The far-out future: wormholes and time machines

Reference webpages:

http://en.wikipedia.org/wiki/Wormhole and
http://en.wikipedia.org/wiki/Time_travel and
Chapters 13 and 14 in Thorne.

Questions to keep in mind are:

1. What are some time travel paradoxes, and possible ways around them?
2. What are the capabilities of an arbitrarily advanced civilization that still obeys the laws of physics?

Introduction

Prepare to set your weird receptors to full, because in this lecture we are going to talk about some truly bizarre stuff. Our theme will be simple: suppose we had an alien species that was arbitrarily advanced but still obeyed the laws of physics. What could they accomplish?

Time travel and the grandfather paradox

Many science fiction stories have explored the concept of time travel. An early classic is "The Time Machine" by H. G. Wells, but more recent ones include the "Back to the Future" trilogy and "12 Monkeys"Is this possible in principle for a sufficiently advanced species?

If you think about it for a while, there is an objection that might seem fatal. This goes by the name of the "grandfather paradox", although I'm not sure why it couldn't just be the father paradox. The idea is as follows. Suppose that I am an evil, but brilliant, scientist and I construct a time machine. I go to St. Louis in 1930, where I meet my then 12-year-old grandfather. Being evil, I kill him. Naturally now he won't be able to meet my grandmother and therefore my father won't be born. But then I can't be born, which means that I can't cackle evilly and construct a machine that I use to go back to 1930 and kill my grandfather. This means that my grandfather *would* be able to meet my grandmother, and I could be born, so I could go back and kill him, so I couldn't, so I could, so…

This kind of paradox loop might seem to kill all time travel. In science fiction the resolution often comes down to personal choice. For example, in the first "Back to the Future", Marty McFly does change things, but for the better; his father ends up being a confident winner instead of a wimp. There are other creative solutions that have been used, too. In "The Men Who Murdered Mohammed" by Alfred Bester, a rather whacked scientist goes back and forth in time, killing historical characters, but finds that as a result he cannot access his original plane of reality!

People have confronted this a bit more seriously, though. The basic point researchers such as Kip Thorne have made is that it is *inconsistency*, not time travel itself, that must be avoided. That is, it is inconsistent to imagine a time sequence in which I am born and then kill my ancestors, because to be consistent we would have had to take into account that my ancestors would already have encountered my future self.

To give one example that doesn't involve human decisions, imagine that we shoot a pool ball into a pocket that allows the ball to travel backwards in time. Can we arrange things so that the future ball hits the past ball and prevents it from going in the pocket? That's the inanimate version of the grandfather paradox. The answer is no, we can't. What *can* happen self-consistently is that the future ball grazes the past ball and makes it go through the pocket in such a way as to produce a future grazing collision. Going back to science fiction, this principle of consistency was a key element of the plot to "12 Monkeys". Without ruining the film with details, I'll say that the time traveler has gone back in time to investigate an effect, but it turns out that the travel itself initiated the effect. More recently, there was a sequence in "Harry Potter and the Prisoner of Azkaban" that illustrated the consistency issue.

The net result is that, with some restrictions, time travel might be possible in principle. It actually also might *not* be possible in principle, but with what we know at this time it can't be ruled out absolutely. What methods might we use?

Faster than the speed of light?

If you look at Einstein's equations for special relativity you might convince yourself that one way to travel backwards in time is to move faster than the speed of light. This has interested people enough that they have coined a term for particles that do this: "tachyons". The problem is that nothing can be *accelerated* from a slow speed to beyond the speed of light. You can see this by noting that as you get closer to light speed the effective mass increases. That means, from Newton's second law $F = ma$, that more and more force is required to accelerate the mass. Ultimately an infinite force would be needed to move the mass at the speed of light, so this can never happen. In fact, even tachyons, which probably don't even exist, aren't accelerated to beyond light speed. Instead, they *always* travel faster than light. Even if they do exist, this won't work for normal particles such as make up humans and aliens.

Wormholes

In the wonderful book "A Wrinkle in Time", a tesseract is explained as a folding in spacetime. Imagine, for example, a piece of paper. Going from the top to the bottom is a long way. However, if the paper is bent over, then although the normal distance (along the paper) from top to bottom is still the same distance, the distance through the air is much less. Therefore, even if you are restricted to less than the speed of light you can get to your destination faster.

Wormholes, therefore, are essentially shortcuts through spacetime. At any given point on a journey through a wormhole the local speed is less than the speed of light. Constructing them might take some serious effort, but let's assume our aliens could do that. Might they have set up wormholes in various places in our galaxy or beyond so that they could zip in and have a quick chat with that nice multitentacled cephalopod from Rigel?

In detail, there turn out to be some difficulties. The simplest wormholes that obey the equations of Einstein's general theory of relativity are unstable. That means that if anything went through them (alien, matter, photon) the wormhole would collapse at the speed of light, destroying the traveler. That's not nice.

