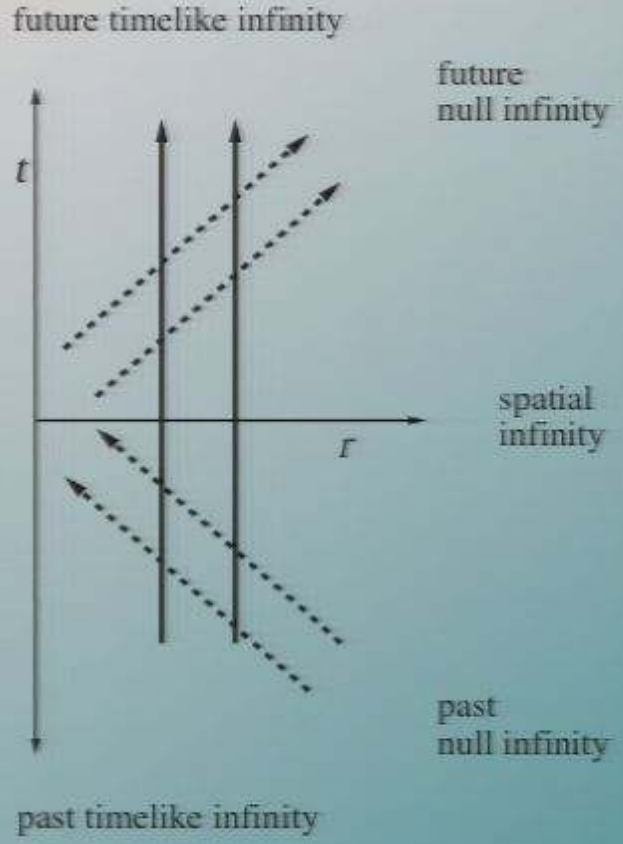
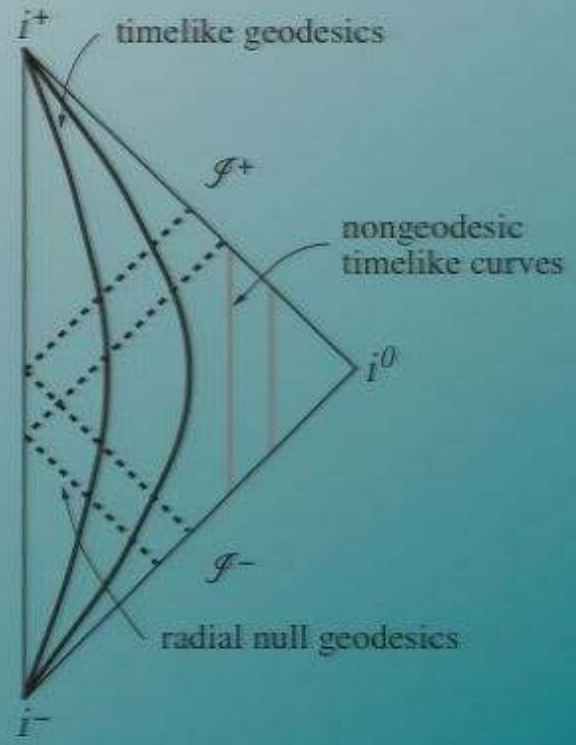
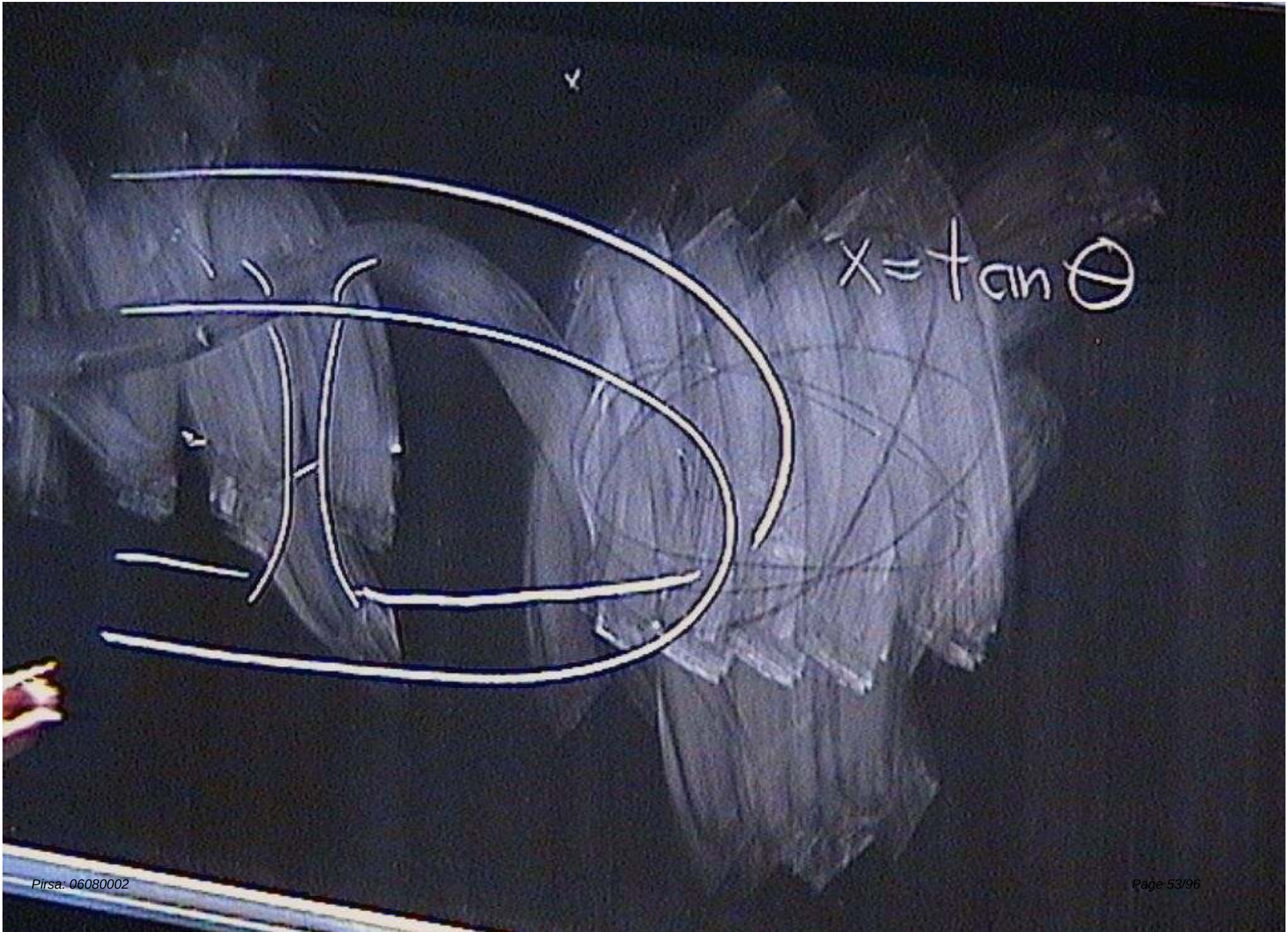
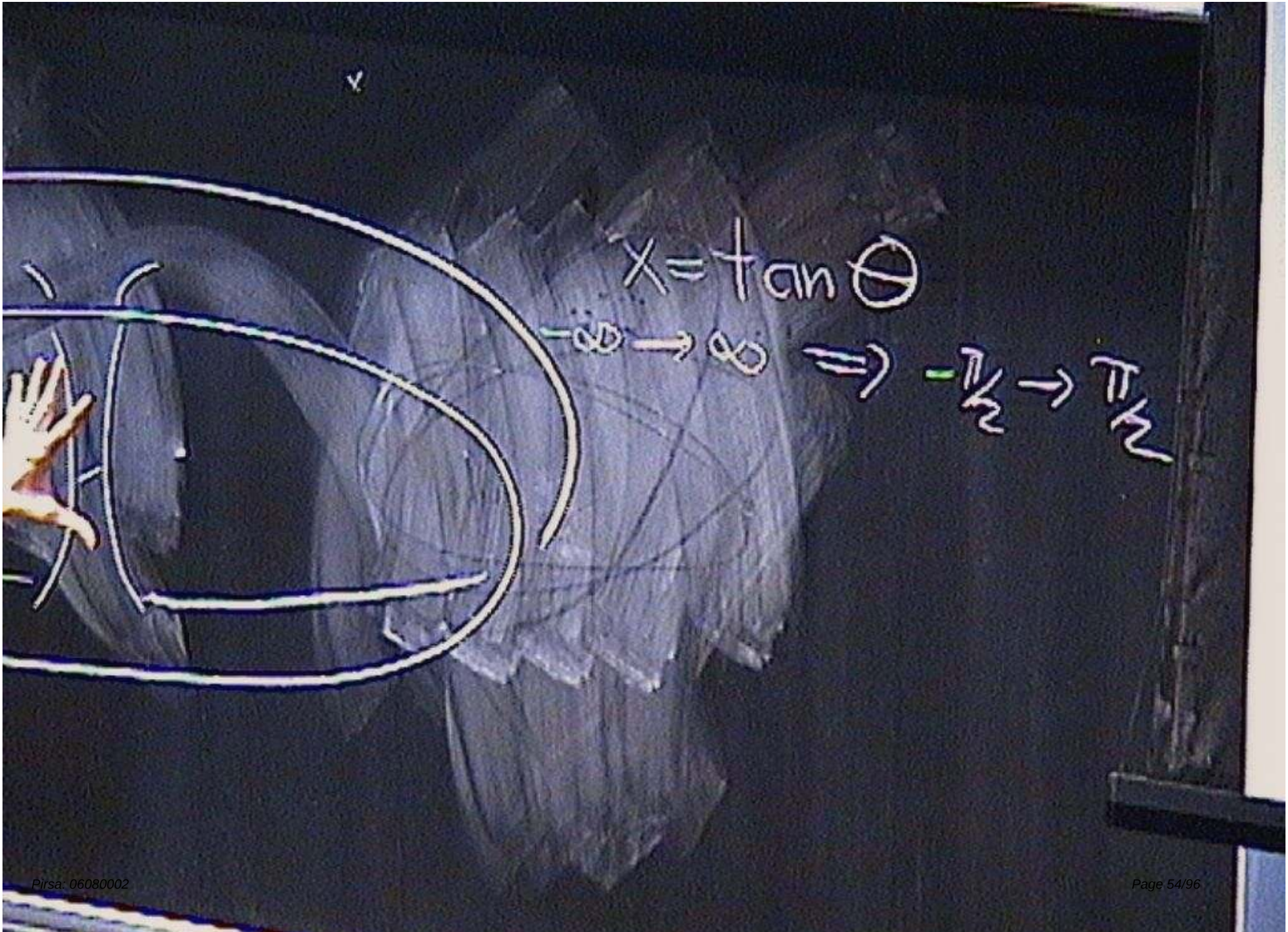





x
$x = \tan\theta$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$-\infty \to \infty \Rightarrow -\pi/2 \to \pi/2$

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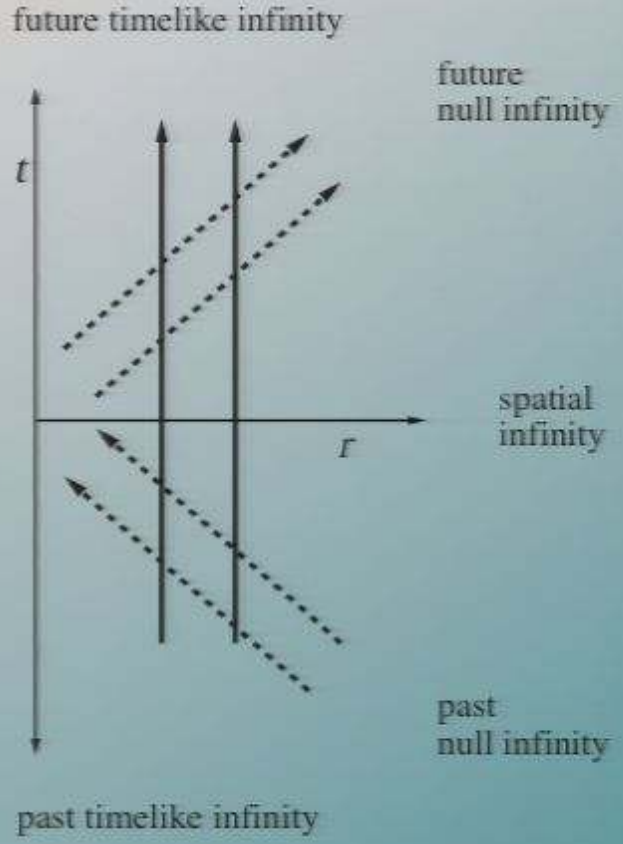
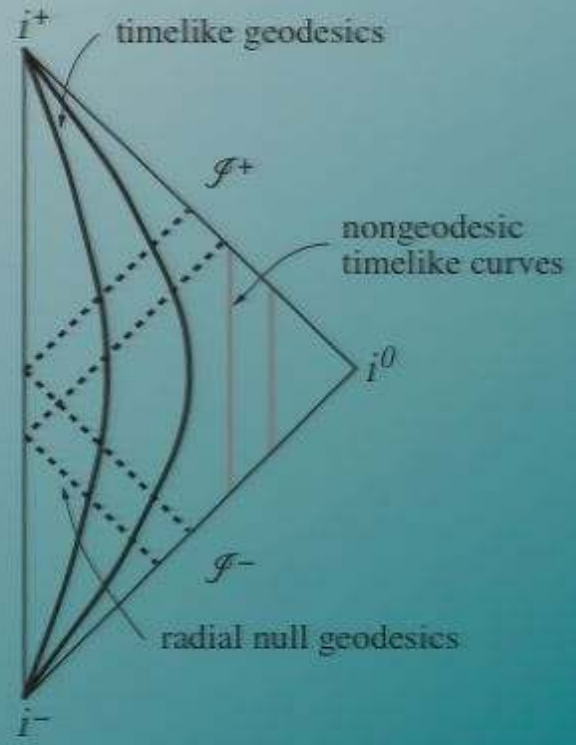
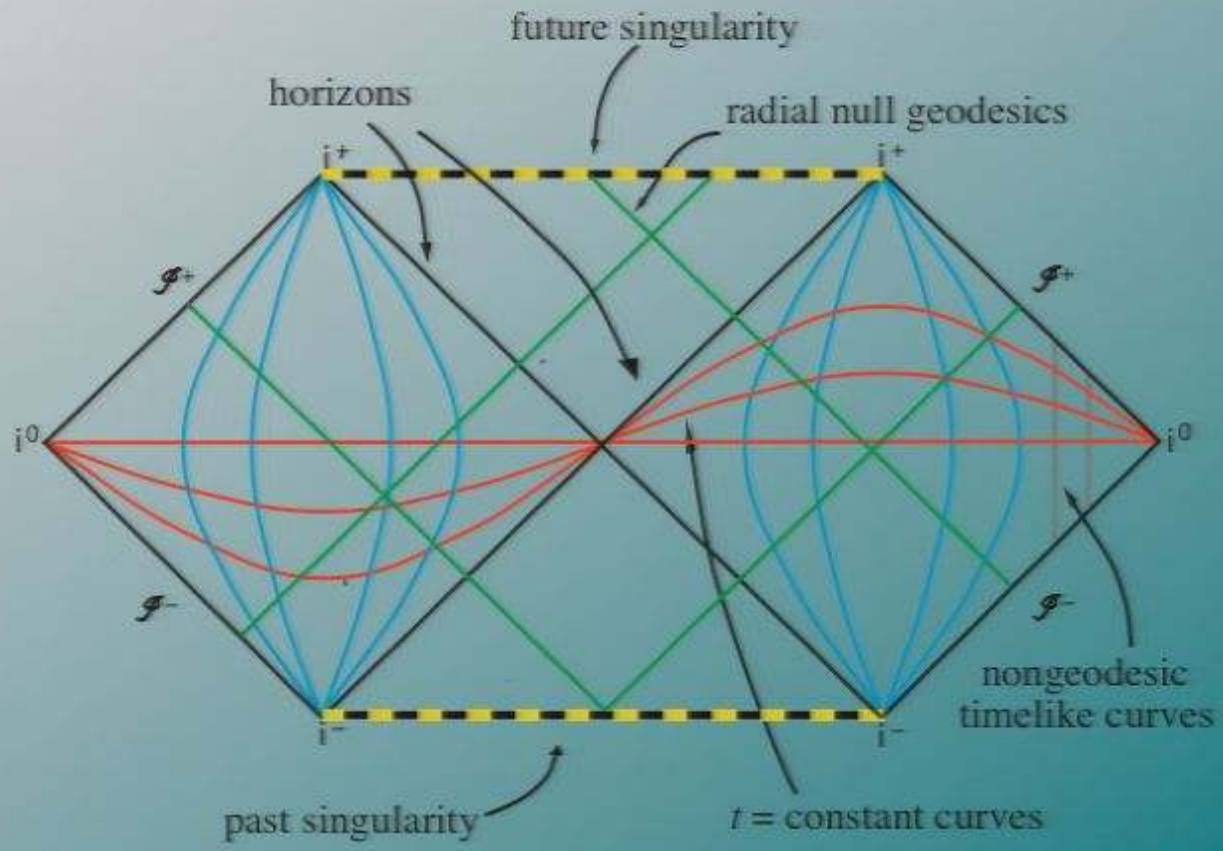




