# Space: The Final Frontier?

# 11

## Deep Impact

ARE we "cleverer" than the dinosaurs? One day, about 65 million years ago, a fireball streaked across the sky above what is now Central America, and impacted the ground in the region of the Yucatan peninsular. The object, traveling at huge speed, was an asteroid about 10 km (6 miles) across, and the enormous energy released by the impact produced global devastation and played havoc with Earth's climate. As a consequence of this meeting of the celestial with the terrestrial, many scientists believe that the 160-million-year reign of the dinosaurs was brought to an end. Could this happen again, with people this time being the victims of potential extinction?

The answer, disquietingly, is yes. It will happen again. But impacts of the magnitude of the Yucatan event fortunately do not happen often—about once every 100 million years. So it is probably something we do not need to worry about for a long time. However, as we develop the technology to look out into space, we are beginning to realize that there are a large number of objects in orbit around the Sun that potentially could collide with Earth. These objects are called *near-Earth objects* (NEOs). A NEO is an asteroid or comet in an orbit that crosses or comes close to Earth's orbit around the Sun, and so represents an impact threat. There is intense activity at present to detect and catalogue the NEO population, and so far we have estimated that there are about 1000 objects on the order of 1 km (0.6 miles) in diameter or bigger. The detection of smaller objects becomes more difficult, so it is not known how many smaller objects there are, but we do know that the number of objects increases as the size decreases. Current estimates of the number of objects bigger than 100 m (330 feet) is about 100,000. As a consequence, we are never quite sure when one of these objects will be discovered to be on a collision course with Earth.

The last significant impact event took place in 1908 at Tunguska, Siberia, and this object was estimated to be about 50 m (165 feet) across. Fortunately, the impact site was uninhabited, but the explosion flattened about 2000 square kilometers (770 square miles) of forest. If the object had landed in

G. Swinerd, *How Spacecraft Fly: Spaceflight Without Formulae*,
DOI: 10.1007/978-0-387-76572-3_11, © Praxis Publishing, Ltd. 2008

central London, for example, the area of devastation would correspond approximately to everything within the M25 orbital motorway. An impactor of this size can be expected about once every few hundred years. Consequently, a NEO impact is a fairly rare event, but nevertheless there is a probability we will have to face one in the not-too-distant future! National governments, charged with the responsibility of looking after their citizens, are now at least considering this type of event as a natural disaster, alongside things like earthquakes and hurricanes. Hollywood has also done its bit to raise awareness with films such as *Armageddon* and *Deep Impact*, which with the aid of computer-generated images give a graphic depiction of some of the devastating impact-generated effects. For land impacts, these include the effects of blast, heat, and ejecta from the impact site, and the generation of seismic disturbances. However, since the majority of the Earth's surface is water, it is more likely that such an object will fall into the ocean. For this type of event, the main impact-generated effect is a large tsumani wave, which propagates at high speed across the ocean. Tsumanis are very effective at transporting the energy of the impact to distant shores, bringing devastation to coastal cities where most of the world's population is concentrated.

So what can be done? Unlike the dinosaurs, we are at least in a position to see something coming, and to do something to deflect its path to avoid a collision. The technology needed to do this is available now, but the usual roadblock is funding. Budgets available for NEO detection surveys are relatively small, and agency budgets for the development of spacecraft that could be used to deflect a threatening NEO are similarly inadequate. If a 500-m object suddenly came over the horizon today on an impact trajectory, threatening devastation on a continental scale, the funding situation would dramatically change. But would there be enough time to develop and test the require space hardware to be assured of success? Can we afford to take the chance? I would suggest not.

There are a number of ways of deflecting the path of a threatening NEO. They all have one feature in common: they depend on there being sufficient warning of an impact, so that the missions can be launched several years in advance. This is because, generally, the methods are only able to produce small changes in the trajectory of the NEO. Such a small change is able to deflect the object successfully if it is done a long time in advance, as the effects of a small change build up over time to avert disaster. However, if the time to impact is short, then much larger changes are required, which are effectively beyond our current capabilities. This is why surveys designed to detect threatening NEOs well in advance are so important. The following list of deflection techniques is not exhaustive, but it does give a flavour of some of the ideas that are being proposed.

