Wormholes:
Space Machines and Time Machines

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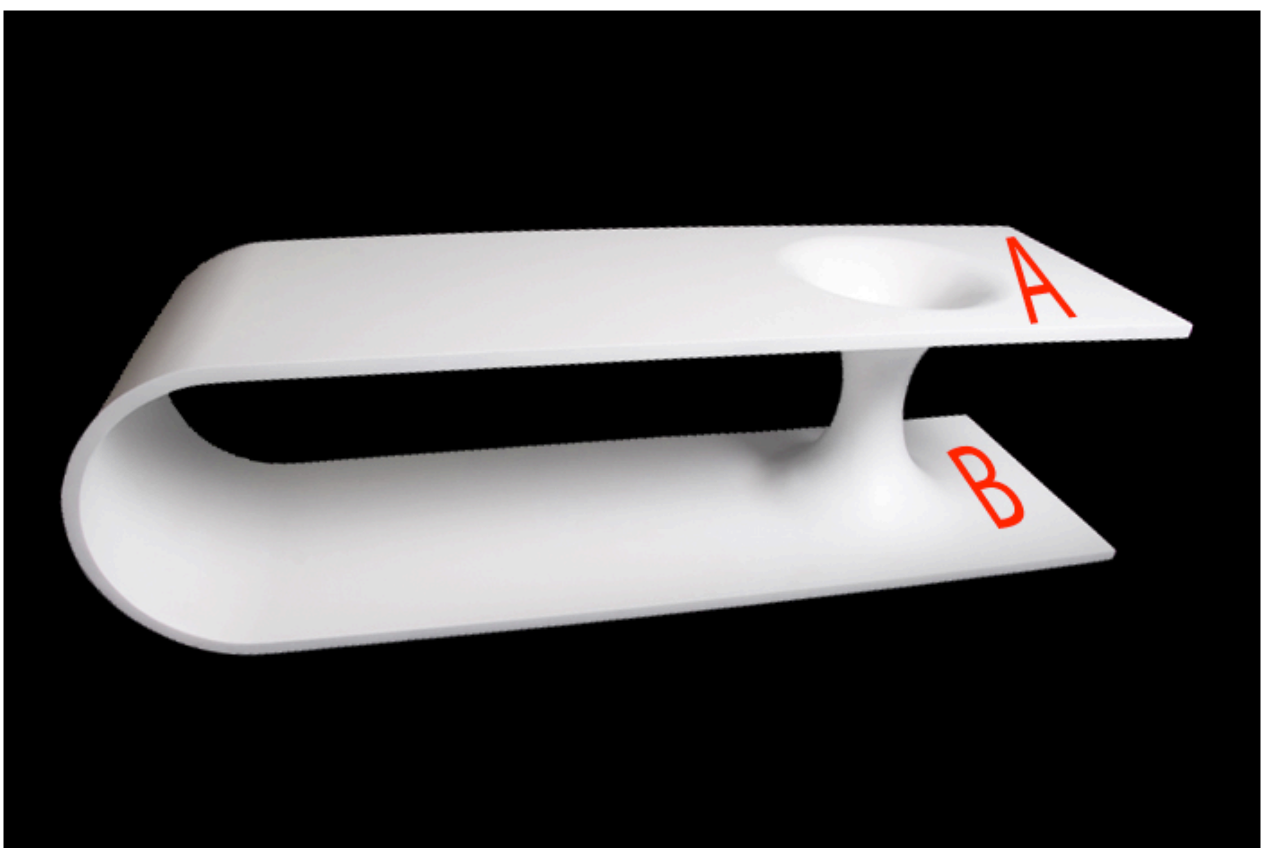
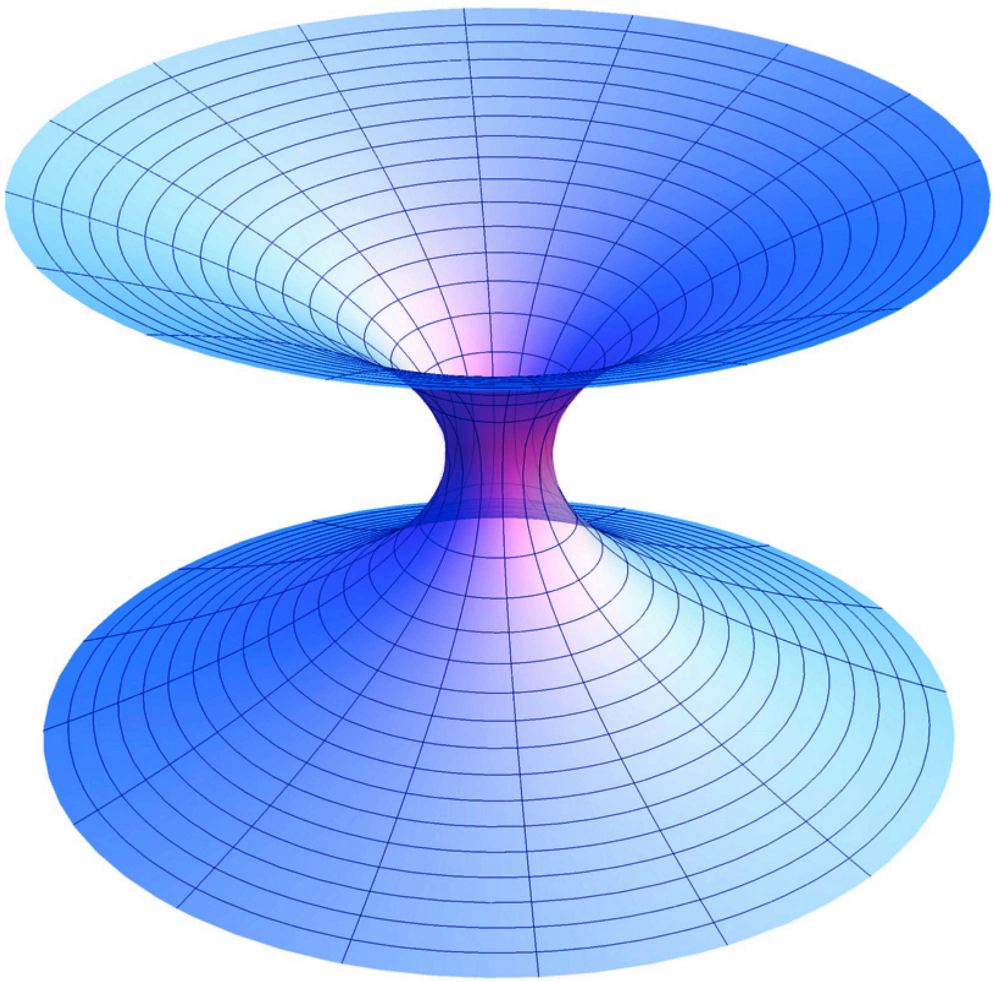
Space Travel with Wormholes