Schwarzschild Spacetime



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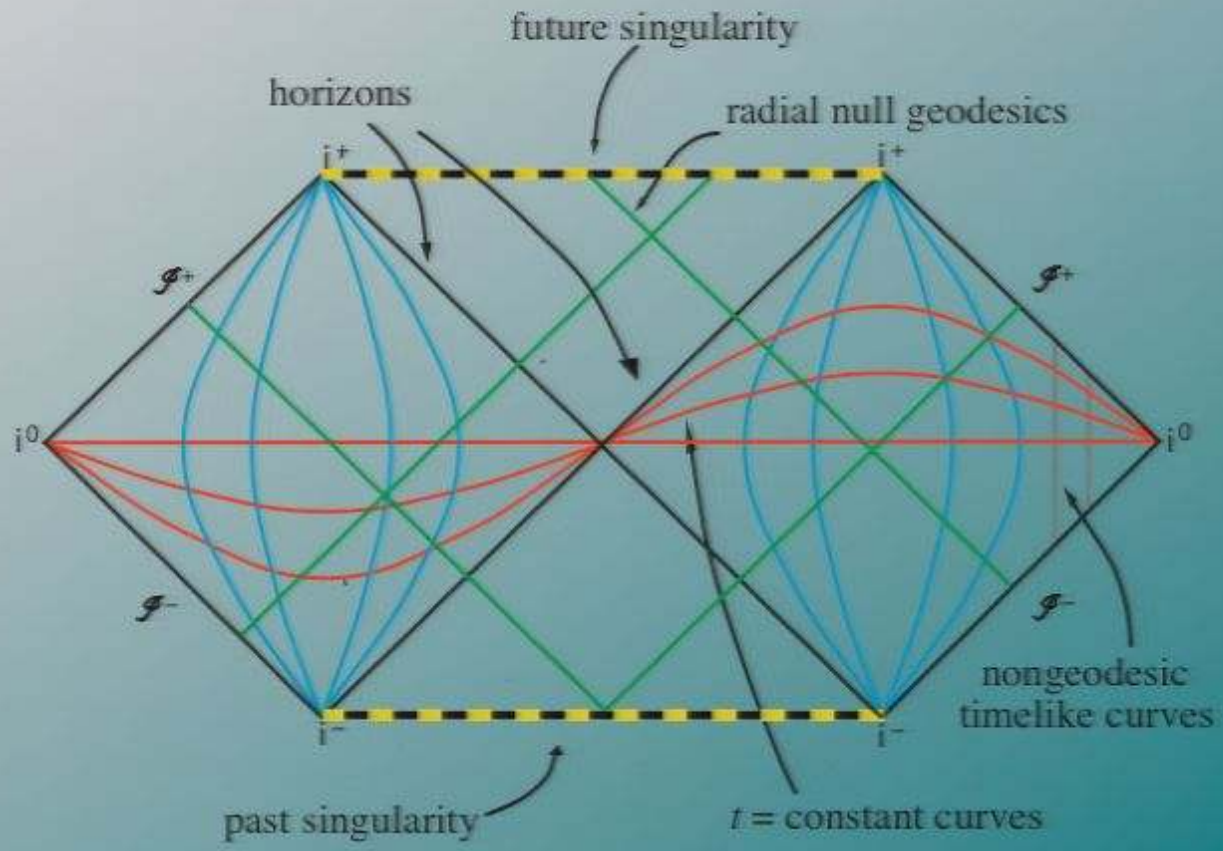
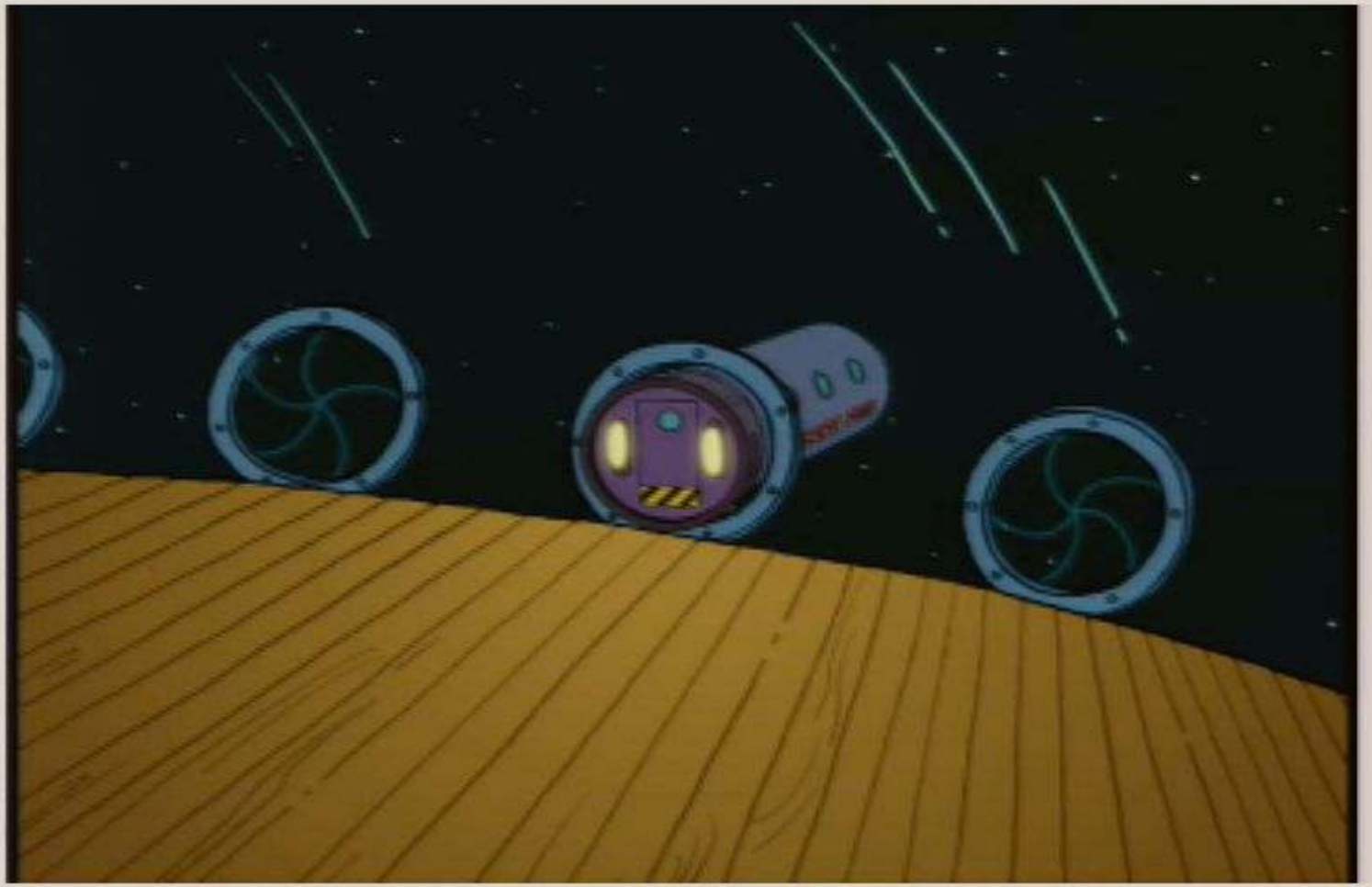
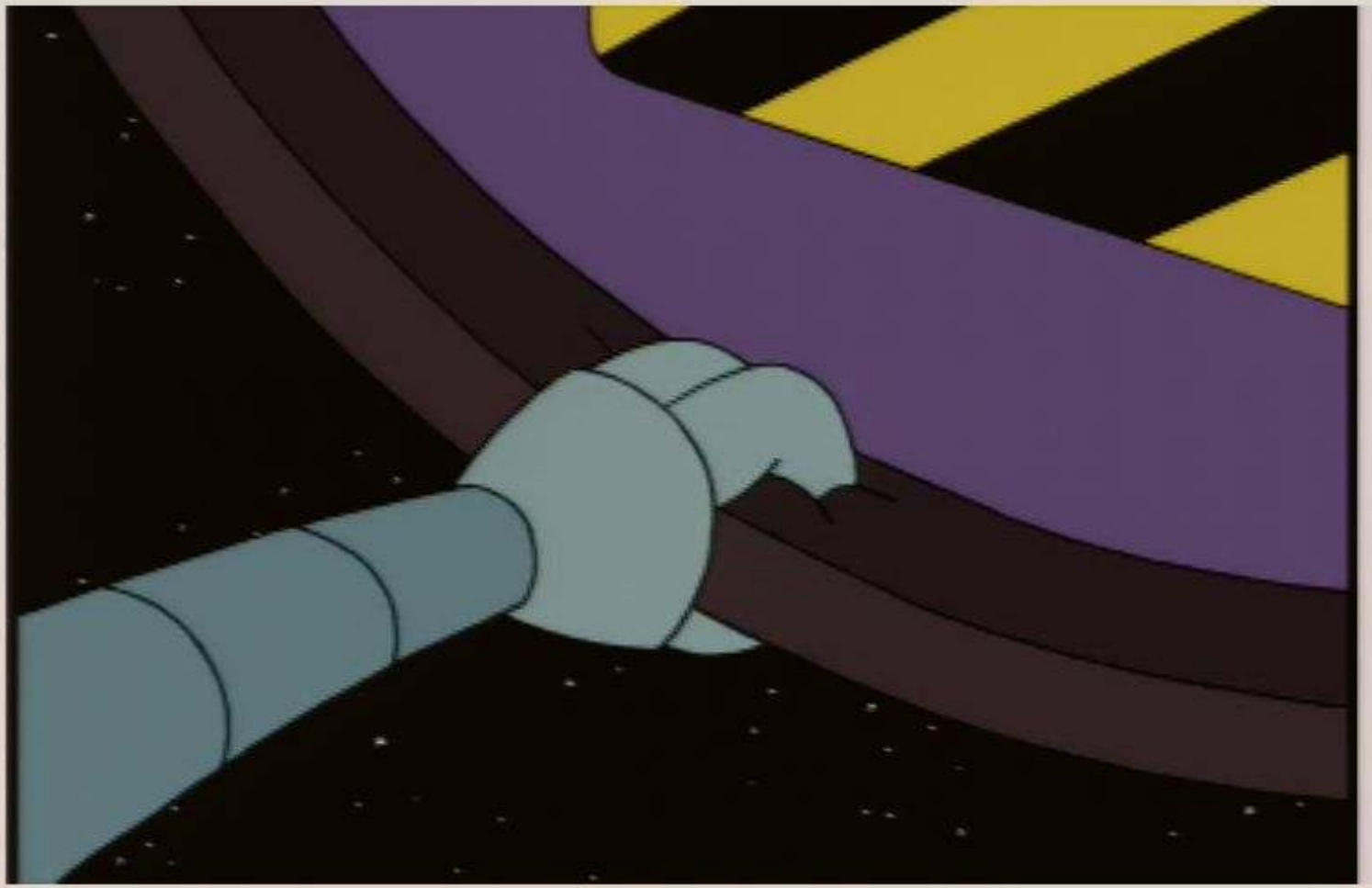
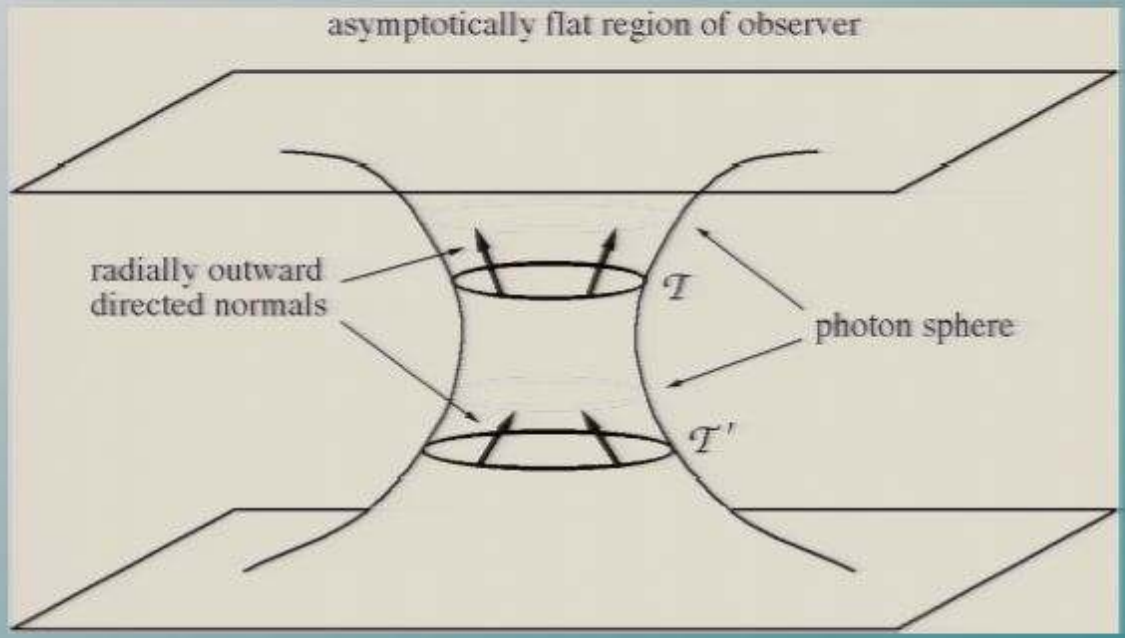