- **The use of nuclear weapons**: This is invariably the Hollywood solution, as it makes for good cinema! The strategy is to launch one, or a number of nuclear warheads against the incoming object to blow it off course. The problem here is that no one really knows how the nuclear blast will affect the object's motion, and tests need to be done to find out. In the vacuum of space, the detonation produces a blast wave that is very much less powerful than it would be in Earth's atmosphere, so that the effect of the explosion on the asteroid's motion may be inadequate. However, there is another deflection mechanism that may be effective if the nuclear weapon is detonated in close proximity to the asteroid's surface. Then the surface layer may possibly be heated sufficiently to vaporize the asteroid and blast it at high speed into space. On the basis of Newton's laws (Chapter 1), this ejection of material would produce a thrust on the asteroid, a bit like a rocket engine, which may be sufficient to deflect the object's path from a collision course. There are many unanswered questions about this technique, which emphasizes the need for flight tests to ascertain how nuclear explosions influence the motion of a NEO in its orbit around the Sun. The other issue with the use of nuclear detonations is the risk that the NEO may be fragmented, resulting in a cloud of smaller but still potentially lethal impactors on their way to Earth. In this case, the situation may have been worsened, with a multitude of Tunguska-type impacts bringing worldwide devastation.
- **The use of an impactor**: This is an intuitive idea—crashing an impactor spacecraft onto the surface of the object to deflect its trajectory, like a billiard ball changing its path after the impact from another ball. But the thing to note about the billiard balls is that a significant change is produced because the two balls are of the same size. Obviously, we are unable to launch an impactor spacecraft with the same mass as, say, a 200-m asteroid, so the amount of deflection is tiny. However, if the deflection is done sufficiently far in advance, then a small change will be adequate to avoid a collision with the Earth.
- **The use of a gravity tractor**: This is a rather less intuitive idea, but one of the most effective ways to achieve a controlled deflection of a threatening NEO such as an asteroid, without needing to know anything about its physical characteristics, such as the nature of its surface, or its state of rotation. The idea is a relatively recent one, being proposed in 2005 by Ed Lu and Stan Love of the National Aeronautics and Space Administration's (NASA) Johnson Space Center. The gravity tractor is an unmanned spacecraft that is launched to rendezvous with the asteroid. On arrival, the tractor

positions itself a small distance from the object, and then uses small rockets to hold this position above the surface, as shown in Figure 11.1. As the spacecraft hovers above the surface, a force is exerted on the asteroid equal to the mutual gravitation force between them. Effectively, the tractor is using gravity as an invisible tether with which to tow the asteroid off it collision course with Earth.

To get an idea of the numbers, let's suppose the asteroid is 200 m across. Then a quick calculation gives its mass as about 10,000,000 metric tonnes. If the tractor spacecraft's mass is about 5 metric tonnes and it is stationed 50 m above the asteroid's surface, then it will require a thrust of only about 0.2 Newtons to remain stationary above the asteroid. This small force is equal to the mutual gravitational force between the tractor and the asteroid, and it is this force that produces the acceleration to shift the asteroid from its collision course. The application of such a small force to such a huge mass produces a tiny acceleration. However, the saving grace is that this tiny acceleration can be applied for a long period of time to allow a useful change in speed of the asteroid to build up. If the mission is performed a sufficiently long time in advance of the predicted Earth impact, then the required change in the asteroid's orbit to avert disaster is similarly small, and easily accommodated by the technique. The operation to successfully divert the asteroid in this case can be achieved in about 10 days, but much longer periods can be realized if required.

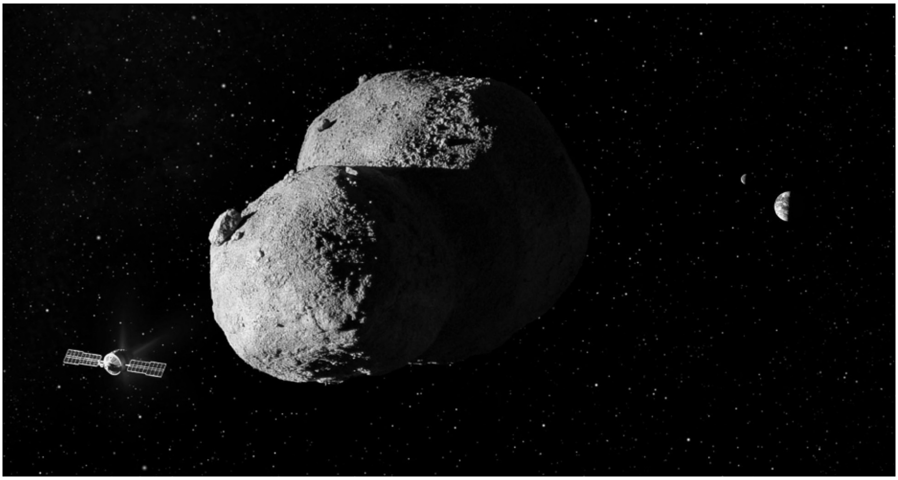

**Figure 11.1:** An artist's impression of a gravity tractor spacecraft on-station above an asteroid on collision course with Earth. (Image courtesy of Dan Durda, B612 Foundation/FIAAA.)

In terms of the spacecraft, the propulsion requirements can be achieved by two ion drives, each with a thrust of 0.1 N. The electrical power required for these would be about 4 kW, and the fuel mass used in this case is approximately 4 kg.

