Victoria University of Wellington
Te Whare Wānanga o te Ūpoko o te Ika a Maui

Wurmlöchur
und
Zeitreisen

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Raum, Zeit, und Jenseits
Neuen Galerie Luzern
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Questions and answers:

1. • Q: Erlauben die Gesetze der Physik Wurmlöchur für Interstellare Reisen?

   • Q: Do the laws of physics permit wormholes for interstellar travel?

   • A: — Vielleicht —

   • A: — Maybe —

2. • Q: Erlauben die Gesetze der Physik Maschinen für Zeitreisen?

   • Q: Do the laws of physics permit machines for time travel?

   • A: — Unwahrscheinlich —

   • A: — Probably not —

Why do physicists care about these issues?

- Physicists will only be interested if you can take these words ("wormholes" and "time travel") and turn then into precise mathematical statements.

- Without mathematics, and without a solid physical background, the discussion is empty noise.

- Once you do set up the proper mathematical/ physical framework, these questions are a way of probing the outer limits of Einstein's general relativity.
  (Kip Thorne: Einstein's outrageous legacy.)

- Mathematically, there's strong hints of peculiar behaviour — no physics guarantees mind you.

What is a "wormhole"?

- Any closed curve in space.
- Any way of finding a "shortcut" through space.
- Any way of travelling "between universes".

What is a "time machine"?

- Any closed curve in space-time.
- Any way of having your future self meet yourself five minutes ago.
- Any way of having your future self send a message to yourself five minutes ago.

Warning:
I'm simplifying a lot of mathematical details.

The basic issue:

- The Einstein equations of general relativity are local:

$$\boxed{\text{Curvature(here)} \propto \text{Mass-energy(here)}}$$

- These equations do not constrain global features — long distance features — such as topology.

- In particular, they do not constrain either *spatial topology* ("wormholes") or *temporal topology* ("time machines").

Consequence:

- General relativity (Einstein gravity) *seems* to be infested with both wormholes and time machines.

Einstein–Rosen bridge:

- Old-style wormholes (the Schwarzschild wormhole, *aka* the Einstein–Rosen bridge, and related geometries) are non-traversable — any attempt at crossing from one "flat" region to the other leads you into the singularity. You will die.

- Even if your personal death is not a concern, the presence of an event horizon means you are not getting any messages back to the folks at home. As far as they are concerned you might as well not have sacrificed yourself.

- (Unless, of course, you have faster-than-light [FTL] drive or FTL communications; but that opens up another can of worms.)

Morris–Thorne wormhole:

- Mike Morris and Kip Thorne asked:

  "What sort of matter distribution would be needed to generate a traversable wormhole?"

- Traversable means you want a spacetime with at least two large flat regions connected by a throat, and with no event horizon between them.

- Answer: You need violations of the Averaged Null Energy Condition (ANEC); essentially — you need negative energy.

- At this stage classical physicists tend to choke and have difficulty in breathing.

Energy conditions:

- Violating the ANEC, "negative energy", is not as big a deal as you might naively think.

- Classical physics: ANEC violations are relatively difficult to achieve — though certain theories can cause havoc in this regard.

- Quantum physics: many significant examples of semiclassical ANEC violation are known.

- Braneworlds are also a good source of traversable wormholes — with the ANEC violations coming from the higher dimensions.

- Highly technical mathematial calculations needed to justify all these statements.

Traversable wormholes:

- You can also consider modifying the Einstein equations.

- With some devious trickery, you can design a traversable wormhole using arbitrarily small quantities of ANEC violating matter.

- Conclusion: Nihil Obstat.

- That is: There do not seem to be any fundamental physical laws preventing traversable wormholes.

- This does not mean that they would be easy to make.

- Time travel on the other hand...

An infestation of dischronal spacetimes:

- Kurt Goedel's universe.

- van Stockum time machines.
  (Tipler cylinders/Spinning cosmic strings.)

- Gott time machines.