Schwarzschild throat at t=0



trapped surface τ' collapses to zero area in finite affine parameter if ANEC satisfied

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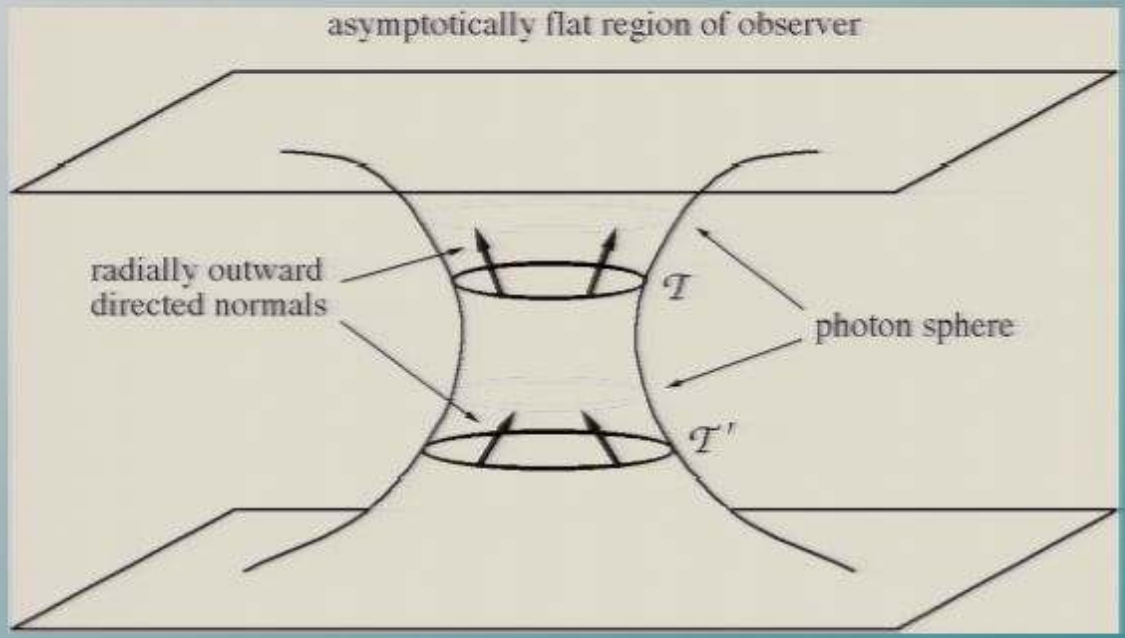
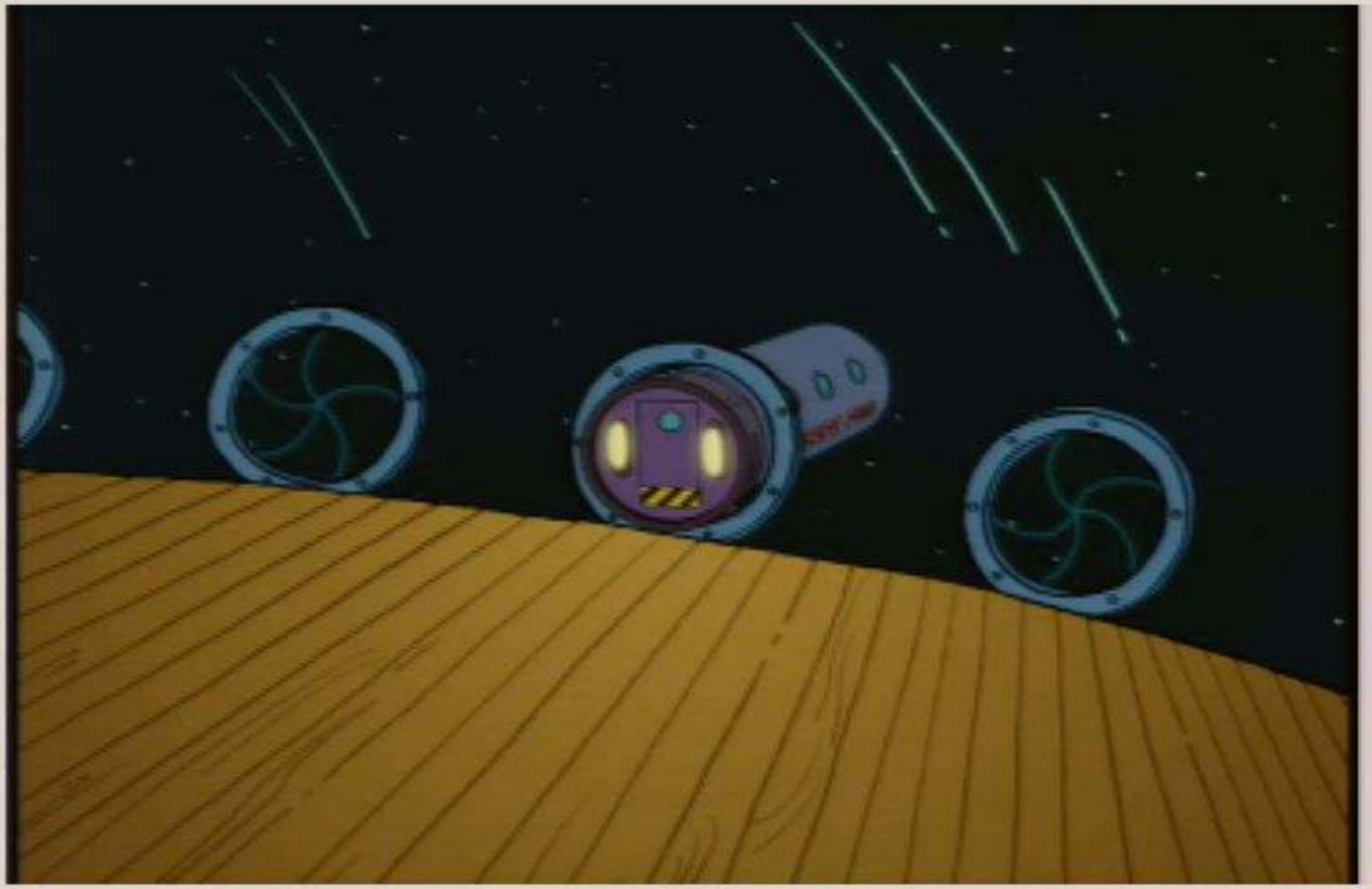
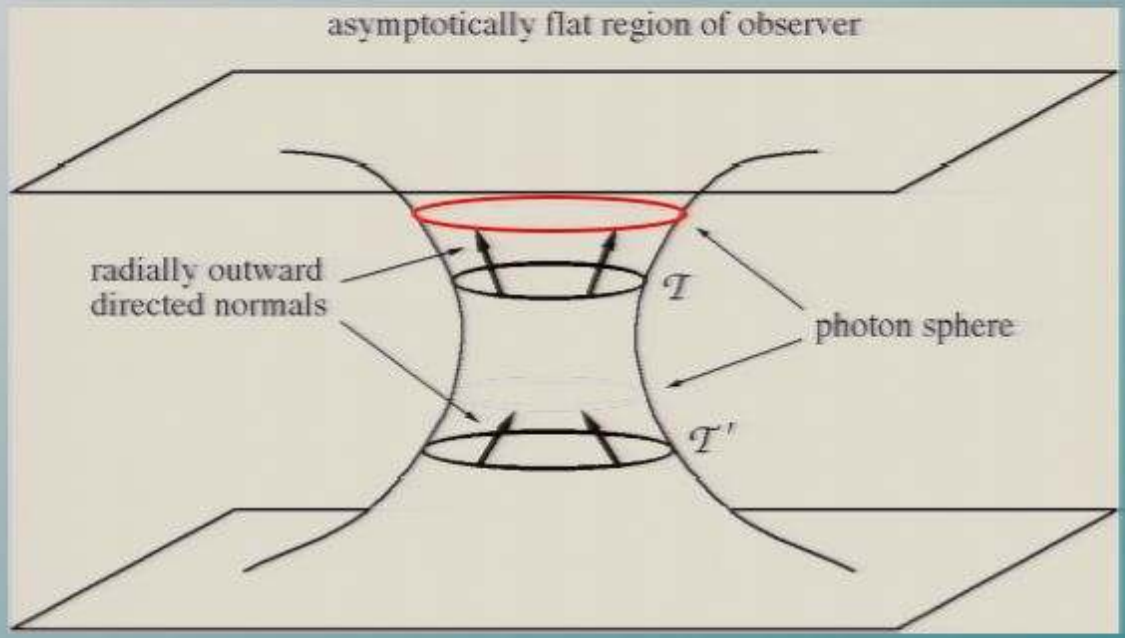


trapped surface τ' collapses to zero area in finite affine parameter if ANEC satisfied

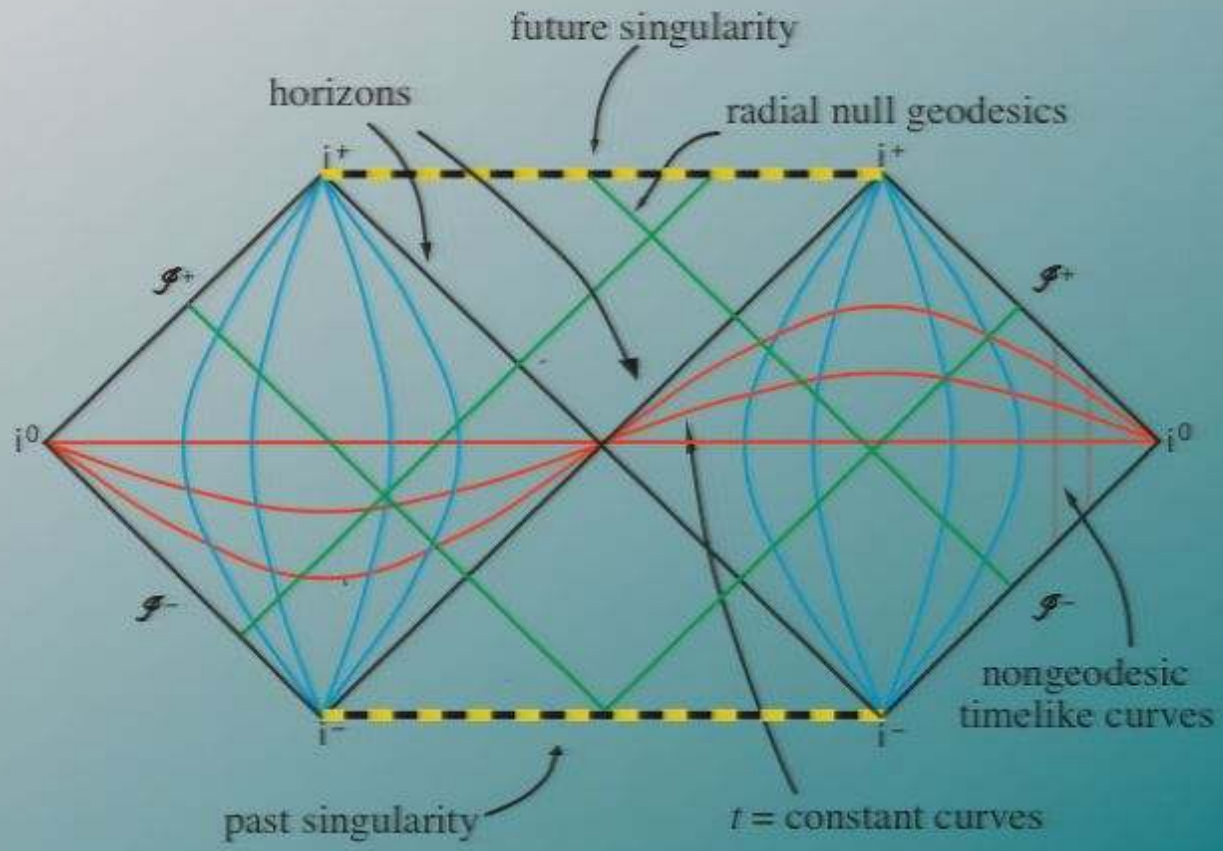


Schwarzschild throat at t=0



trapped surface τ' collapses to zero area in finite affine parameter if ANEC satisfied