As well as the technical issues discussed above, there is also a political dimension to the issue of NEO deflection. Once a potentially threatening NEO has been identified, the first task to be undertaken is to determine its orbit around the Sun so that the likelihood of an impact can be estimated. If the object is indeed on a collision course, the site of the impact on the Earth's surface can be estimated, although if the impact is some years away there are going to be significant errors in this process. However, let's suppose that such a process has led to a likelihood that the object will fall somewhere on the North American continent. In this situation, the United States would be eager to launch a deflection mission as soon as possible to avoid the devastating consequences of such an impact on its territory. However, once the spacecraft has reached the object and the deflection process is underway, say, with a gravity tractor, then the resulting changes in the NEO's orbit will progressively change the location of the impact site. In this situation, should the impact site be moved out over the Pacific Ocean where significant tsunami damage to the west coast of the U.S. can result? Or should it be moved east toward the continents of Europe and Africa? Of course the objective is to move the impact site so that the object misses Earth entirely, but what if the gravity tractor spacecraft fails before its mission is completed? In such a time of crisis, the international community may be called upon to make some monumental decisions that will affect the lives of millions of people. But as yet there is no agreed international mechanism through which such decisions can be made.

As we have seen, the probability of an asteroid impact with Earth in the next few decades is small, but nevertheless if one were to occur the consequences are horrible to contemplate. The prospect of such an event provides a good case for developing our space-faring capabilities. I think it is time that we grasped the nettle and showed that we are indeed "cleverer" than the dinosaurs!

## Leaving Home

One day, about 5 billion years from now, the last perfect day will dawn. It is at about this time that scientists estimate the nuclear fuel of the Sun will begin to run out. As we discussed in Chapter 6, the Sun is powered by a nuclear fusion reaction at its core, with hydrogen atoms being fused together to form heavier atoms, and in the process producing the energy that has made the

Sun shine steadily for the last 5 billion years or so. The Sun has shone stably for all that time because of the balance between the huge amounts of energy being generated at its center, tending to blow it apart, and the force of gravity tending to hold it together. On this last perfect day, 5 billion years in the future, the nuclear fuel at the Sun's center will be just about depleted, and the stable balance between energy generation and gravity will be disturbed. The consequences for the Sun will be dramatic as far as the inhabitants of Earth (or indeed any other planet in the solar system) are concerned. I'm not sure who those inhabitants will be; people have been around on Earth for only about a million years, and it seems strange to think of them still being here 5 billion years in the future. Perhaps some other species, directly descended from humans, will exist then, but that's a different story.

What will happen to the Sun when its hydrogen fuel begins to run out? According to our best theories, it will evolve into a red giant star, expanding to a sphere about the same size as Earth's current orbit. In this process the Sun will lose a significant amount of mass, so Earth's orbit radius is predicted to increase to about one and a half times its current radius. Thus Earth will probably escape being engulfed by the Sun. But the surface environment on Earth will be transformed into a blazing desert, with all the oceans' water having boiled away. Put simply, Earth will no longer be able to support life, other than perhaps microbial life buried deep within Earth's crust.

This rather bleak picture of the Sun in its death throes tells us that ultimately people will have to leave Earth. This notion of our successors having to leave home in the distant future has perhaps become a bit of a cliché in contemporary science-fiction literature. Some people believe that other factors, such as climate change, may be more important in forcing the evacuation much sooner. However, the bottom line is still the same: to ensure our ultimate survival as a species, we have to learn how to live and work in space. More importantly, we need to develop and master the technologies required to travel across the cosmos, that is, to transform Hollywood space engineering into reality! How are we going to do this? The technical challenge is huge, simply because the universe is huge. This is expressed rather eloquently by Douglas Adams in his book, *The Hitchhiker's Guide to the Galaxy:* "Space is big. You just won't believe how vastly, hugely, mind-bogglingly big it is." To describe the sorts of distances we are talking about, the nearest star (apart from the Sun) is about four light years away. This is the distance that light travels in 4 years at the enormous speed of 300,000 km/sec (186,000 miles/sec). A quick calculation gives this as about 38,000,000,000,000 km (23,000,000,000,000 miles), a distance probably too large for our minds to comprehend. Using our current spacecraft technology, we know that it takes many years to reach Pluto, the most distant outpost of our solar system. However, the *nearest* star outside the solar system is about 6500 times more distant. This demonstrates the magnitude of the challenge, without even addressing the prospect of traveling across our home galaxy, the Milky Way, which is estimated to be about 100,000 light years across!

How are we to achieve travel across such vast distances? Well, going very fast is obviously a good idea, but our currently accepted laws of physics, due to Einstein, set a speed limit equal to the speed of light (see Chapter 1). Although I think that Einstein might not be the last word in our understanding of the universe, nevertheless in this discussion I will stay within the boundaries of his theories, and accept the light speed limit. To cross huge distances, it would be good to be able to travel at a speed that is a good percentage of light speed, or alternatively find clever loopholes in the laws of physics that will allow us to effectively travel faster than light speed without strictly violating the speed limit. Although the latter sounds like a bit of a contradiction, nevertheless we will see that there are some interesting ideas along these lines (see Exotic Systems, below). Let's take a brief look at some of these ideas for achieving interstellar travel, starting with some less exotic but still futuristic rocket systems.

