

Today in Astronomy 102: time machines

- ❑ Traversable wormholes, not made from black holes.
- ❑ Wormhole time machines.
- ❑ Is it possible to travel into the past?



View through a Reissner-Nordstrom wormhole ([Alain R](#), Wikipedia)

Traversable, constructible wormholes

Advising Carl Sagan in the writing of *Contact* got Kip Thorne and his grad student Mike Morris interested in how an advanced civilization might build wormholes for transportation. They wrote a [set of instructions](#) based on the following principles:

- ❑ For simplicity, the wormhole's geometry is taken to be spherical and static.
- ❑ It must represent a solution to the Einstein field equations, of course, and one stable against small perturbations.
- ❑ It must have a throat that connects two regions of flat spacetime, so that it can be used to connect places in our Universe. Thus its equatorial-plane embedding diagram looks like the classic “hyperspace tunnel.”

Traversable, constructible wormholes (continued)

- ❑ There should be no horizon.
- ❑ The tidal forces and accelerations experienced by a traveler must be bearably small; they took < 1 Earth g.
- ❑ A traveler must be able to cross the wormhole in a finite time in both the traveler's frame and in a frame of reference at rest with respect to the wormhole's mouths; they took < 1 year.
- ❑ The matter and fields that generate the wormhole's spacetime curvature must be physically reasonable.
- ❑ It should be possible to assemble the wormhole: that is, it should require energy much less than the mass of the Universe times c^2 , and take time much less than the age of the Universe.

Traversable, constructible wormholes (continued)

The toughest constraints turn out to be on the material that generates the curvature:

- It must be able to withstand enormous tension: the pressure represented by this tension turns out to be approximately

$$P = \left(\begin{array}{l} \text{pressure at the center of the} \\ \text{most massive neutron stars} \end{array} \right) \times \left(\frac{20 \text{ km}}{\text{circumference of throat}} \right)^2$$

- This tension must exceed the material's mass density, and there is no such material known.

Traversable, constructible wormholes (continued)

- In fact, if it were to have this property and be part of the structure, it would appear in the viewpoint of a distant observer to have negative energy density: that is, it's **exotic matter**, again.
- So there doesn't seem to be any way to avoid exotic matter in the construction of a traversable wormhole. All they could do was consider ways to minimize the amount.

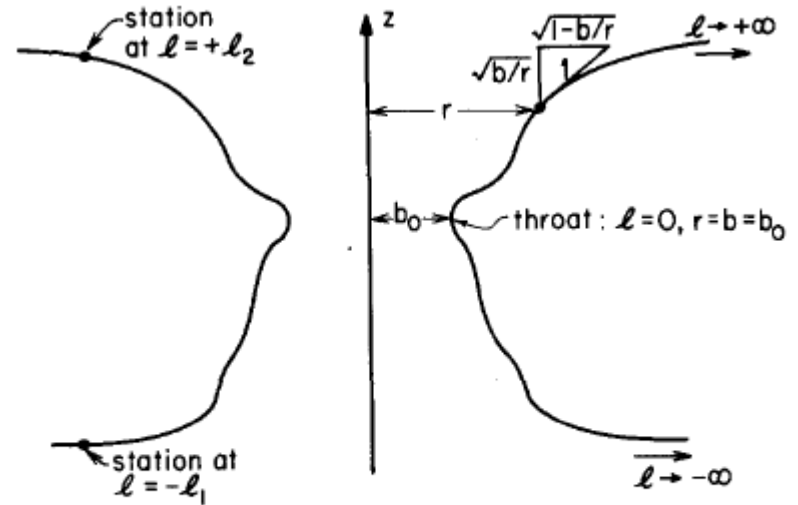


Fig. 2. Embedding diagram for a general wormhole, as seen in profile. (The diagram must be rotated about the vertical z axis to make it complete; cf. Fig. 1.).