Schwarzschild Spacetime



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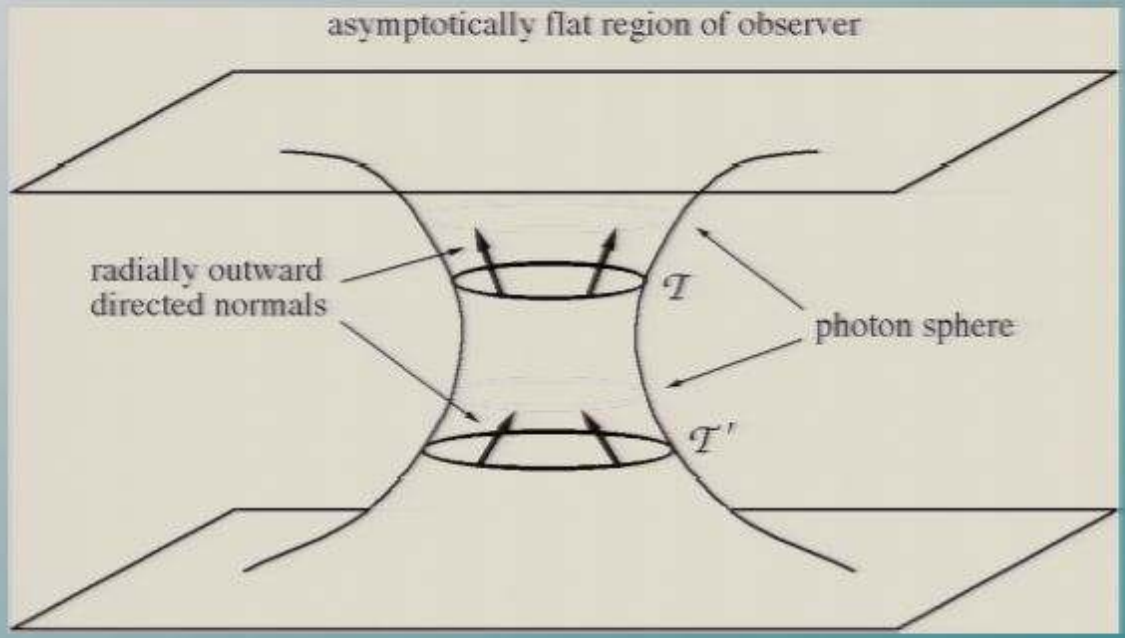

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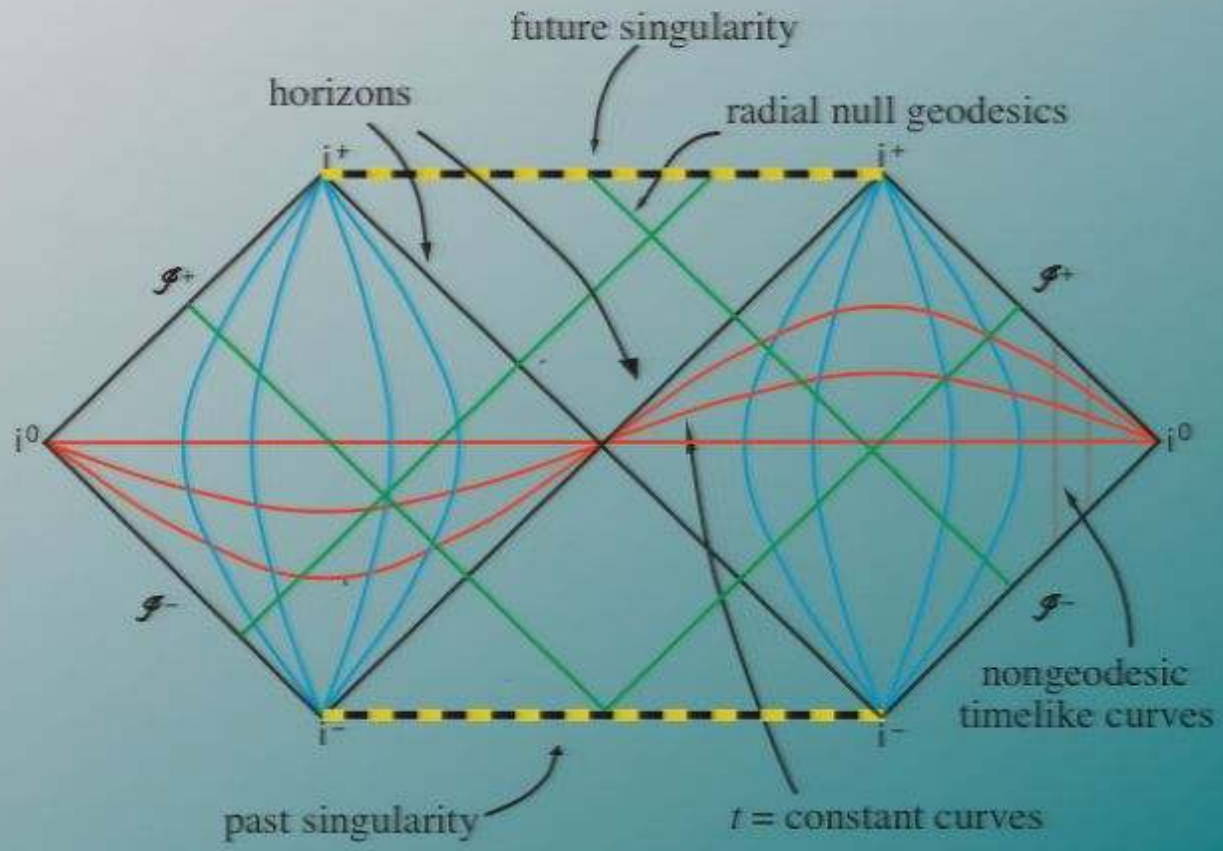

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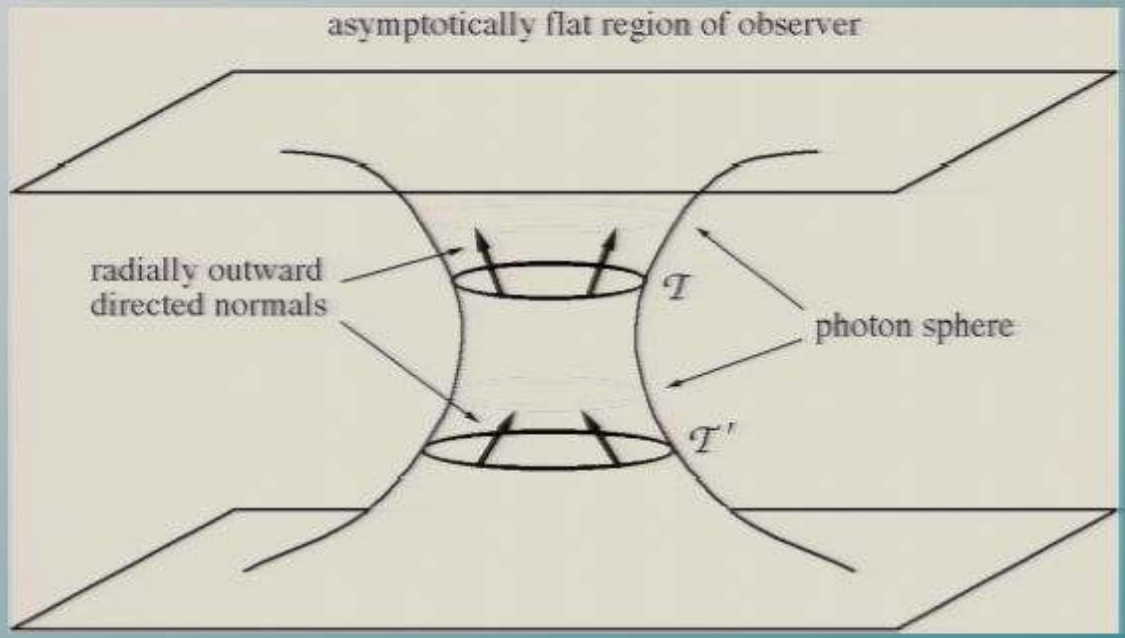

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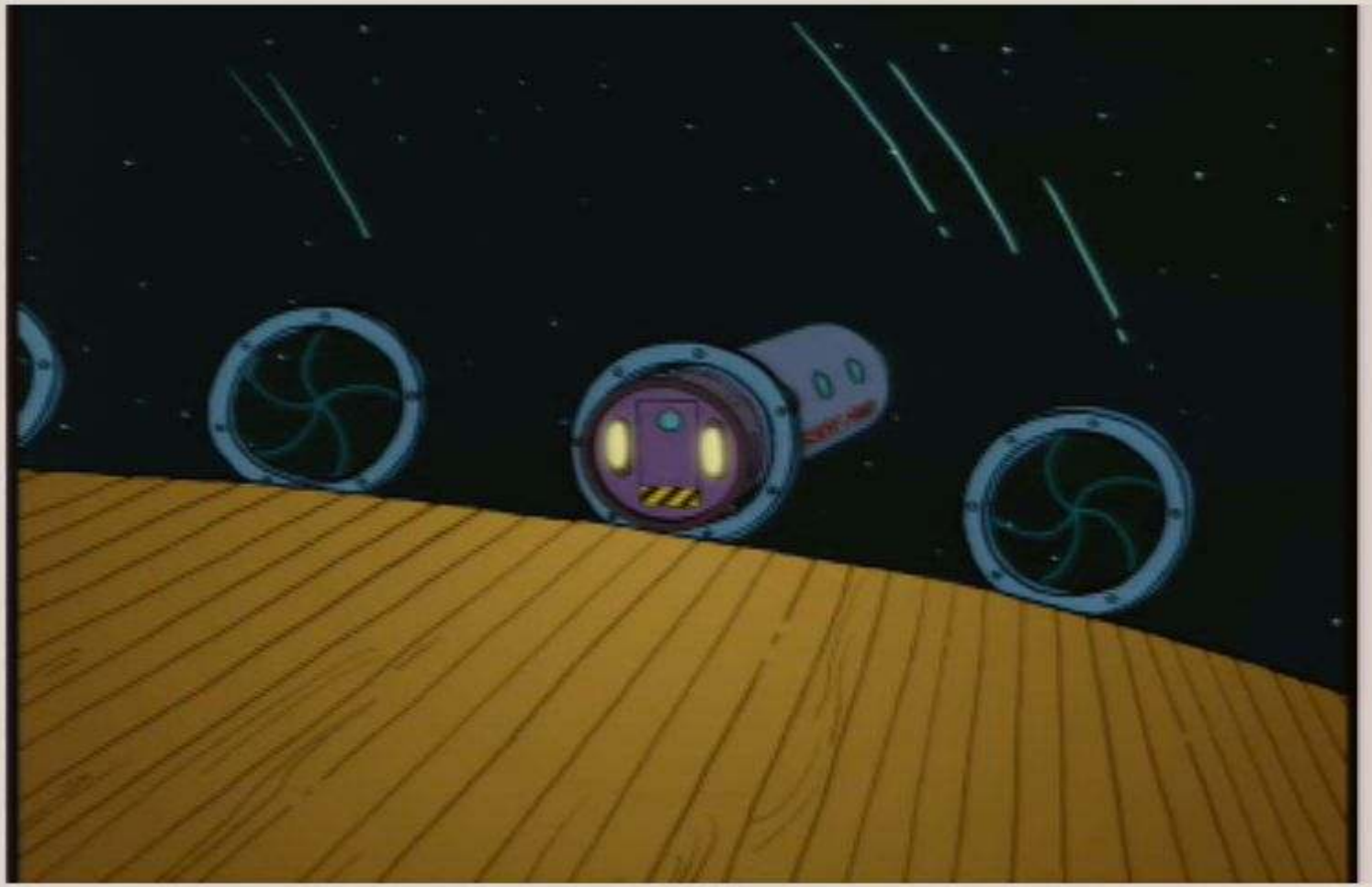
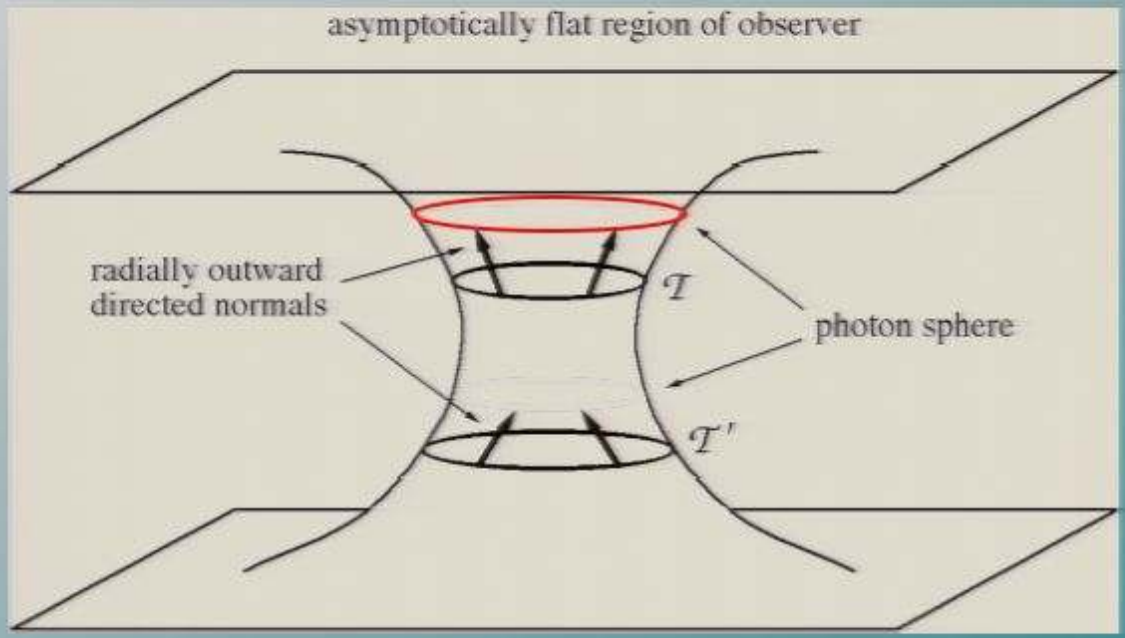
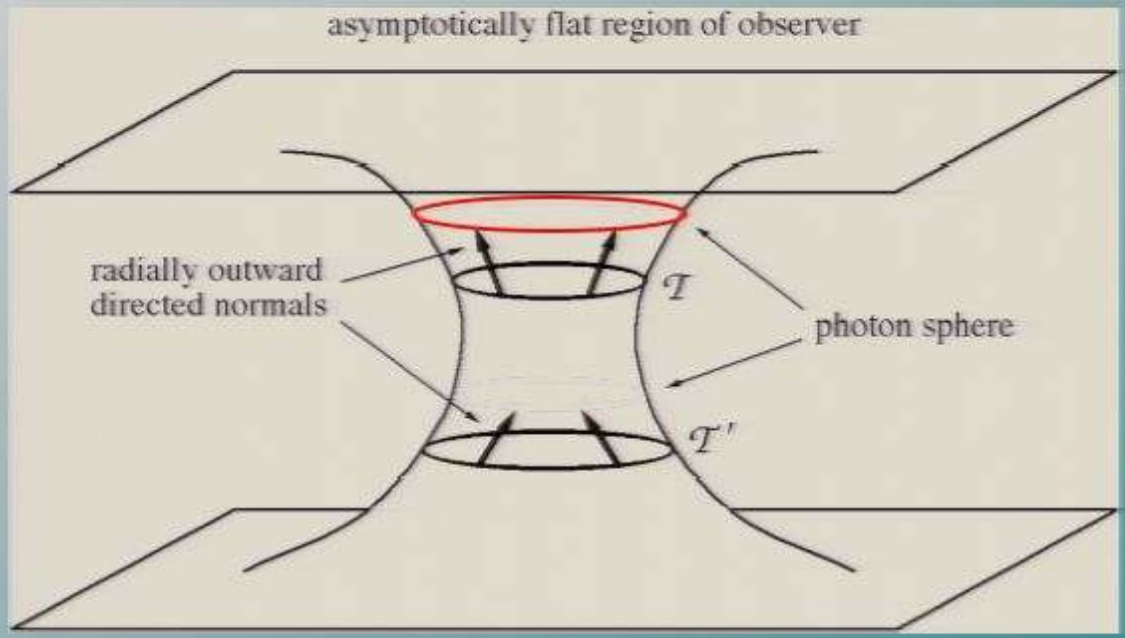