## Rocket Systems

Many of the ideas for achieving what might be called slow interstellar travel are based on using the principle of a rocket, along the lines of a device like the Space Shuttle main engine that uses Newton's third law of motion to operate: for every action there is an equal and opposite reaction (see Chapter 1). Also, when I say "slow," I mean spaceships with a maximum speed of, say, 10% of the speed of light—around 30,000 km/sec. Although this seems fast by the standards we adopt in our everyday lives, it does mean that such a vehicle would still take about 40 years to reach the nearest star outside the solar system. To travel to stars in the local neighborhood, say, 100 light years distant, it is going to take several human generations to get there!

### Nuclear Impulse Engines

The first such idea is that of the nuclear impulse engine, which adopts the unlikely notion of the detonation of numerous atomic bombs to accelerate the vehicle. The concept was first proposed in the 1940s, and subsequently fleshed out into a design concept called *Project Orion* in the 1960s. Intuitively the idea is an easy one to understand. Small nuclear bombs with a yield of about 10 metric kilotonnes of TNT (this is about half the size of the atomic bomb that destroyed Hiroshima in August 1945) are detonated behind a rigid pusher plate, which in turn is connected to the starship by a system of springs and shock absorbers. This form of propulsion is unusual in that it has both a high specific impulse (exhaust velocity) and a high thrust level. The impulse of each explosion is transferred to the starship, to accelerate it to an anticipated speed on the order of 10% of light speed. Clearly, for a manned starship, there are issues concerning the protection of the crew from high accelerations, blast effects, and nuclear radiation. However, the severity of these problems are reduced for large vehicles—on the order of 1000 metric tonnes or more—for which the pusher plate can be scaled up to be several meters thickness of steel, and so provide adequate shelter for the crew.

### Fusion-Powered Rockets

These rockets have great potential for powering interstellar travel, but since a controlled nuclear fusion reaction has not yet been achieved in terrestrial laboratories, such propulsion technology must for now remain a promising prospect for the future. Recall from Chapter 6 that the Sun is powered by nuclear fusion, where atoms of hydrogen are fused together to form heavier atoms while releasing energy in the process. Nuclear power stations here on Earth generate our electricity needs, but they use a different kind of nuclear reaction—*nuclear fission,* in which heavy elements such as uranium are split to form lighter atoms, which also produces nuclear energy. Our current technology allows us to control the nuclear fission reaction, but taming nuclear fusion to produce a controlled reaction for the purpose terrestrial power generation is something that has escaped our ingenuity so far. Solving this problem would meet the world's energy needs, as there is an inexhaustible supply of fusion fuel, in the form of hydrogen and similar light elements, in the world's oceans. Needless to say, a huge research effort has been expended to try to crack this problem, but unfortunately we have managed to achieve only an uncontrolled nuclear fusion reaction in the hydrogen bomb for destructive purposes. Controlled fusion currently eludes us, but scientists working in the field appear confident that the difficulties can be resolved in two or three decades.

The reason why controlled fusion is so difficult to achieve is the high temperature at which the reaction takes place. To sustain a fusion reaction, the fuel needs to be at very high temperature—millions of degrees Celsius. We have to go some way to emulate the conditions found at the center of the Sun, where the fusion reaction occurs naturally. The fuel is confined within the reactor as a hot gas made up of charged particles, and this is referred to as a *plasma.* Such an extremely hot plasma must be confined in the reactor in such a way as to prevent contact with the reactor walls, which is usually done in terrestrial laboratories by containing it within a magnetic field. However, this confinement within a "magnetic bottle" is the stumbling block; it is difficult to produce a method of magnetic confinement that is stable. Even if this problem were to be solved for terrestrial reactors, for space applications it is thought that magnetic confinement is not the best solution because the mass of such a system would be prohibitive. Alternative methods of sustaining a fusion reaction for a rocket system have been investigated, such as igniting small pellets of nuclear fuel (just a few millimeters across) using electron beams or lasers.

However, whatever method finally proves successful, the point is that a fusion-powered rocket can produce an extremely high temperature plasma, and this can be channeled through a magnetic nozzle to produce thrust. The performance of such a rocket is unknown, but exhaust velocities of the order of 10,000 km/sec may be feasible! Taking this value, a quick calculation shows that a fusion-powered starship could be accelerated to one-tenth the speed of light if 95% of its initial mass is propellant.