A wormhole is a hypothetical shortcut between two distant regions of space-time. Although a three dimensional wormhole is impossible to fully visualize, a two dimensional analogue can be constructed to aid visualization. Imagine an intrinsically flat, two dimensional, space as a folded piece of paper embedded in a higher three dimensional space, where a tube connects two distant points, A and B, on the paper. The length through the tube (the wormhole) can be much less than the distance from A to B along the paper, creating a shortcut.



A full three dimensional wormhole would have entrances and exits that are three dimensional spheres rather than two dimensional rings like the mouths of the paper tube. Such lower dimensional, human-friendly, visualizations are termed embedding diagrams, and the iconic wormhole image is usually shown as the well known Schwarzchild embedding diagram, which is the wormhole analogue for a static, non-rotating, Schwarzchild black hole.



An observer passing through such a wormhole could, in principle, traverse the wormhole in less time than it would take to travel from point A to point B through normal space-time outside the wormhole. Moreover, if A and B are sufficiently distant in space and the wormhole length is sufficiently short, an observer could potentially traverse the wormhole in a time less than it would take to send a light signal from A to B through normal space. Wormholes could thus be used as a cosmic ``cheat" to effectively bypass the limitation that no object can travel faster than the speed of light in special and general relativity. Faster than light travel itself presents many paradoxes, since it could be used to send messages and information back in time. Certain other uses of wormholes could also potentially allow observers themselves to travel into the past.