Schwarzschild throat at t=0



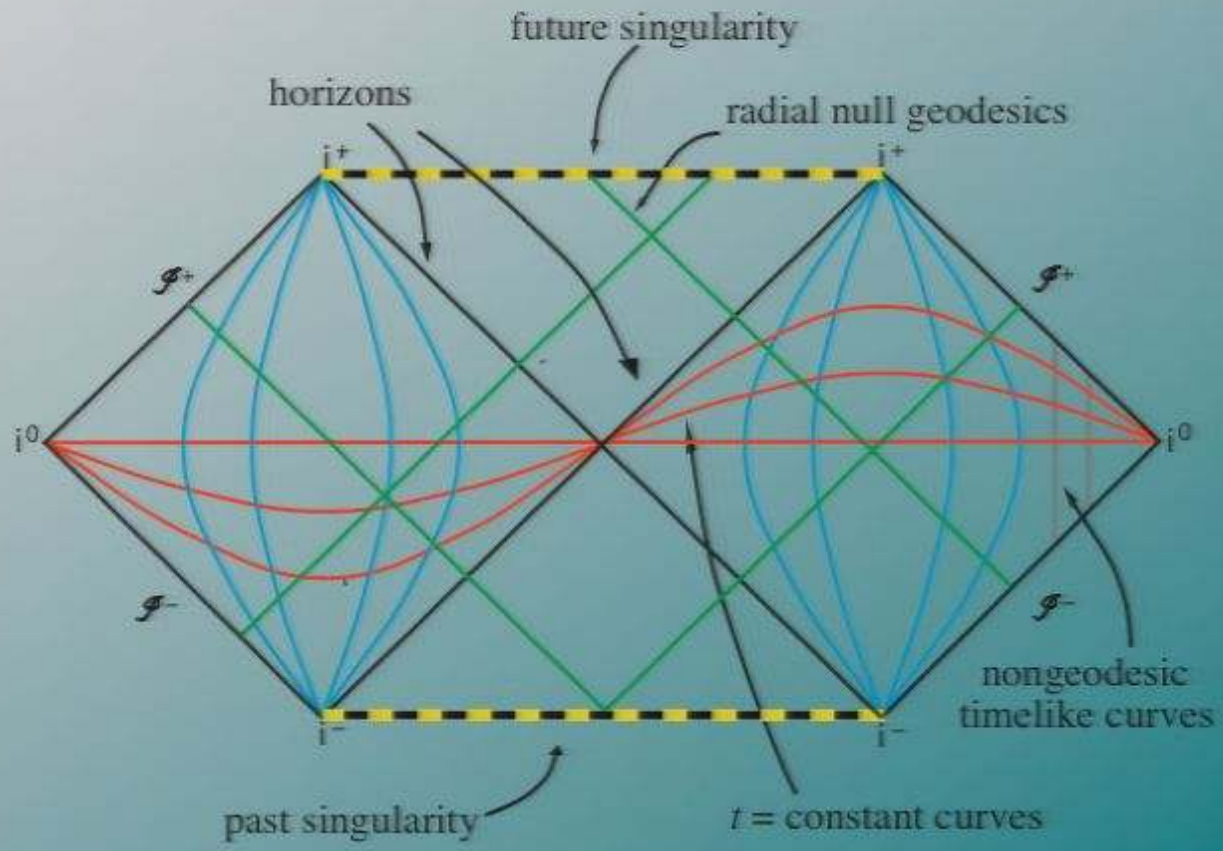
trapped surface τ' collapses to zero area in finite affine parameter if ANEC satisfied

Schwarzschild throat at t=0

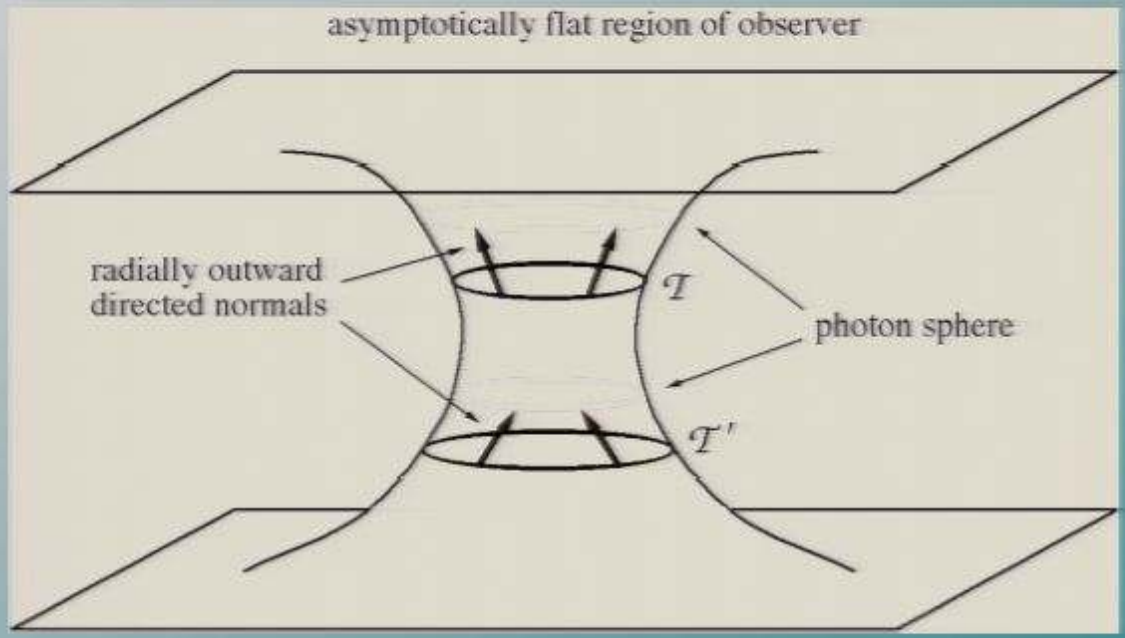


trapped surface τ' collapses to zero area in finite affine parameter if ANEC satisfied

Schwarzschild Spacetime



Schwarzschild throat at t=0



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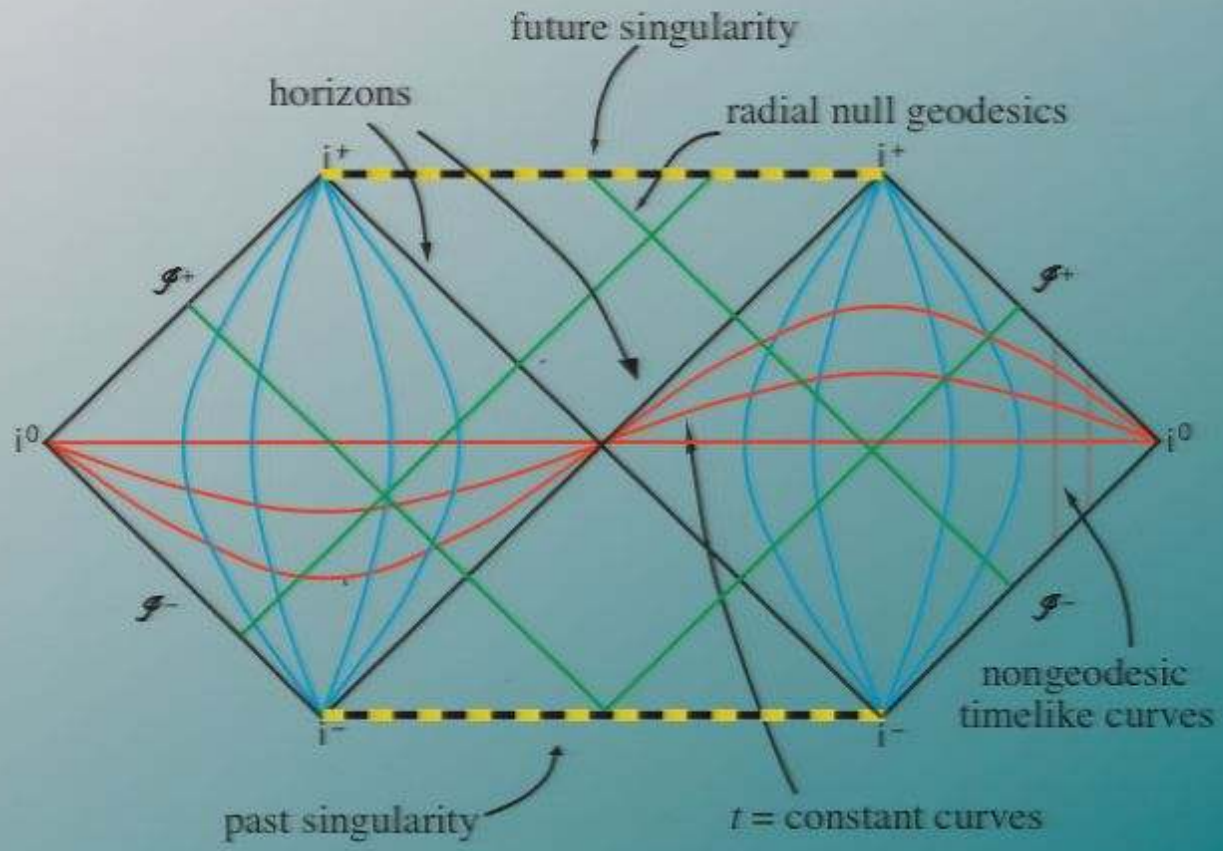
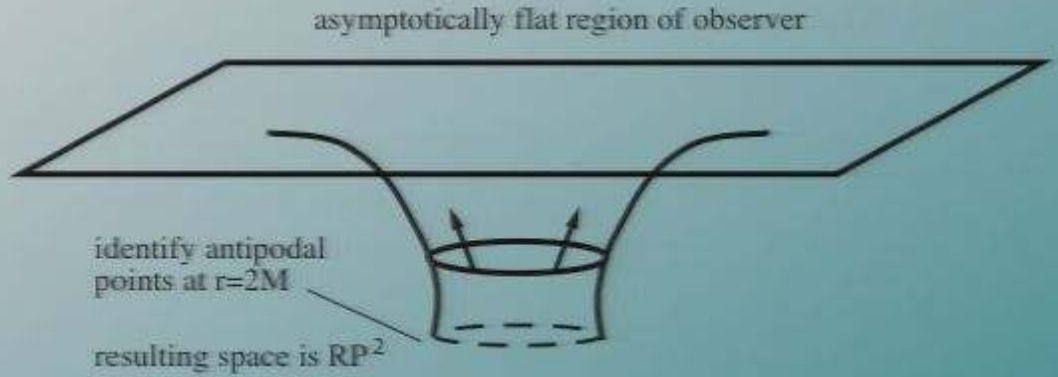
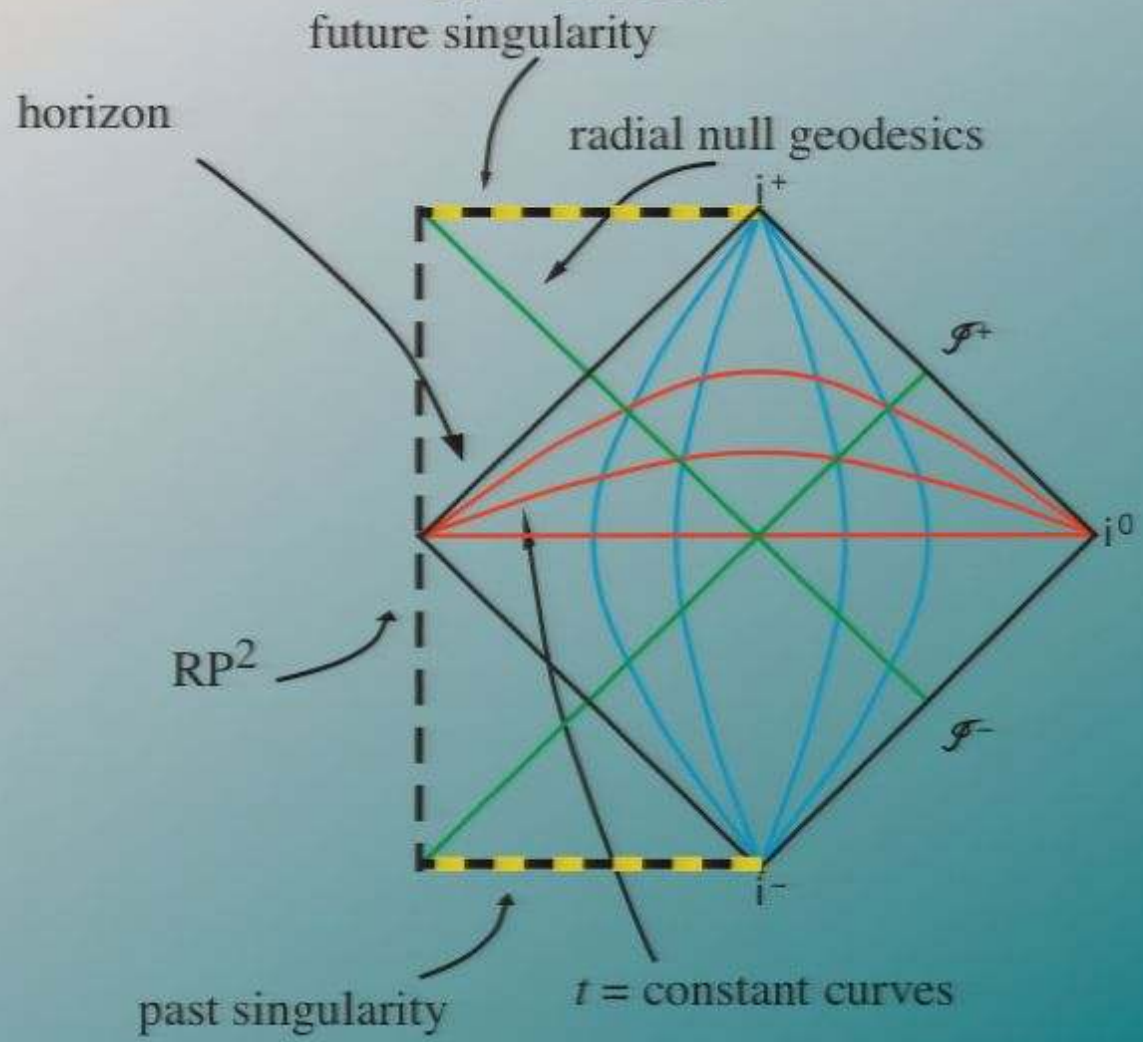
Schwarzschild Spacetime