### Antimatter Rockets

Readers may be familiar with the word *antimatter* from watching too much *Star Trek* on TV. Indeed, in contemporary science fiction, antimatter seems to be the ubiquitous source of energy that solves all future problems concerned with interstellar travel, and in fact there is an element of truth in this. Antimatter does actually exist; it is not a figment of the imagination of science-fiction writers. All subatomic matter particles, such as electrons and protons, have their corresponding anti-particles. For example, the anti-particle of an electron is called a positron, which has the same mass as an electron but has the opposite electric charge. The other thing about matter and antimatter that is relevant to this discussion is that when they come together they go bang, inasmuch as they annihilate each other in a burst of pure energy. For example, when an electron and a positron come into contact with each other, their combined mass is converted completely into energy in the form of a burst of electromagnetic gamma radiation (see Chapter 6). In fact, this process of matter–antimatter annihilation releases more energy than any other reaction known to physicists. Thus the fusion reaction that powers the Sun is not the last word in energy generation; fusion converts only 0.7% of mass into energy, whereas the matter–antimatter reaction gives 100%! Thus if antimatter could be harnessed to power a starship, then maybe we can begin to compete with the Hollywood space engineers!

Before we get carried away, however, there are one or two issues about using antimatter that mean that such a propulsion system is a prospect only for the long-term future. The first of these is containment of the antimatter fuel within a matter starship. We can perhaps imagine a magnetic containment system, similar to that we have discussed for the fusion reactor, to prevent contact between the antimatter and matter parts of the ship. But what if the confinement process becomes unstable, which seems to be a fairly frequent occurrence on the starship *Enterprise*? The consequences for the ship and crew (and indeed for any nearby planet!) in this circumstance would be totally catastrophic. The other problem is that there appears to be not much antimatter around, which is fortunate. Small quantities can be obtained from experiments in terrestrial physics laboratories (such as the European Council for Nuclear Research [CERN] high-energy particle accelerator buried beneath the city of Geneva, Switzerland), but currently we have no means of industrial-scale production that would be required to produce anti-rocket fuel. As a consequence, we could say that antimatter is the most expensive substance on Earth.

Most of the starship rocket technologies that could be envisaged being developed this century (nuclear impulse engines and fusion-powered rockets, but perhaps not antimatter rockets) give speeds in the region of 10% of light speed—around 30,000 km/sec. Although this sounds fast, this can be considered to be something of a snail's pace given the scale of the universe. For example, if we were to send a starship to explore one of the approximately 2000 stars within 50 light years of Earth, the journey would take 500 years at this speed. One way to do this is to launch a large, self-contained interstellar ark, in which the ship would need to sustain many generations of crew, until finally the distant successors of the original crew finally arrive at the destination. This type of starship has become popularly known as a *generation ship*. However, one disadvantage of this type of ship is that it could easily be overtaken literally, and in terms of technology by a future starship with more sophisticated propulsion technology that left Earth at a later time. The crew of the generation ship would be shocked to find that their destination planet had already been colonized for many years by visitors from Earth! Let's take a brief look at some of these more exotic ideas for interstellar transportation.

## Exotic Systems

It's interesting that many of the more exotic ideas for achieving interstellar travel derive their inspiration from science fiction. Perhaps the most obvious example of this is the warp drive, with which we have become familiar through Gene Roddenberry's epic *Star Trek* series.

## Warp Drive

Miguel Alcubierre, a Mexican theoretical physicist, was intrigued by this idea, and in the early 1990s he set about attempting to find a way of describing how it might work within the formal framework of Einstein's theory of general relativity. As a consequence, he published a rather mathematical paper in 1994 in the learned journal *Classical and Quantum Gravity*, and since then his name has become synonymous with the idea of warp drive. As we mentioned in Chapter 1, Einstein's general relativity is essentially a new way of looking at how gravity works, which involves the notion that space and time are curved, or warped, by the presence of mass. Since Einstein also said that mass and energy are simply different forms of the same thing (see Chapter 6), space-time is also warped by the presence of energy. In Chapter 1 we saw how Newton's theory of gravity was overthrown by Einstein's new vision, in which the planets moved along their orbits around the Sun, like racing cars on a banked circuit, governed by the curvature of space-time produced by the Sun.

The key issue is how a warp drive–powered starship can travel at arbitrarily large speeds, effectively in excess of light speed, without violating the light speed limit. This sounds like an impossible trick, but there are ways to do this. The explanation resides in the more precise statement that, in general relativity, nothing can travel *locally* faster than the speed of light. In his deliberations about warp drive, Alcubierre found the illustration of the motion of objects in an expanding universe helpful in explaining his idea. So let's have a look at it to see if it helps.