[Morris and Thorne 1987](#)

Traversable, constructible wormholes (continued)

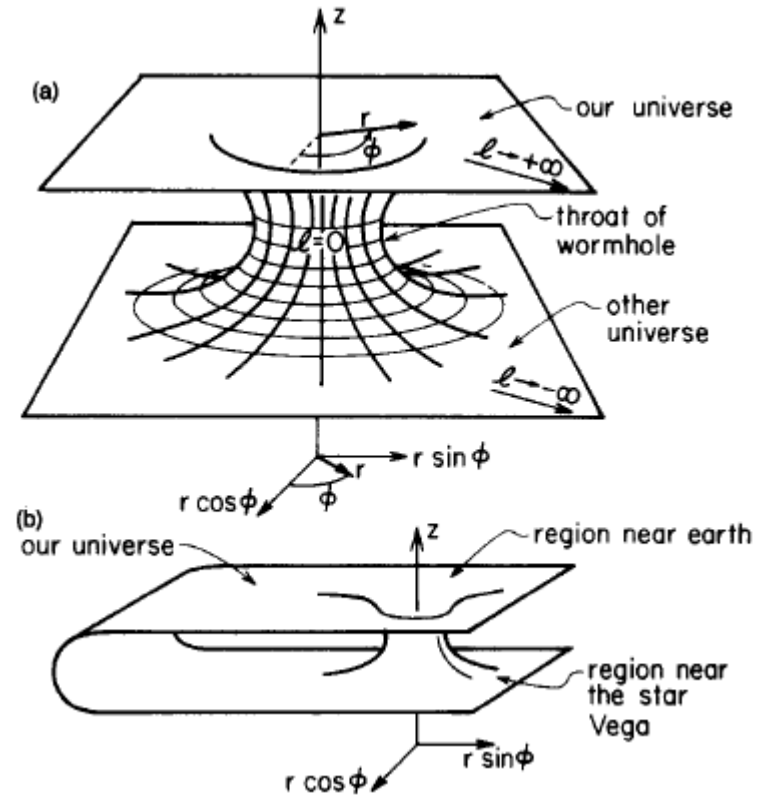
Properties of the minimum-exotic-matter solution:

- ❑ Exotic matter provided as a spherical shell slightly larger than the throat of the wormhole. All the other matter is non-exotic.
- ❑ Characteristic size of the mouths is rather large (600 times the size of the Solar system) in order to keep the accelerations modest.
- ❑ Acceleration no greater than one Earth g, small tidal forces, so traversing it would be perfectly comfortable.
- ❑ It would take 200 days to traverse the wormhole.
- ❑ How long it is in physical space determines the total mass.

So all we need is that exotic matter!

Mid-lecture Break

- Homework #5 is due tomorrow at 5:30 PM.



[Morris and Thorne 1987](#)

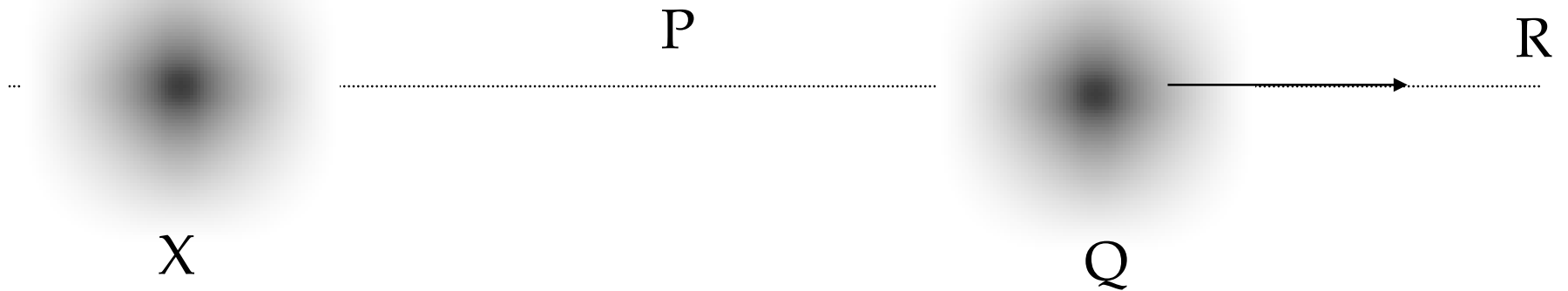
Wormholes as time machines

How does time hook up inside a wormhole? Imagine a wormhole with **constant length in hyperspace**, but with the **two mouths moving with respect to each other in physical space**, with one of them experiencing acceleration.