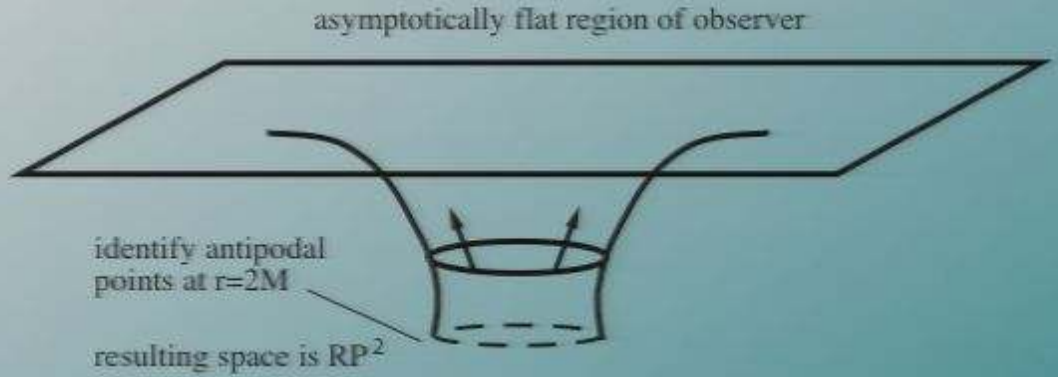
RP^3 throat at t=0



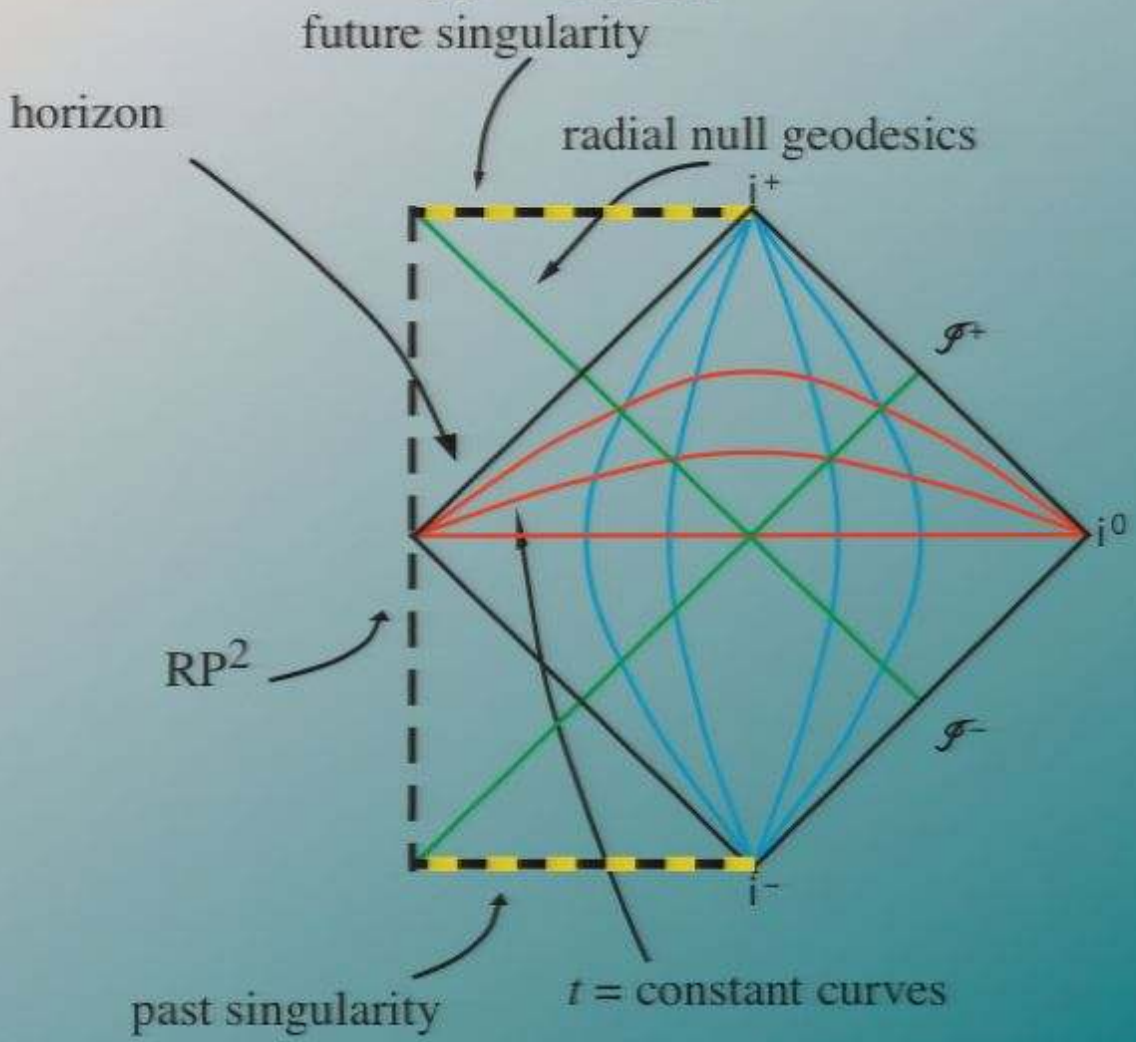
RP^3 Geon


future singularity
horizon
radial null geodesics
i^+
$\mathscr{I}^+$
i^0
RP^2
$\mathscr{I}^-$
i^-
past singularity
t = constant curves

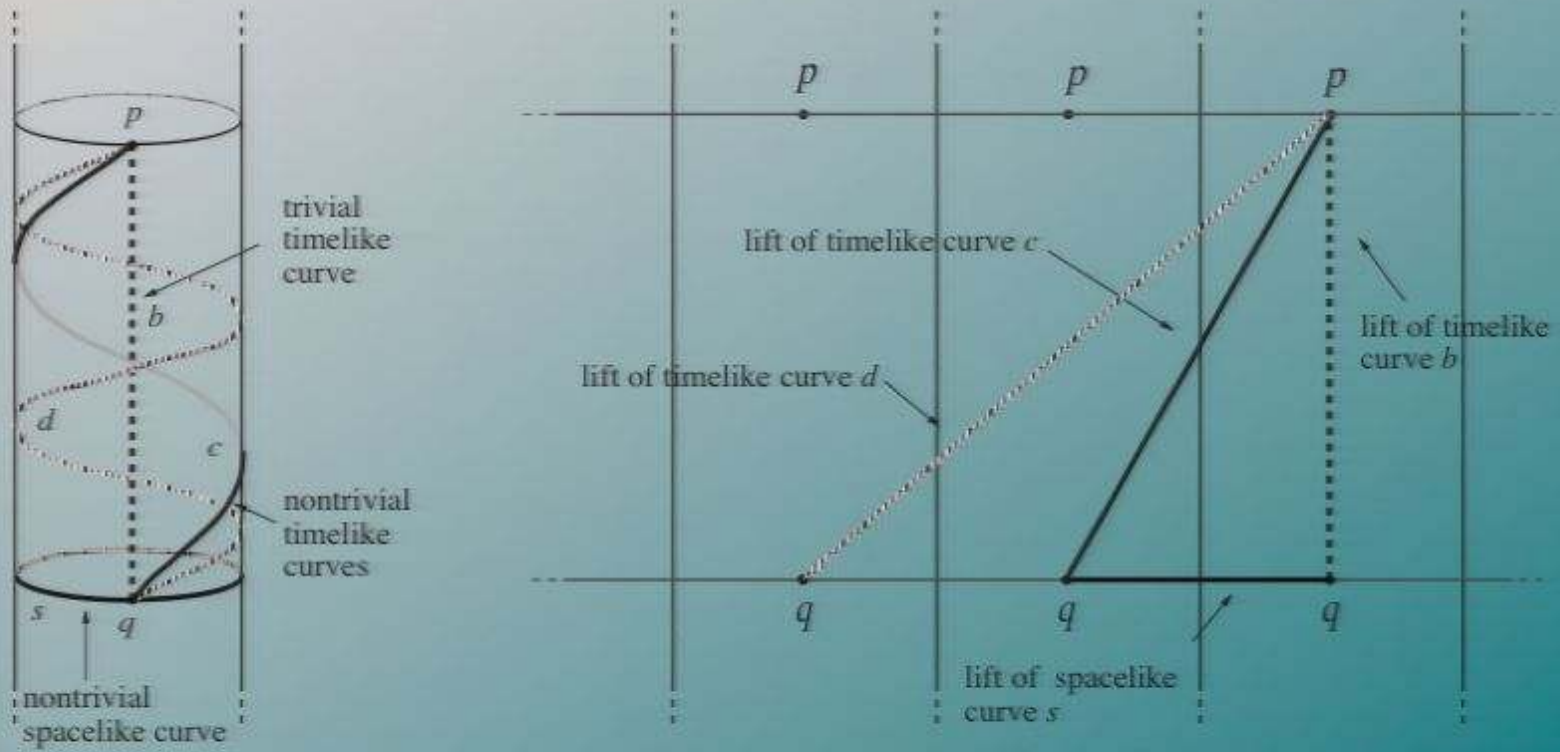
RP^3 throat at t=0

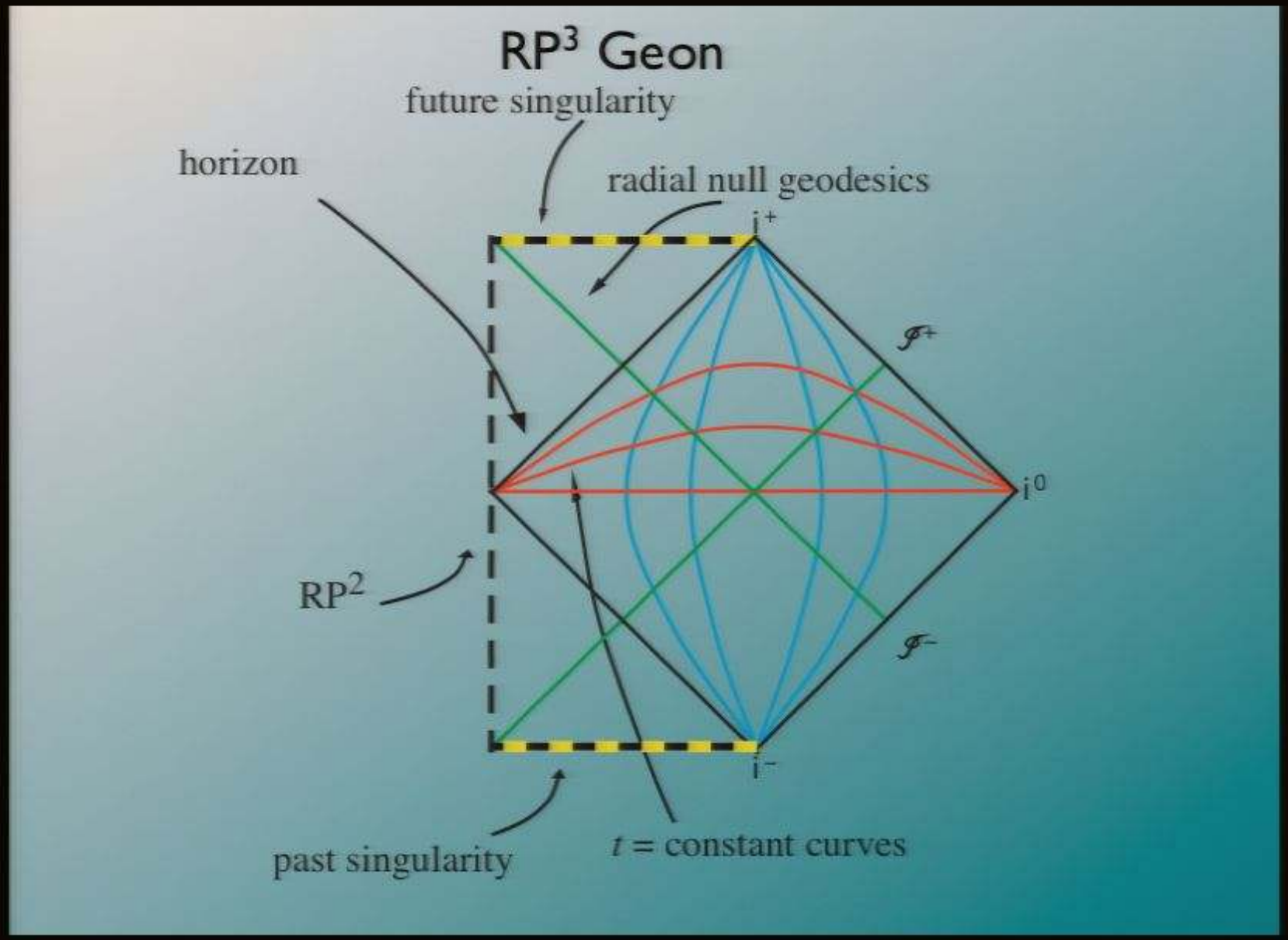


RP^3 Geon

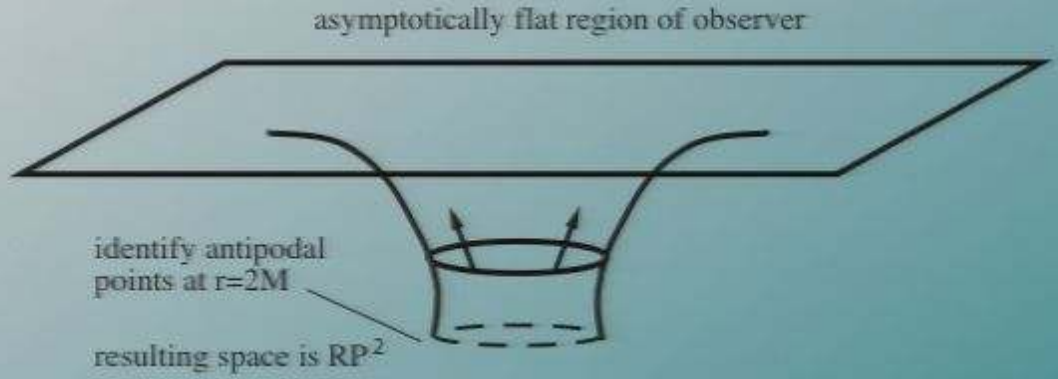

future singularity
horizon
radial null geodesics
i^+
$\mathscr{I}^+$
i^0
RP^2
$\mathscr{I}^-$
i^-
past singularity
t = constant curves