One of the great triumphs of Einstein's theory of general relativity is that it predicts the expansion of the universe. This is one of the most profound achievements of theoretical physics in the 20th century, but it is also associated with an affair that Einstein himself considered to be one of his biggest blunders. Soon after the publication of his general theory in 1916, Einstein set about applying it to the universe as a whole, and showed that the universe would naturally be in a state of expansion. However, on the basis of the limited astronomical data then available, he was convinced that in fact the universe was actually static, so he introduced a new term into his equations of general relativity, essential a fudge factor, which he called the *cosmological constant.* With this new term in the equations he could model a static universe, in accord with what he then believed to be the case. However, in 1929, an astronomer named Edwin Hubble (after whom the famous space telescope is now named) published detailed observational evidence that, on the large scale, the universe is most definitely in a state of expansion. If only Einstein had believed his own analysis, he could have made one of the most profound predictions of theoretical physics, but it was not to be, and

Einstein had to return to his original equations, abandoning his cosmological constant (in fact, Einstein's cosmological constant has had a checkered history, and recent developments in theoretical physics have provoked scientists to consider its reintroduction into Einstein's theory).

What does it mean to say that the universe is expanding? A common misunderstanding is that the universe is effectively an infinite expanse of space-time, and at some moment in time, and at a particular point in space, the Big Bang happened. Thereafter, all the matter (galaxies) in the universe would appear to be moving away from each other and from a common point in space-time (the location of the Big Bang), gradually filling the huge expanse of space-time. However, the currently accepted view of the universe's expansion is subtly different from this. Rather than thinking of the universe as an explosion in a huge, fixed expanse of space-time, we have to envisage the universe—and by this I mean the fabric of space-time itself—as expanding. A good model of this, which is often quoted, is that of blowing up a balloon, although we have to lose a couple of dimensions. The four dimensions of space-time are now represented by the two dimensions of the rubber membrane of the balloon's surface. It is quite instructive to perform this simple experiment yourself, which emulates the expansion of the Universe. As we inflate the balloon, the rubber membrane (space-time) expands, and it is easy to see that each galaxy moves away from every other galaxy, representing Hubble's profound observational result that the balloon (the universe) is expanding.

Getting back to our attempt to understand Alcubierre's warp drive, it's important that you grasp the subtleties of the last paragraph, so if you haven't, I suggest you go back and give it another go. Because here's the point: as the balloon expands, "galaxies" on opposite sides of the balloon can move away from each other at speed, and yet at the same time they are stationary with respect to the rubber membrane (space-time). If we now contemplate the real, expanding universe in which we live, and think about the implications of this statement, we can have a situation where two galaxies are so far apart that the expansion of space-time itself causes their speed relative to each other to be in excess of the speed of light, while at the same time neither galaxy is *locally* exceeding light speed.

It is this kind of thinking that underlies Alcubierre's idea of how a warp drive–powered starship might work. He envisaged a drive system that warps the space-time surrounding the starship, in such a way that space-time is expanded behind the starship, and contracted ahead of it, as illustrated in Figure 11.2. The expansion of space-time behind the starship effectively pushes the departure point many light-years back, while the contraction in front of the vehicle acts to bring the destination similarly closer. The starship

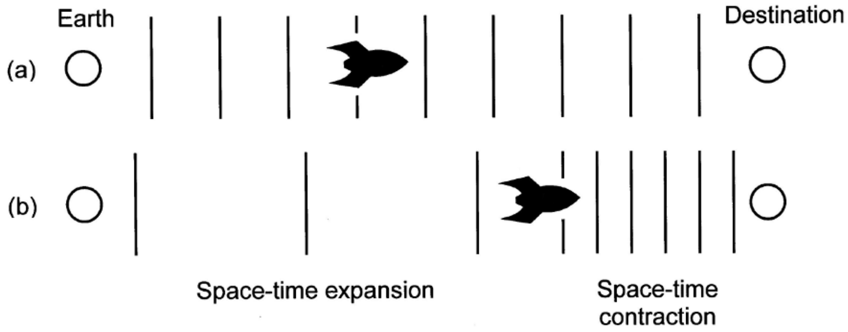

**Figure 11.2:** (a) Warp drive off: starship journeys through flat space-time. (b) Warp drive on: the space-time surrounding the starship is distorted to achieve faster than light speed travel.

itself is left in a locally flat region of space-time between the two warped regions. In this way, motion faster than light is possible, as seen by an observer outside the region disturbed by the warp drive, while at the same time light speed is not exceeded locally by the starship—a really neat idea!

