Today in Astronomy 102: Wormholes

- Wormholes, and how to construct one using black holes.
- Wormhole maintenance: how objects like the StarTrek: DS9 wormhole might work.

Hypothetical spacecraft about to enter a hypothetical wormhole (NASA Glenn Research Center).
Wormholes

Wormholes are solutions to the Einstein field equation that involve two mass-density singularities. A wormhole can be thought of as a special combination of two black holes. By special, we mean that the interiors of the two black holes are connected under some circumstances.

- Remember how strongly warped space is, near and within a black hole horizon: a lot of space is contained therein, and if it weren’t so strongly curved it could reach a long way – and, if it reaches inside another black hole…

- Or, if you prefer the hyperspace paradigm (as we do in this class): black holes that are distinct in physical space can overlap in hyperspace.

A concrete example may show better what we mean…
Construction and destruction of a wormhole

Start with two black holes that overlap in hyperspace, each in a configuration in which the mass-density singularity is *singularity* (time flows out of the singularity; this is sometimes, but inconsistently, called a “white hole”).

- According to our present (incomplete) understanding of quantum gravity, two such singularities may “unwarp” each other to produce a “tube” of continuous paths through hyperspace between the two black holes.
- The “unwarping” may even eliminate the horizons!
- This tube through hyperspace is the wormhole. It wouldn’t look like a tube in *physical* space, though; each mouth would still look spherical from the outside. (We will describe in a little more detail *how* it looks in physical space in a little bit.)
Construction and destruction of a wormhole (continued)

Expanding mass-density singularities

Contracting mass-density singularities

Figure from Thorne, *Black holes and time warps.*
Construction and destruction of a wormhole (continued)

Like the previous page, but animated. (From Andrew Hamilton’s wormhole pages, which can be found [here](http://example.com).)
Construction and destruction of a wormhole
(continued)

- Since the mass-density singularities were of the expanding type (time flows out in both hyperspace directions), the diameter of the wormhole initially expands with time.
  - **Practical upshot:** the paths through hyperspace become somewhat less strongly warped: there would be decreasing gravitational forces and tides on bodies that found themselves there, while it expands.

- It is possible for the path through hyperspace to be short, while the distance between the singularities is very large, measured in “real” spacetime.
  - **Practical upshot:** the wormhole can be a shortcut through spacetime. (Of course, it could also be longer than the straight path through regular spacetime…)
A hyperspace shortcut via a wormhole

A embedding diagram of a wormhole with the properties described in Carl Sagan’s novel and movie *Contact*, that was used by the lead character, Ellie Arroway, to travel to the neighborhood of Vega (and then to the Galactic center) and back in about eighteen hours.

From Thorne, *Black holes and time warps*
Other methods of wormhole construction

Making wormholes from mass-density singularities (‘‘quantum strategy’’):

- The quantum foam of a mass-density singularity contains many wormhole-like structures. Perhaps one could be expanded by throwing enough exotic matter into a black-hole mass-density singularity.

Making wormholes without first making a singularity (‘‘classical strategy’’):

- Severely warp and twist spacetime. It is possible, according to the Einstein field equation, but extremely hard to picture (and to illustrate), and impossible to do without distorting time as seen from all reference frames, in a manner that involves time reversal.
How an open wormhole might really look.

It’s spherical, and like a giant globe of the sky as seen from the other mouth.
Passing through the wormhole...
...and out the other side

In your rearview mirror, you would now see a globe of the sky seen from the mouth you entered.
Use and abuse of wormholes

The down side: what happens if you try to enter the wormhole to employ the shortcut?

- You are accelerated to relativistic speeds on your way through. As a result, your energy (and mass) increase dramatically, in the rest frame of the wormhole.

- Your mass eventually becomes large enough, halfway through the wormhole, that your own gravity warps spacetime, collapsing the wormhole onto you.

- As your gravity “pinches off” the wormhole, singularities form again - but this time, they’re of the black hole type. Your energy is added to the black holes, and the wormhole is destroyed (and you are, too).
Use and abuse of wormholes (continued)

How could we prevent the collapse of the wormhole under your gravitational influence, so you could make it through unscathed?

- By putting exotic matter into it. Exotic matter, with its negative energy density, would be “anti-gravity”: it would warp spacetime in senses opposite to the way normal matter warps it.