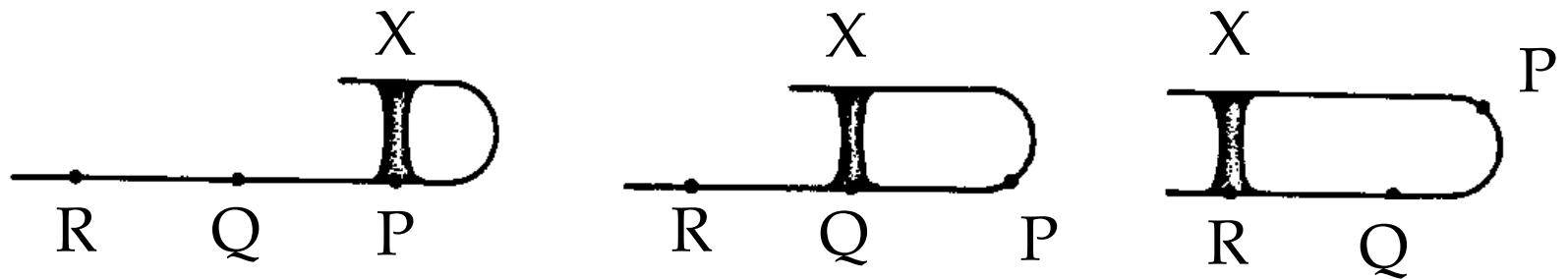
- ❑ Time dilation: clocks just outside the two mouths would appear to a distant observer to run at different speeds; the rates of time flow are different.
- ❑ From the inside, though, the mouths appear at rest with respect to each other; the rates of time flow are the same.
- ❑ This effect, the difference in time flows at the two mouths and the joining in the middle, could enable the use of a wormhole as a time machine, as follows...

Wormholes as time machines (continued)

Wormhole “mouths” in physical space at one instant of time



Hyperspace (at three instants of time)