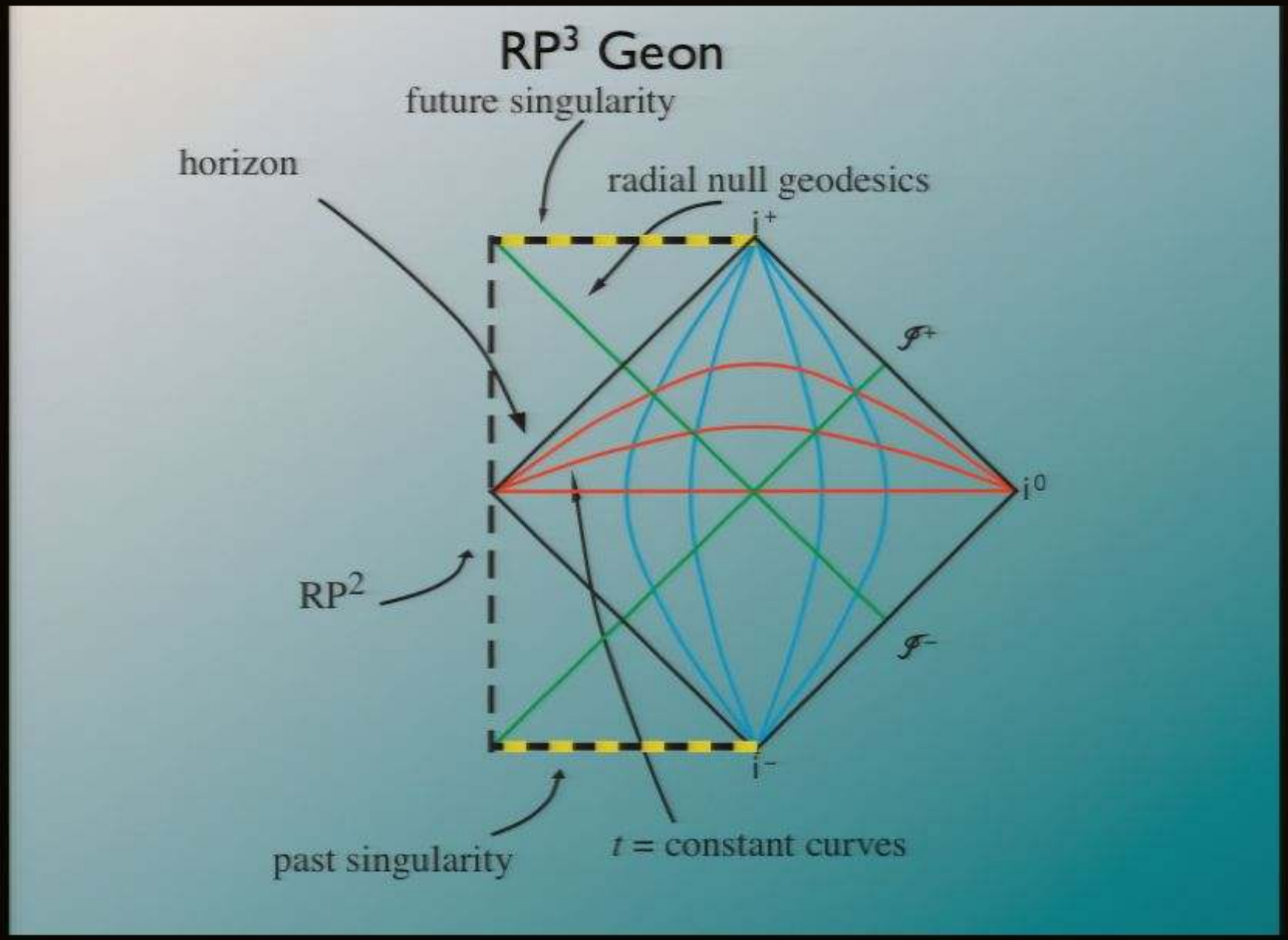
Covering Space



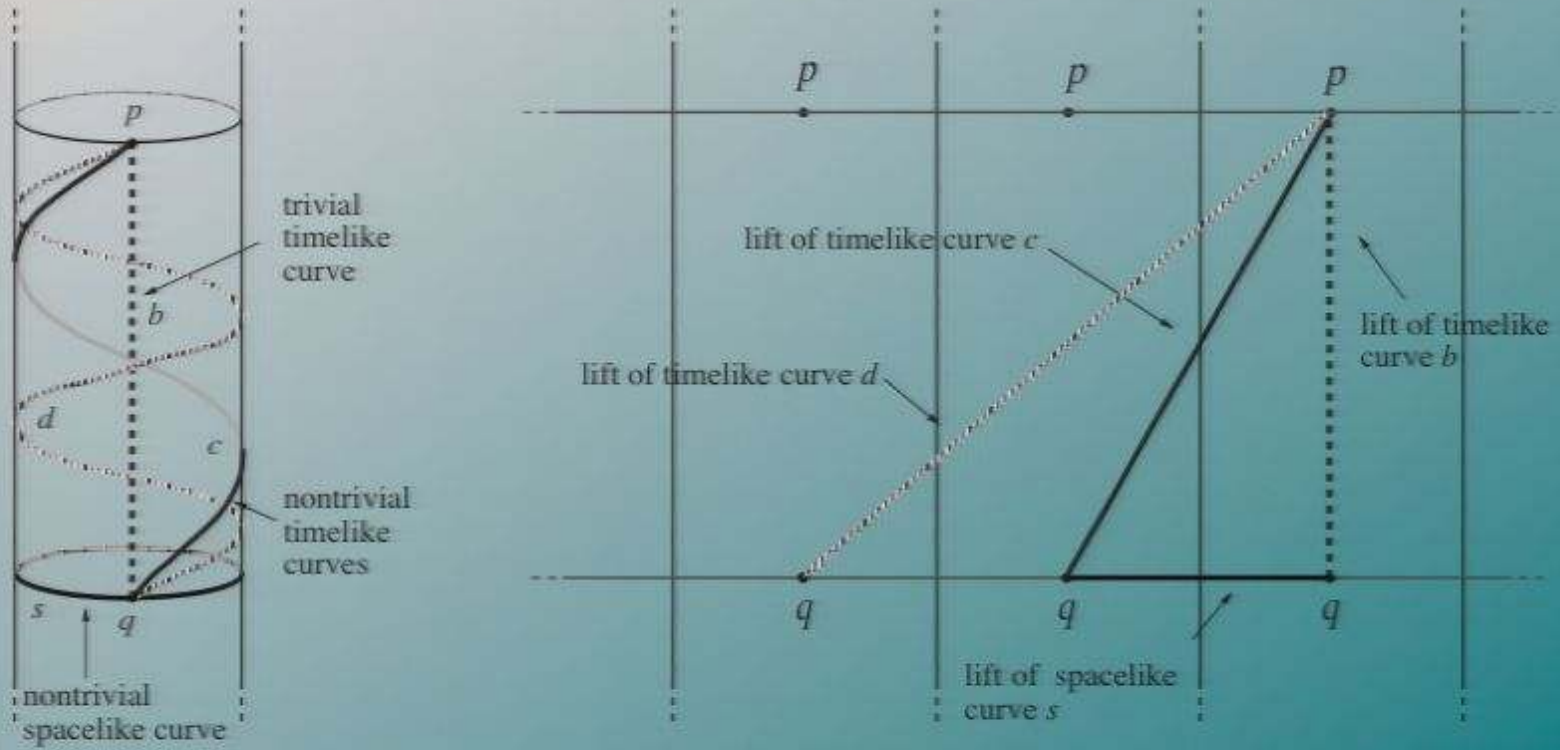

RP³ Geon
future singularity
horizon
radial null geodesics
i+
𝒥+
i0
RP2
𝒥−
i−
past singularity
t = constant curves

RP^3 throat at t=0

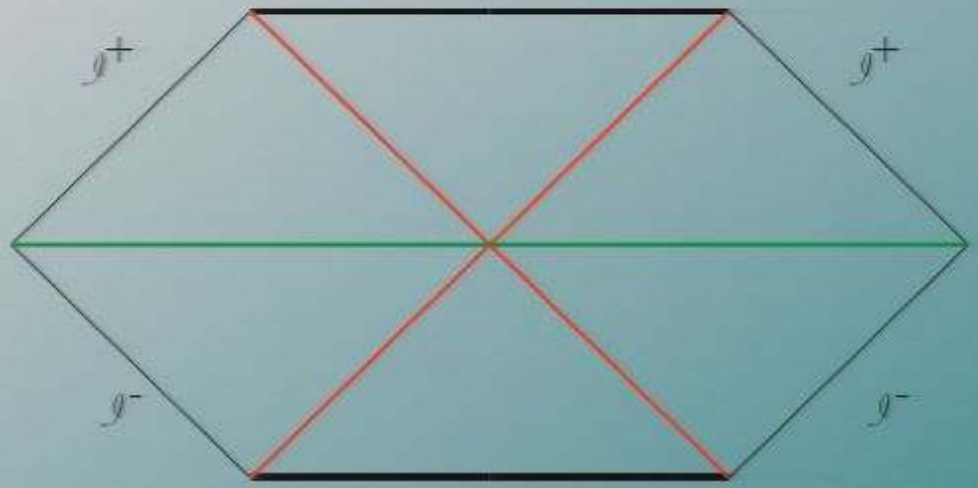


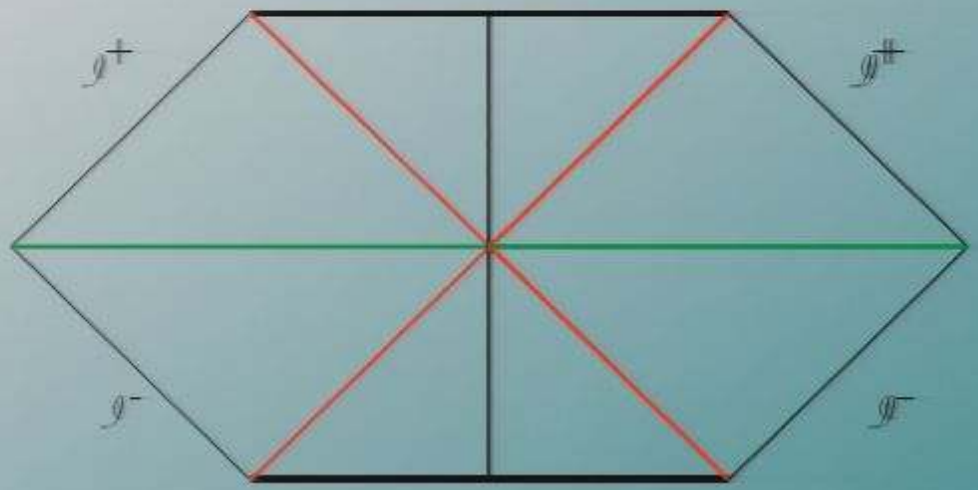

RP3 Geon
future singularity
horizon
radial null geodesics
i+
ℱ+
i0
RP2
ℱ−
i−
past singularity
t = constant curves