Is warp drive technology a feasible means of interstellar travel? To warp space-time behind and ahead of the vehicle, we know that the drive system must be able to manage and manipulate huge amounts of mass and energy. (*Star Trek* fans now have some idea what the famous dylithium crystals do in energizing *Enterprise*'s warp drive.) Alcubierre wrote down the equations defining the necessary warp field for a starship, and then went on to investigate the kind of mass-energy source that would be needed to generate such a field. And here's the really bad news: the required space-time curvature needs the presence of a negative energy density. What this means is that the Alcubierre warp drive can be fueled only by a form of material that the scientists call *exotic matter.* Effectively, this comprises material that possesses characteristics such as negative mass, and there is debate among the experts about whether such matter even exists. Classical physics says it does not, whereas quantum theory says maybe it does. Either way, so far it is something that has escaped detection by scientists. Obviously, this is a bit of a blow to the feasibility of the Alcubierre warp drive, but his paper is probably not the last word on this topic. Fundamentally, we know that warp drive will be a difficult nut to crack, simply because of the huge amounts of mass-energy that is required to manipulate the curvature of space-time. However, I am sure alternate views will be presented in the future by theoretical physicists, and perhaps one of them will find a viable technical foundation for such a form of interstellar travel.

## Wormholes

In many ways, wormholes are an even more curious idea than warp drive, but one that is a little easier to explain. Again, it is a technique that has its foundations in Einstein's theory of gravity for achieving super-light-speed travel without actually exceeding the light speed limit. Like warp drive, the wormhole concept has been grasped enthusiastically by science-fiction writers to overcome that awkward problem of how their space-faring heroes can travel with ease across the Galaxy. One such example, among many, can be found in Carl Sagan's novel *Contact*, in which the heroine Ellie travels 25 light years to the star Vega in the blink of an eye through a network of wormholes engineered by a long-lost civilization.

Space-time is not just a means of measuring where and when an event takes place, but it is also a dynamic entity that can be warped and curved by the presence of mass and energy. It has been known for many years that the equations of Einstein's theory allow solutions that permit space-time to be *multiply connected*. In other words, it allows for the existence of what are essentially short cuts through space and time, so that two distant regions of the universe can be connected by a much shorter higher-dimensional route. The term *wormhole*, first coined by physicist John Wheeler in 1957, has been universally adopted to label this curious feature of relativity theory, having its origins in the analogy used to explain the phenomenon. The usual analogy is to imagine a worm moving on the surface of an apple, starting out at a point A and moving to a point B that is on the other side of the apple (Fig. 11.3a). It has two choices: either it can go the long way round on the two-dimensional surface of the apple (route 1), or it can take a shorter journey (route 2) via a wormhole through the three-dimensional interior of the apple.

We can relate this analogy to a starship journeying between two points in space-time that are light years apart (Fig. 11.3b). It too can take the long route through space-time (represented by the two-dimensional curved surface) or use a conveniently located wormhole (represented by the three-dimensional passageway through hyperspace) to take a short cut. The wormhole allows the starship to effectively cover the distance at super-light speed, but without actually exceeding Einstein's speed limit. The analogy of the apple is helpful, but again we have lost a couple of dimensions in the discussion of the process.

So, is this form of interstellar travel a viable proposition for the future? Well, things are not quite as simple as the above analogy implies. One of the earliest wormhole solutions to the equations of general relativity was found by Einstein himself, in collaboration with a colleague Nathan Rosen, in 1935. This was christened an *Einstein-Rosen bridge*, but it took a good few years more for the theoretical physicists to realize that this type of wormhole was

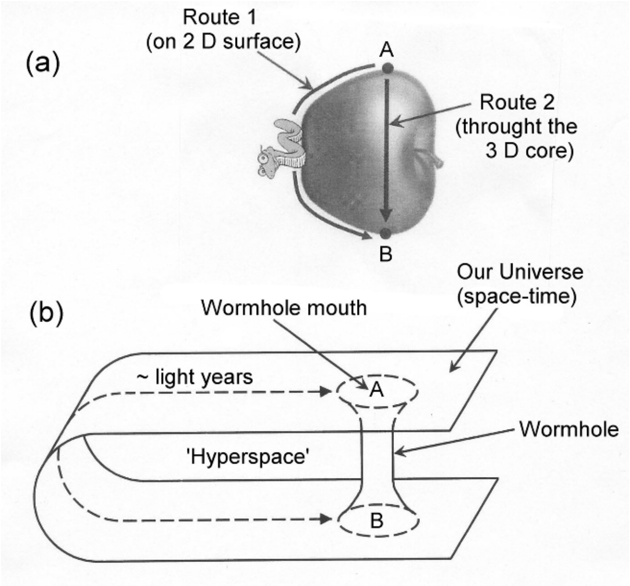

**Figure 11.3:** (a) Moving from point A to point B, the worm has a choice of taking the longer route on the apple's surface, or the shortcut through the middle. (b) This analogy is often used to illustrate the idea of a using a shortcut through a cosmic wormhole between two points A and B in the universe that may be light years apart.

unstable. It would close as soon as it was formed, making the transfer of people or starships through the cosmic passageway impossible. Since then, a great deal of work has been done investigating the stability of wormhole solutions of Einstein's theory, and again the bottom line is not good news for prospective interstellar travelers. The theory suggests that to keep a traversable wormhole open requires the use of exotic matter—the same stuff that we cannot find to power the warp drive! So although wormholes remain an intriguing prospect for the future, we seem to have hit the buffers again, with the engineering of such a scheme requiring huge amounts of negative mass and energy.