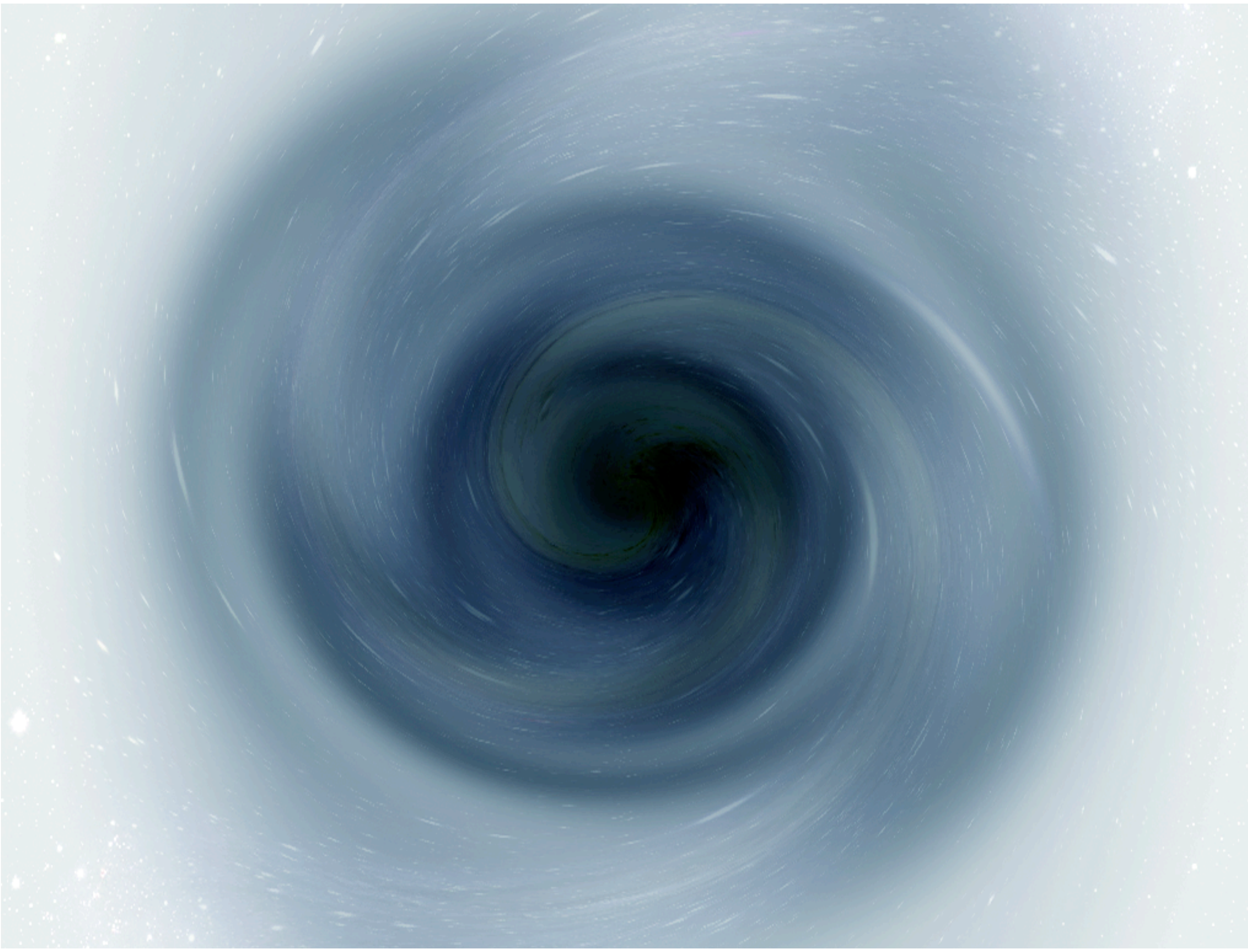
Time Travel with Wormholes

In addition to facilitating effectively faster than light travel, wormholes could potentially be used as time machines, in the following sense first developed by Caltech theoretical physicist Kip Thorne. Imagine an advanced technology capable of creating, manipulating, and containing both ends of a stable, traversible, wormhole. Place one end in a laboratory on Earth and the other on a spacecraft capable of traveling through space at some reasonable fraction of the speed of light. Imagine the wormhole connecting the lab and spaceship is created in some future year, say 2500. Now keep one end on Earth and send the spaceship off in any direction at some appreciable fraction of the speed of light for a finite duration after which it will decelerate, turn around, come back to Earth, and stop, so the wormholes ends are brought back together.

Relativity tells us that the clocks of observers left on Earth and those in a relativistically moving spacecraft will begin to differ by an amount that depends on the speed of the craft. Since moving clocks run slow in relativity, a spaceship observer might experience a short subjective duration of say, a few weeks, but thousands or millions of years could pass in the external universe depending on how fast they were traveling. In this sense, time travel to the future is easy, and does not require wormholes, just a ship capable of moving at relativistic speeds. A spaceship executing the above maneuver might find itself thousands or millions of years in the future after stopping. Yet an observer at the wormhole mouth in the laboratory on Earth would still have its clock synchronized with the shipboard wormhole. If the ship finds itself, say in year 3500, after returning to Earth, any observers on the ship could return to the year 2500, traveling 1000 years into the past, simply by stepping through their shipboard wormhole back into the laboratory on Earth.

In this way, wormholes could theoretically be used to travel into the past. However, in this case, the shipboard time travelers could never travel to before the year 2500. This poses a striking answer to the question, ``If time travel to the past is possible, how come we aren't being constantly visited by time travelers from the future?" For these types of wormhole time machines, the answer is simply, because they haven't been invented yet! Time travel of this sort can never take an observer back to before the original date when the wormhole connection was set up. This is a particularly clever resolution to an interesting time travel paradox.