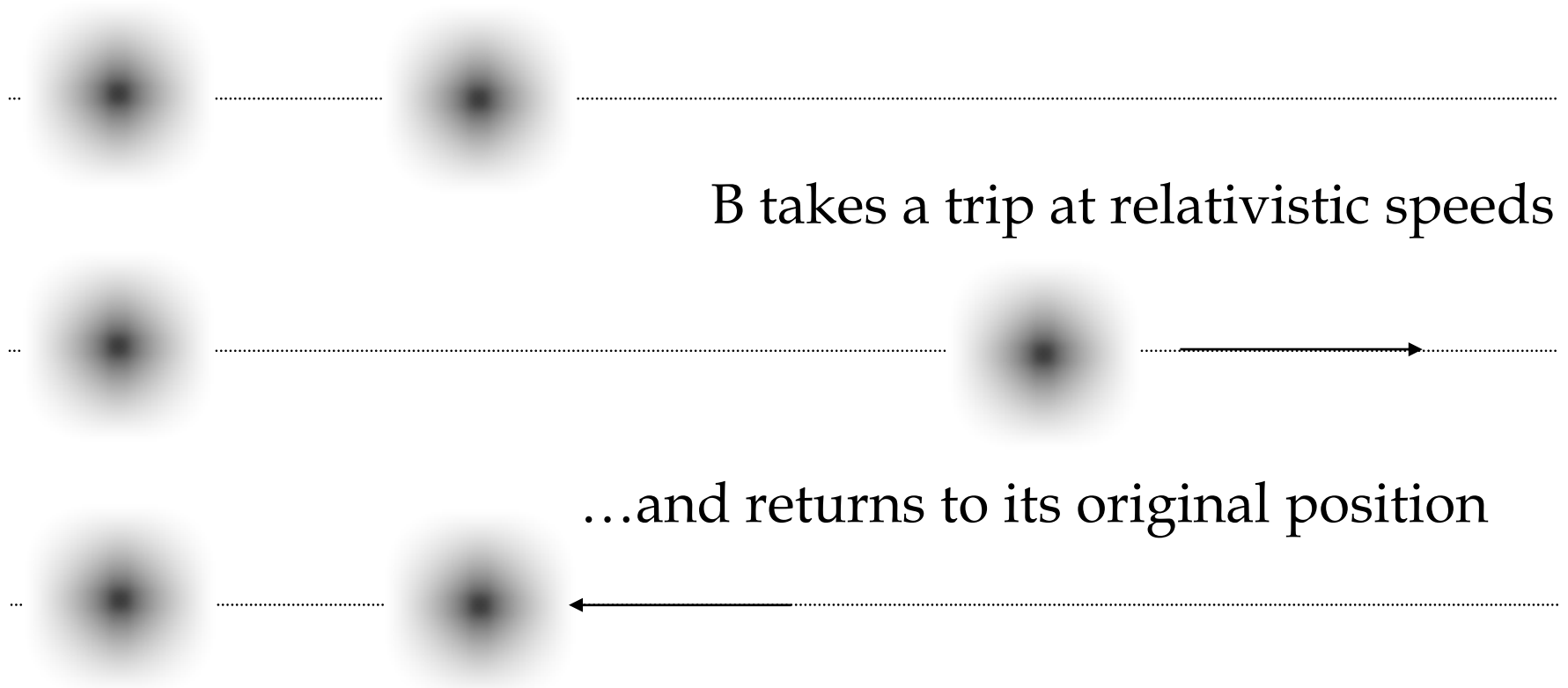
How to build a wormhole time machine

- ❑ Start with a wormhole whose two mouths (called mouths A and B) are close together in space. Fix things up so that they stay the same distance apart in hyperspace.
 - In Thorne's description in the book, this is illustrated by two people reaching into opposite mouths and holding hands.
- ❑ Take mouth B on a trip at high speeds (approaching light speed), out a great distance, and then back to its former spot, **without ever changing the distance between the two mouths in hyperspace.**

How to build a wormhole time machine (continued)

Mouth A

Mouth B



How to build a wormhole time machine (continued)

- Because of time dilation, the trip will take a short time according to an observer travelling with mouth B, and a much longer time according to an observer who stays with the “stationary” mouth A.
- **While B is gone**, the observer at A can **travel into the future** (to the time when B returns) by passing through mouth A.
- **After B returns**, an observer at B can **travel into the past** (to the time when B left) by passing through mouth B.
- The length of time travel is thus the time lag between clocks fixed to A and B during B’s trip, and is thus adjustable by adjusting the details of the trip.
- Travel between arbitrary times is not provided!

Odd features of time travel

Paradoxes such as the “matricide paradox” come up! One could use a time machine, for example, for travelling back through time before one’s birthday and killing one’s mother.

Does physics prevent one from being born and travelling back through time in the first place?