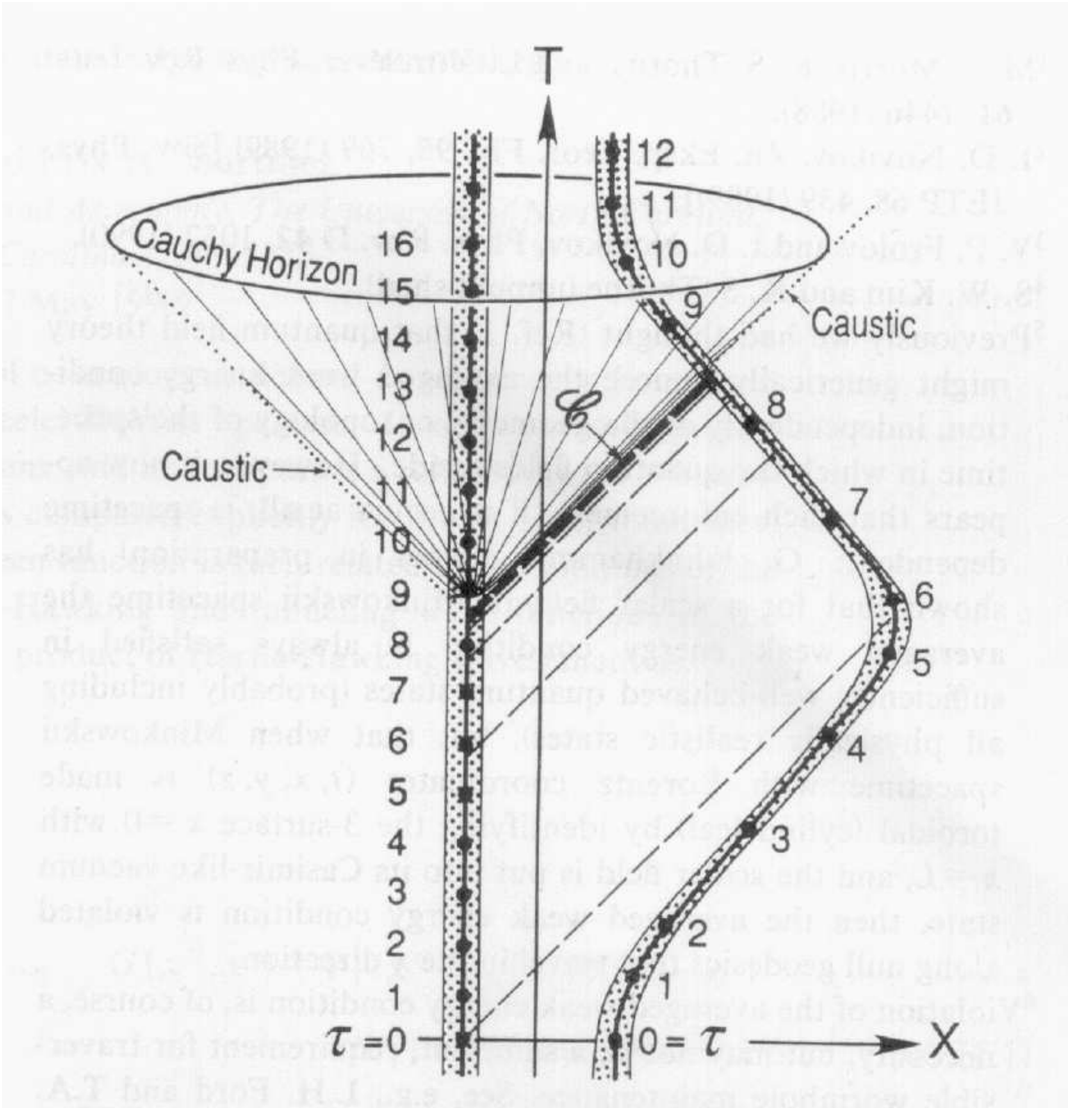
- Kerr and Kerr–Newman geometries.

- Wormholes — quantum.
  (Wheeler's spacetime foam.)
  [Spatial topology change $\Rightarrow$ time travel.]

- Wormhole-induced time machines.

Wormhole-induced time machine:

In the presence of a traversable wormhole the twin pseudo-paradox of special relativity becomes a true logical paradox...



So what?

- Time travel is problematic, if not downright repugnant, from a physics point of view.
  — Consistency paradoxes.
  — Bootstrap pseudo-paradoxes.

- One can either learn to live with it or do something about it:

  1. Radical re-write conjecture.

  2. Igor Novikov: Consistency principle.
     "You can't change recorded history".

  3. Stephen Hawking:
     Chronology protection principle.

  4. Boring physics conjecture.

Having your cake and eating it too:

- Stephen Hawking's chronology protection principle permits a rich structure of strange and interesting objects without indulging in a free-for-all.

> "It seems that there is a Chronology Protection Agency which prevents the appearance of closed timelike curves and so makes the universe safe for historians."

> "There is also strong experimental evidence in favour of the conjecture — from the fact that we have not been invaded by hordes of tourists from the future."

> "The laws of physics do not allow the appearance of closed timelike curves."

Conclusions:

- There does not seem to be anything intrinsically wrong with traversable wormholes.

- This does not, however, guarantee that traversable wormholes really exist.

- Time travel is much more difficult to reconcile with known physics — maybe not impossible but certainly hideously complex.

- Hawking's chronology protection principle keeps life "interesting", without letting things get *too* "interesting".