In the 1980s, however, Kip Thorne and colleagues started taking a serious look at wormholes in response to Carl Sagan's request to come up with a plausible interstellar transport system for his novel "Contact". What Thorne realized is that a traversable wormhole could in principle exist if it were constructed from "exotic matter". Specifically, the matter would have to have a net negative mass-energy density. Huh? Negative mass-energy? Sounds impossible. A simple argument given to me by Professor Ted Jacobson of our physics department motivates why you need negative mass-energy. In spacetime, you can picture a traversable wormhole as a throat: the hole converges, then diverges, and never gets to a point at the center. This means that if you were to imagine two photons falling in from initial parallel trajectories at a large distance, they would initially come together as in normal gravity, but from the midpoint of the throat and onwards they would need to move apart. Normal gravity, produced by matter with positive mass-energy density, causes things to come together, so if you need stuff to be pushed apart you need negative mass-energy density.

Er, okay, but how in the heck could this happen?? Incredibly enough, there is a specific candidate, called the Casimir effect, that has actually been measured in the laboratory. As with Hawking radiation, it relies on the counterintuitive idea that the vacuum isn't really empty. Instead, it is chock full of "zero point energy." Contrary to the impression you may have received from "The Incredibles", this is not something you can tap as an energy source, any more than you can get more energy out of an atom that is already in its ground state. The basic idea is that the universe is full of oscillation modes, and the vacuum has those modes in their ground state, or state of lowest energy.

In the Casimir effect, you put two uncharged parallel metal plates close to each other in a vacuum, they feel an attractive force that is produced by an effectively negative pressure (and thus mass-energy density) between them. The physical idea behind this is that although modes of all wavelengths can exist outside the plates, in the region between them only some can exist (the ones whose wavelengths fit into the region), hence there is more pressure outside than in and the plates go together. There is even a real-world analogy that I haven't personally observed but am told can be seen. Suppose you have two ships next to each other (with some separation), just floating along and initially not in relative motion. They will gradually come together. As in the Casimir effect, the waves between the boats are limited in wavelength, but outside are not, so the pressure between the boats is decreased by comparison. This is in fact the same type of effect that some people believe is accelerating the expansion of the universe (albeit the simplest estimate of its strength is off by 120 orders of magnitude!). So in principle we could imagine harvesting negative energy to keep open our wormholes.

The problem comes back to time travel. It turns out that if you can move faster than light would through normal space (which is the point of wormholes!), it is also possible to travel backwards in time. So, consider an advanced civilization that has just completed a traversable wormhole. As soon as it opens up, various things go through it, such as light and even weirder things like quantum fluctuations of the vacuum. They travel backwards in time and go through again. If there really is a closed timelike loop that forms, this means that the fluctuations can build up indefinitely. This could lead to a singularity of some sort. There appears not to be absolute agreement on the consequences of this (as Kip discusses in his book, Stephen Hawking has proposed a "Chronology Protection Conjecture" that essentially means that any time travel would be choked off by these kinds of effects). My general feeling is that Hawking is probably correct, and that the net result is that probably wormholes and related things like warp drive can't exist. The conclusion is that, most likely, although aliens could buzz around close to the speed of light with the resulting effects, faster than light travel is not promising. Poor aliens! Is there another way?

Alcubierre Drive

Here I freely admit that I am out of my zone of familiarity, so I will describe what I can and you can do additional investigation if you want to learn more. In 1994, general relativist Miguel Alcubierre (whom I have met; nice guy) suggested a way that one might imagine traveling between points faster than light could in normal space. His idea is somewhat similar to some of the driving ideas behind cosmological inflation: although neither matter nor energy can travel faster than the speed of light, spacetime itself can. I admit that this is a tough concept to grasp, but note that the reason we see only a finite portion of our cosmos (which might actually be infinite) is that the parts beyond our view are moving faster than the speed of light from us. To make it even weirder, if the accelerated cosmic expansion continues on, then the total amount of the universe we can see (more specifically, the total mass-energy within our horizon) will decrease until eventually we see only our local galaxies.

Lonely...

Anyway, Alcubierre used this general principle to think of a way in which one could essentially ride a spacetime bubble (which we can call a “warp bubble” in deference to Star Trek fans) that moves faster than the speed of light and thus gets to a given destination more rapidly than otherwise possible. Alcubierre pictured this as contracting spacetime ahead of the warp bubble and expanding it behind, but there have been other interpretations since. Inside the bubble spacetime is flat, so the traveler does not feel accelerated, but in the boundary between the bubble and normal space there are huge amounts of curvature.

Could this work? Since his original suggestion there have been various follow-up papers discussing the idea and improving on it. Everyone agrees that, like Thorne’s wormholes, Alcubierre drive requires exotic matter that has negative mass-energy density. What is less resolved is the in-principle plausibility of the drive. One suggestion, not universally accepted, is that in order to set up the warp bubble one would need to travel faster than light; that is, that you would need the drive to make the drive! In response to this it has been suggested that although this might not actually be required, one would need to set up spacetime-changing machines along the path to be traveled, and that this would have to be done slower than the speed of light. As a result, one could not just travel at will with Alcubierre drive. It would be rather like a train track. In addition, even when the track had been set up it would not be possible to do one’s faster than light travel along it at will, because signals would have to be sent to the (normal space) stations. One might thus think of this as a subway station where the departures are rigidly determined. Still, if this is possible at all (and I am at best agnostic about it) one might imagine that it could allow the maintenance of an interstellar empire or communication with other civilizations.

I told you this would be a weird lecture...