9 View to the Future and Exploration of Our Galaxy

9.1 Introduction

The Andromeda Galaxy (Messier 31 or M31), see Fig. 9.1, is the nearest galaxy to the Milky Way, our galaxy. Both are residing within the neighborhood of the galactic cluster, which consists of an assembly of galaxies that are bound together by gravity. The Milky Way Galaxy contains our Solar System. The Milky Way is some 100,000 light-years in diameter, with its central bulge about 20,000 light-years in depth. That central bulge contains the very massive black hole that drives the kinetics of the Milky Way Galaxy (Smith et al. 2012).

In Chap. 8, we have seen that our Solar System is on one of the spiral arms some 32,000 light-years from the galaxy center, and there is a group of stars (about seven) that are within 10 light-years of our Sun. Beyond that local group, our galactic stars are much more distant. Even if we travel at the speed of light, our nearby star neighbors are up to a 20-year round-trip away. Can we overcome such distances, or are we bound to our Solar System, or at most our nearby stars? That is the question that dominates our view to the future, after the sobering conclusions in Chap. 8.

Using General Relativity, researchers can theorize approaches to traveling at fractional light speed, and even at greater than light (superluminal) speed. The validity of some of these theories has being investigated by NASA Glenn Research Center (Millis 2004, 2005). The Earth's Milky Way Galaxy contains up to 100,000 million stars. The Earth is about 32,000 light-years from the center. Without super light speed, the Galaxy is isolated from our ability to explore it in any realistic time frame, except perhaps for our very nearby galactic neighbors. The distances are almost not comprehensible. At 1000 times the speed of light, it would take 32 years for us to reach the Galactic center. Yet, some researchers think that to consider superluminal speed is no more daunting than the past century's researchers considering supersonic travel. Although thinkable scenarios need to be sifted, there are indeed concepts that appear to be based on solid physics.

Many of these are presented at the annual International Astronautical Federation (IAF) Congress. Some will be discussed in terms of what might be possible. As already pointed out in Chap. 8, and shown in Fig. 9.2, we are nowhere near having the capability to reach the nearest star in our current projection of future systems for this century. Nevertheless, the number of research or speculative papers and books describing means of achieving interstellar travel is quite large, see for instance (Mallove and Matloff 1989; Woodward 2013; Cook 2002; Rodrigo 2010; LaViolette 2008), containing a compendium of scientific, engineering, and, sometimes, hypothetical knowledge about interstellar travel, overall underscoring the continuing appeal of this topic. But what are the possibilities, or at least the potential?

As done in research papers, we can indeed marshal and calculate numbers, but achieving the conditions computed remains questionable. Again, our foes are inertia and mass. Dr. David Froning states in 1991:

> … It is well known that enormous amounts of rocket propellant are required to overcome gravitational and inertial resistance to Earth-to-orbit flight. Here, overcoming gravitational and inertial resistance to upward and forward flight requires impartation [imparting] of about 7.5 km/s velocity to Earth-to-orbit rocket ships, and this requires that about 90 percent of single-stage-to-orbit (SSTO) rocket ship weight be propellant. Thus, if field actions and reactions of field propulsion could significantly reduce gravitational and inertial resistance, rocket thrust and propellant needs would be significantly reduced. But a major obstacle to reducing such resistance by field propulsion is current lack of understanding as to the origins of gravitation and inertia - of why and how they instantly arise to resist vehicle acceleration (or deceleration) and the vehicle's upward flight. Although the relation of gravity and inertia to parameters such as motions, distances, and ponderosities of material bodies are well known, there is no consensus whatsoever as to the origins of gravity and inertia … (Froning 1991)

Froning discusses three possible origins of mass and three possible origins of inertia. None of the six possibilities have been confirmed. Then, until a new understanding such as quantum gravitation can change the situation, we are confined, optimistically, to about 10 light-years from our Sun.