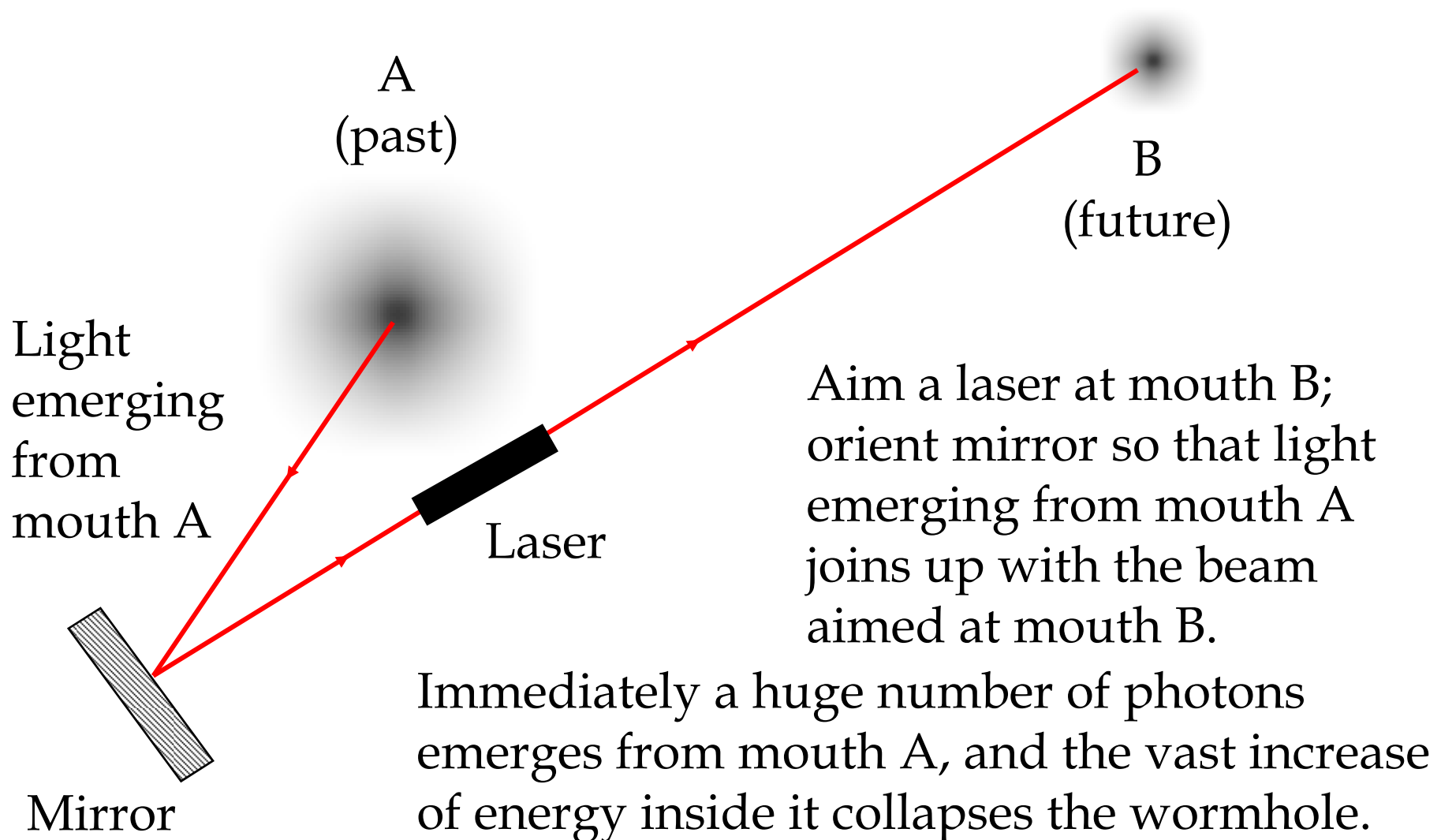
- Maybe.** How is it that one can start with laws of physics like the Einstein field equation, that have cause and effect built in, and derive from them violations of cause and effect?
- Maybe not.** What about quantum mechanics? Vacuum fluctuations, for instance, have no “cause.” If quantum behavior (associated with mass-density singularities) is inherent in the wormhole, one could still exist after committing paradoxical matricide.

Alas, it may be impossible to build a stable wormhole time machine

Geroch, Wald, and Hawking on self-destruction of wormhole time machines:

- ❑ Light leaving the origin during B's trip, and entering mouth B as it is returning, can travel backwards in time, emerge from A, and meet itself in the act of leaving.
- ❑ It can do this as many times as it likes, even an infinite number of times.
- ❑ Since light can interfere constructively (all the peaks and troughs of the light wave lining up), a large positive energy density could be generated in the wormhole, which would collapse it.
- ❑ This process could take as little as 10^{-95} seconds in the frame of reference of mouth A.

A recipe for wormhole time-machine destruction



Alas, it may be impossible to build a stable wormhole time machine (continued)

- It's also possible for this to happen with light created by **vacuum fluctuations!**
 - Since light has *wave* properties too, the probability that virtual photons from near A to travel to B and re-emerge from A pointed again at B is not zero, even if there is nothing to aim the photons that way.

That would render all wormhole time machines unstable.

- The interference may not be constructive, though, because the wormhole tends to defocus the light in the manner of a negative lens; therefore we do not know whether this is a fatal objection.