- In particular, adding exotic matter to a wormhole would tend to expand the diameter of its effective “hyperspace tunnel.”

Recall the calculation of the effect on gravitational deflection of light by the (exotic) vacuum fluctuations near a black hole’s event horizon (lecture, 10 November):
Exotic matter in wormholes

In the sense of gravitational deflection of light, a black hole acts as a positive lens and the surrounding vacuum fluctuations act as an additional, negative lens.
If a wormhole is stable, it must contain exotic matter

Photons that enter the wormhole travelling radially inward leave it travelling radially outward without their paths crossing, like a negative lens would do; this gravitational defocussing of light can only be accomplished with negative energy-density material, since a positive energy density would have focussed them to a point before they could diverge, as a positive lens would.

Figure from Thorne, *Black holes and time warps.*
Mid-lecture Break

- Homework 5 is on WeBWorK; due this Friday at 5:30.

Embedding diagram of a stable wormhole, by Cliff Pickover. Bits of real matter (note their positive curvature in this embedding diagram!) are about to fall through. See http://sprott.physics.wisc.edu/pickover/.
The Star Trek DS9 wormhole

The most extensively-described fictional wormhole is surely the one in Star Trek: Deep Space Nine, shown here at the end of the show’s title sequence.

This week, in Recitation, you will watch clips from the first episode of DS9, in which the wormhole figures in most of the action.
Wormhole maintenance: how the Star Trek DS9 wormhole might work

In *Star Trek: Deep Space Nine*, a stable wormhole provides a hyperspace shortcut from the “alpha” quadrant to the “gamma” quadrant of the Milky Way galaxy. In the story, it is inhabited by strange, Epicurean beings who permit travellers to pass through by opening and closing the wormhole.

- **How do they open and close the wormhole?** By rearranging large amounts exotic matter within the wormhole.

- **Are the beings themselves made of exotic matter?** They are intelligent. Something as orderly as intelligence can’t arise from random vacuum fluctuations, so if the beings are themselves exotic, there must be other forms of exotic matter besides vacuum fluctuations in strong gravity.
Wormhole maintenance: how the Star Trek DS9 wormhole might work (continued)

- Open
- Pinched off
- Closed

More exotic matter inside the wormhole
Less exotic matter inside the wormhole
Little exotic matter inside the wormhole
Wormhole maintenance: how the Star Trek DS9 wormhole might work (continued)

- **How does the wormhole appear when it’s closed?** The same as a black hole, from both mouths.

- **What does the wormhole look like from the outside, when it’s open?** Like a faint, spherically symmetric source of light; it transmits all the light incident upon the other mouth. Look into it to see a view of the sky on the other side.

It certainly would not look anything like this (*Star Trek: Deep Space 9*, Paramount Studios).
Wormhole maintenance: how the Star Trek DS9 wormhole might work (continued)

- **What does the wormhole look like from the inside, when it’s closed?** Like the neighborhood of a mass-density singularity: spacetime very strongly warped, time ceasing to exist at the center, *etc*. The non-existence of time at the center of the closed wormhole presumably gives the wormhole beings their peculiar view of time as something that can run forward, backward, stop, transpire out of sequence, and so forth.

- **What does the wormhole look like from the inside when it’s open?** Like a spherically symmetrical space where everything is converging toward a center, gradually changing to a spherically-symmetric divergence from a center. It does not look like a tube in physical space, only in hyperspace.
Wormhole maintenance: how the Star Trek DS9 wormhole might work (continued)

- **Is energy required to move through the wormhole?** No; gravity accelerates you and pulls you through. It would take a great deal of thrust to hold still inside the wormhole, contrary to what’s shown on the TV show.

- **How does one open the wormhole from the outside?** By sending a prearranged signal or beam of particles down the mouth; this arrives (highly accelerated or blueshifted) at the singularity, where the wormhole beings live, and when they detect it they proceed to rearrange the exotic matter.

- **Does the wormhole have a horizon?** Only when it’s closed. (Then it has two, one at each mouth.)

- **Is there a limit to how much matter can be moved through the wormhole at once?** Yes; if there’s much more normal matter than exotic matter inside, the wormhole will collapse.