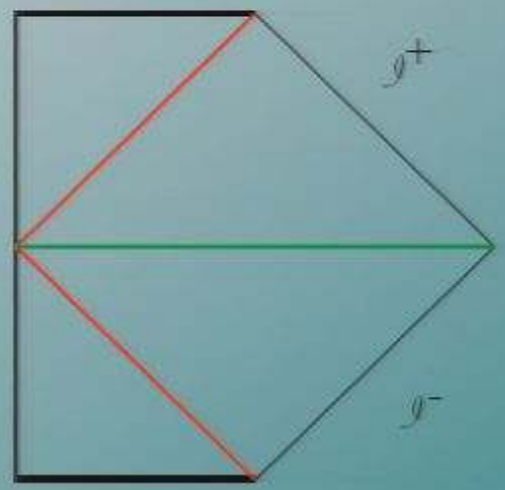
Covering Space

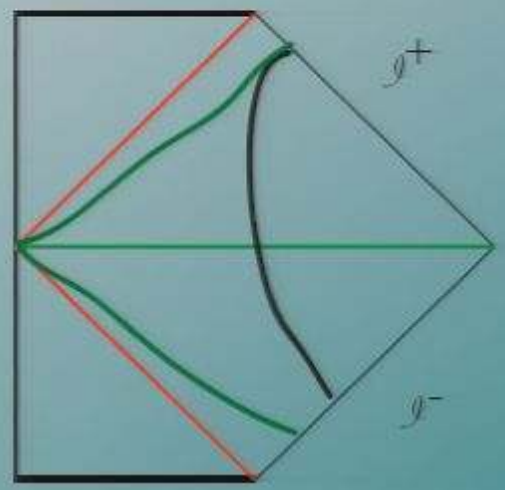


Schwarzschild Spacetime

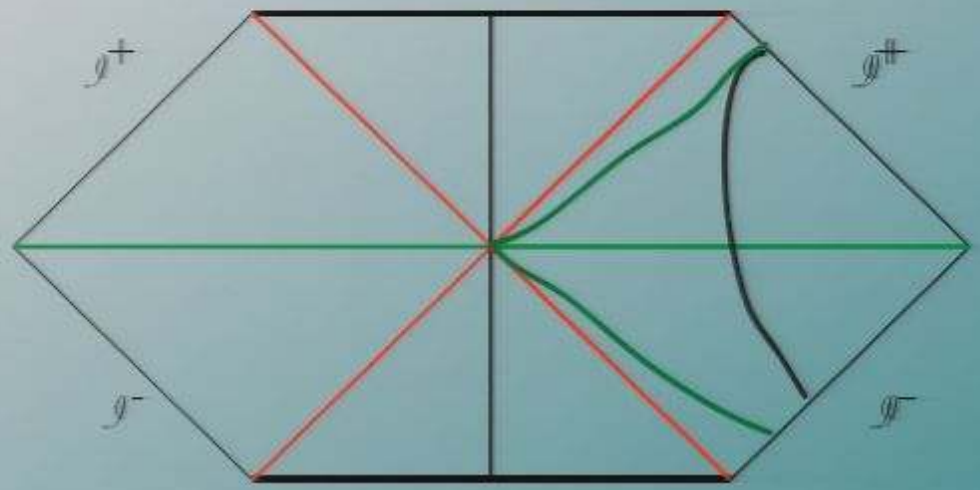



$\mathscr{I}^+$
$\mathscr{I}^+$
$\mathscr{I}^-$
$\mathscr{I}^-$


$\mathcal{I}^+$
$\mathcal{I}^-$

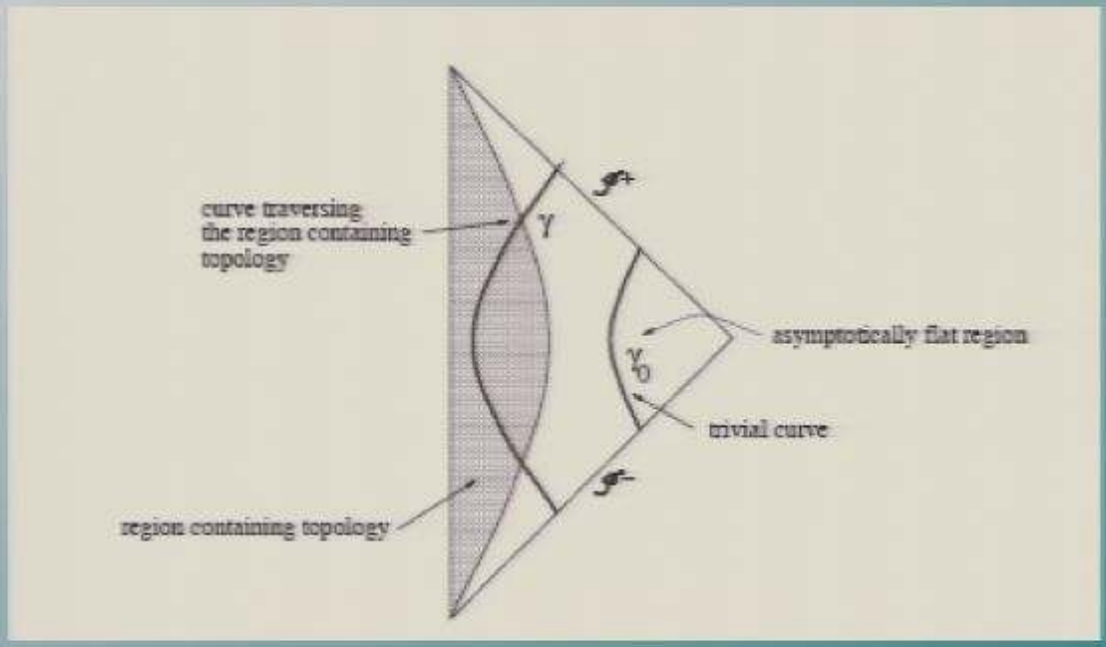


RP^3 Geon

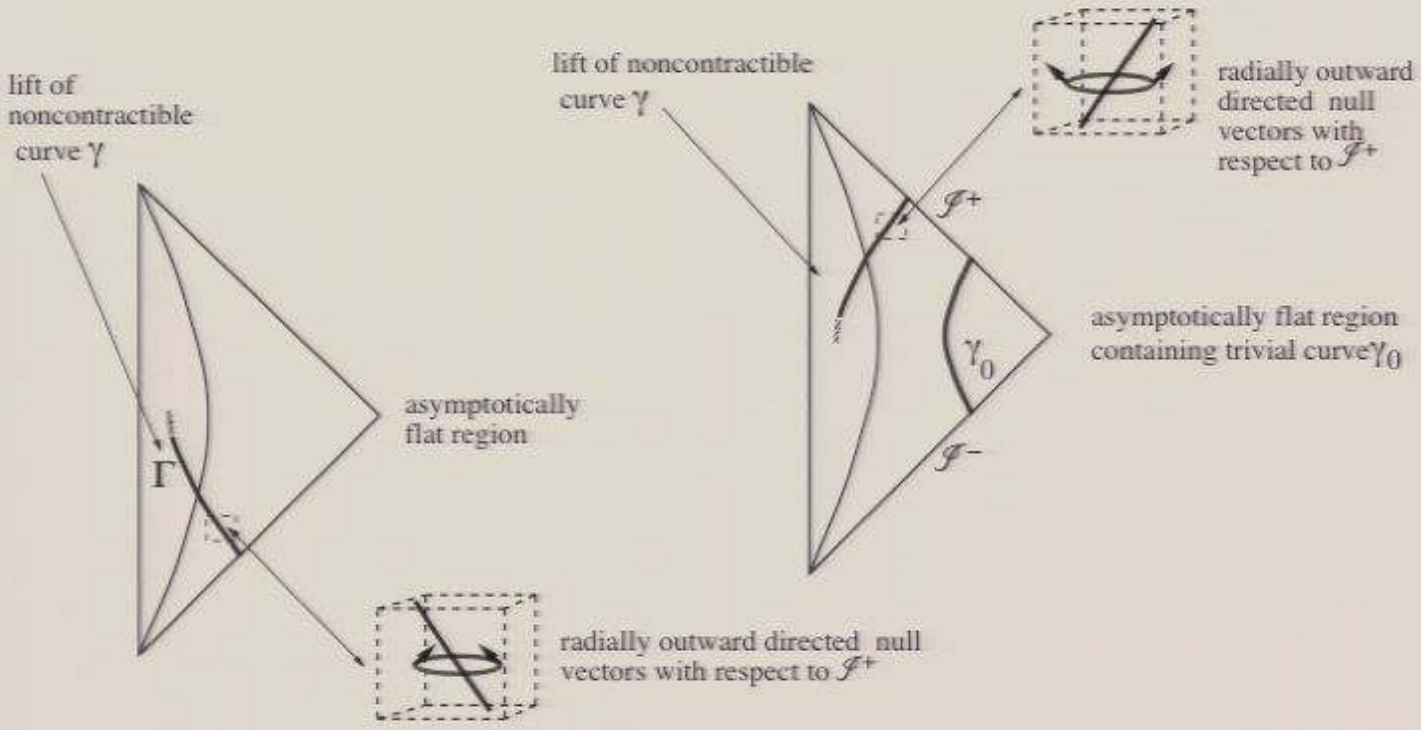


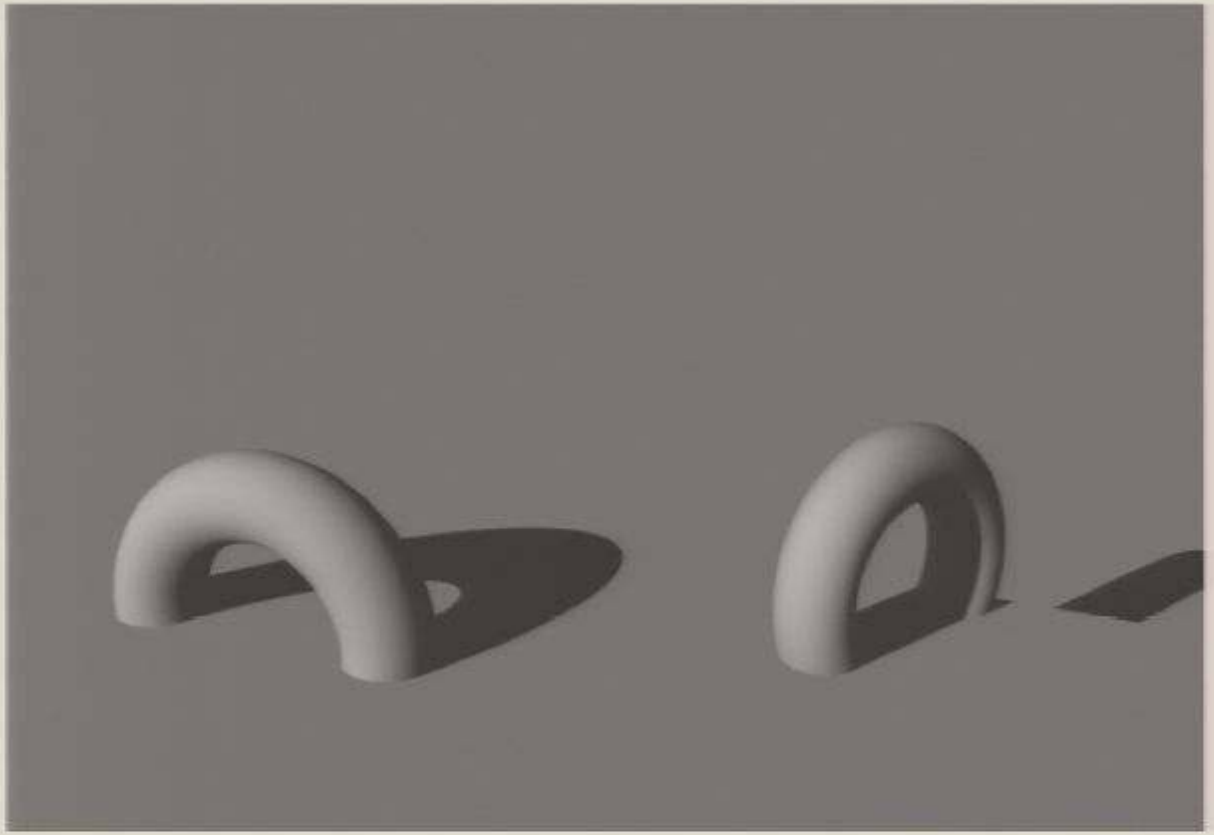
RP^3 Geon

AF spacetime with non-trivial topology

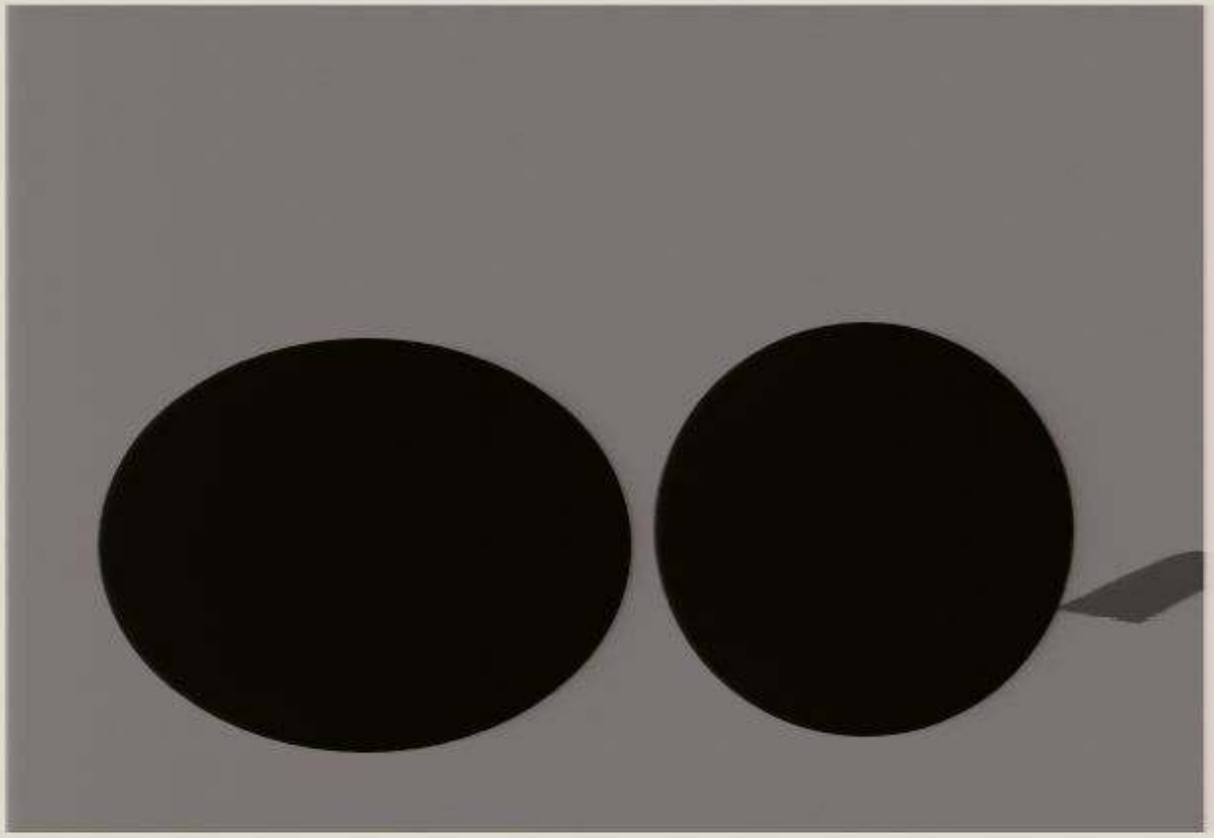


Simply connected cover





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