However, all is not lost. It should be borne in mind that the current wormhole solutions of Einstein's equations are based on his original classical theory, which focuses on the physics of the very large: planets, stars and galaxies, and the like. However, physicists are currently struggling to find a *theory of everything* that will describe the universe, not only on the large scale, but also on the very small scale where quantum mechanics presently reigns. Nobody really knows what such a theory will say about the future prospect of engineering a cosmic wormhole network as a kind of interstellar metro system!

# Epilogue

Its time to wrap up this journey through spacecraft design. I hope readers have found it useful, and that it has fed their interest in space. For my part, I have found the process of writing enjoyable and quite therapeutic, a bit like a download of my interests, enthusiasms, and experience, and I hope in such a way as to make it accessible to people who do not have a technical background. I have found this aspect of trying to explain fairly complicated ideas in an informal and entertaining way challenging.

As I write these final few paragraphs, it is October 2007, which marks a significant anniversary. It is 50 years since the former Soviet Union lofted a small satellite called Sputnik 1 into Earth orbit, thus heralding the dawn of the Space Age! I recently read a quotation from Buzz Aldrin, the Apollo astronaut who followed Neil Armstrong onto the Moon's surface during the historic first landing in 1969. In 1957, Aldrin recalls, Sputnik 1 made no great impression on him: "It seemed little more than a stunt." It is easy to understand this reaction, considering that he was then flying fighters from bases in West Germany at the front line of the Cold War with the Soviet Union. No doubt the beep-beep signal from space seemed to him to be inconsequential compared to the reality of training for a conventional or even nuclear war in that region of central Europe.

However, this view wasn't shared by Buzz's bosses back in Washington, D.C. The Scientific Advisory Board Ad Hoc Committee on Space Technology met in December 1957 at the Department of the Air Force Headquarters in the aftermath of Sputnik. Their report (National Security Agency NSA 00600, dated December 6, 1957), once classified as secret but now released under the Freedom of Information Act, is summarized by the statement, "Sputnik and the Russian ICBM [intercontinental ballistic missile] capability have created a national emergency." To counter the perceived Russian threat, the committee recommended the urgent commencement of a number of active Air Force–led programs:

- A program to develop second-generation ICBMs having a certain and fast reaction to Russian attack
- The acceleration of the development of reconnaissance satellites
- The establishment of a vigorous space program, with an immediate goal of landings on the Moon

So the intention to land men on the Moon was on people's lips long before President Kennedy's famous speech of 1961.

The shock of a little piece of Russian technology over-flying U.S. territory, with the launch of Sputnik in 1957, rocked America, and the first manned flight of Yuri Gagarin in 1961 was like twisting the knife in the wound. How the story unfolded from there is well known, with the Cold War competition between the two superpowers driving the space race to the Moon, culminating in Armstrong's first lunar footprints in 1969. This all seems a distant memory now, but it is for me one of the most vivid, enduring, and inspirational memories that I have of the first half-century of the Space Age. However, as I have said before, the other overriding feeling I have is one of impatience, a feeling that we ought perhaps to have already sent astronauts to stand on more distant planets. It seemed that 15 years into the new Space Age, with the departure of Apollo 17 from the Moon's surface in 1972, manned exploration of space appeared to have almost stalled.

By comparison, the Aviation Age began in 1903 with a 30-mph flight of the Wright brothers' first heavier-than-air airplane at Kitty Hawk. From these humble beginnings, the development of aviation continued unabated, and if we take a snapshot of where things stood half a century later, the first jet-powered civil airliner was already in operation, and experimental aircraft had already flown at twice the speed of sound—fifty times faster than the Wright flyer, at around 1500 mph! If we could achieve a speed of fifty times faster than Sputnik 1 now, we could reach the orbit of Mars in less than 3 days!

Although this kind of argument is flawed, nevertheless it does point to the undeniable fact that the Space Age has differed from the Aviation Age. Looking forward to the next half century, I have a greater optimism that manned exploration of space will accelerate. With the restructuring of the American space program, brought about principally by the retirement of the space shuttle fleet in a few years and renewed international competition from nations such as China, I have confidence that we will return to the Moon and venture to Mars. The other big issue, of course, is the cost of reaching orbit, and again I feel optimistic that the problem of aircraft-like launcher operation to Earth orbit will be solved in the next couple of decades. I feel the time is right.

This is all a bit late for me and for my career in the space sector, but nevertheless I have greatly enjoyed the era of the boom in space applications—communications, navigation, and Earth observation—and space science. What we have learned about the universe through the eyes of instruments like the Hubble Space Telescope has been phenomenal.

I look to the future with optimism, and I hope that this book will play a small part in inspiring young people to get involved in space science and engineering.