Do Wormholes Actually Exist?



No observational evidence for wormholes currently exists, but mathematical solutions describing wormholes have long been known to be valid theoretical solutions to Einstein's field equations of General Relativity. However, wormholes made completely of normal matter with positive energy density would be inherently unstable, and would be likely to collapse in the presence of nearby matter or matter that tried to traverse the wormhole. However, stable, traversible wormholes could exist if their entrances and exits were held open by exotic matter with a negative energy density. Examples of such exotic matter include the quantum field configuration responsible for the Casimir Effect in quantum field theory. Whether such exotic matter could occur naturally in high enough densities to permit a stable wormhole to form via ordinary physical processes or whether it could be created artificially with sufficiently advanced technology remain open theoretical questions.

Astronomers and astrophysicists are actively speculating about how to test for the existence of wormholes observationally. If they exist, perhaps some objects currently thought to be black holes are actually wormholes. Because the metric describing how space-time distances and durations are computed would be different outside of certain kinds of black holes and wormholes, observations could potentially distinguish between the two by observing how gas and dust emits light as it orbits close to a candidate compact object. Observers could also use the way that light from background stars is gravitationally lensed if a wormhole passes between it and us along our line of sight, since this is potentially different than the lensing caused by a black hole. Still, the spatial resolution required to observationally distinguish between black holes and wormholes is currently beyond our capabilities, which would likely require future generations technologies such as constellations of coordinated, space based, radio telescopes that use very long baseline interferometry in order to probe spatial scales as small as the innermost stable orbit or the event horizon of the black hole, to see if space-time and matter behave as expected for certain kinds of black holes or wormholes.

Needless to say, if wormholes are ever discovered observationally, Nobel prizes are certain to be on the horizon.