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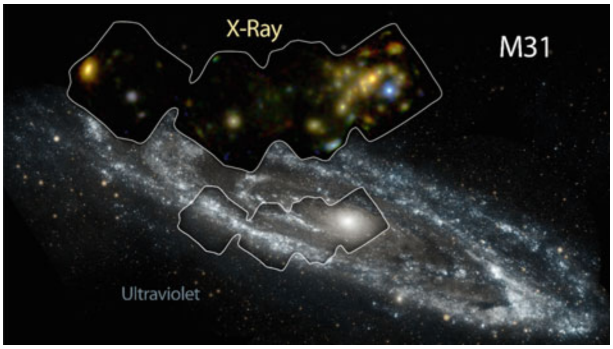


Fig. 9.1 Andromeda galaxy in high-energy X-rays imaged with NASA's nuclear spectroscope telescope array (NuSTAR). *Courtesy* NASA/JPL-Caltech/GSFC

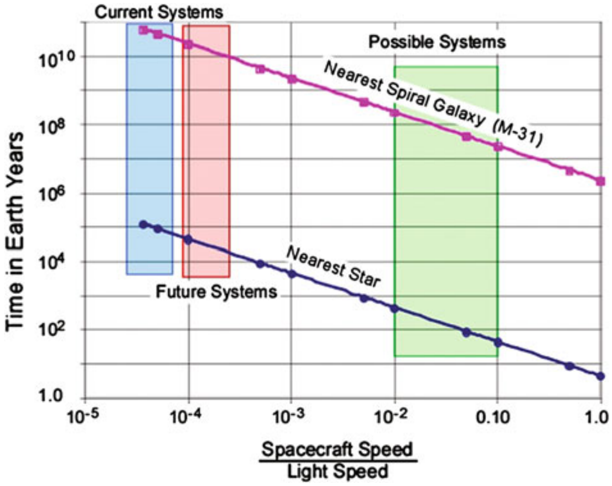


Fig. 9.2 Journey time as a function of spacecraft speed

The speed at which we can reach destinations within this sphere is wholly dependent on the specific impulse and thrust of the propulsion systems we can create. Today, we are limited to the leading edge of this sphere, that is the Oort Cloud. If practical fusion rockets become a reality, we could probably get a little farther, but to reach even the trailing edge of the Oort Cloud, we need a factor of ten increases in specific impulse. In order to reach 10 light-years requires a 10,000-fold increase in specific impulse, simply to limit mass consumption, that is, not considering the thrust required to limit travel time.

Then, what we need to do now is concentrate on getting from the surface of the Earth to orbit and to maneuver efficiently while in orbit. When these far-in-the-future propulsion advances are made, we will have the Earth-orbit-Moon infrastructure to take advantage of these developments.

9.2 Issues in Developing Near- and Far-Galactic Space Exploration

Reaching speeds close to that of light (relativistic speeds) in traveling through space is predicted to have major effects. Some of these effects have been mentioned in Chap. 8, see Stuhlinger (1964). They are the physical result embodied in the *Theory of Special Relativity* created by Einstein (1905). According to this theory, there are no privileged frames of reference such as the famed "absolute inertial frame" of classical physics. It is fact that the laws of dynamics appear the same in all frames of reference moving at constant velocity relative to each other (inertial but not absolute frames). This statement can be rephrased by saying that the laws of dynamics are "invariant" with respect to Galilean transformations, i.e., they remain the same in two frames of references in uniform motion (*constant* velocity) relative to each other. Experiments by Michelson and Morley (Rahaman 2014), repeated and validated for over a century, also showed the speed of light is invariant with the frame of reference, i.e., it does *not* increase or decrease due to the relative velocity between two inertial frames. This has been a disconcerting and counter-intuitive result that troubled many physicists. These two facts ultimately resulted in Einstein's intuition that simultaneous events cannot exist.

The second motivation for abandoning absolute frames of references and Galilean transformations was the need to make invariant not only the laws of dynamics, but also the laws of electromagnetism when changing frames of reference. In fact, contrary to the laws of dynamics, Maxwell equations change in a Galilean transformation. For instance, because the Lorentz force on a charge depends on its velocity, it would differ in different Galilean reference systems. This mathematical result was unacceptable, amounting to the existence of different electromagnetism "physics" in different inertial frames. The work done by Larmor, Lorentz, and Einstein himself convinced Lorentz that the Galilean transformations had to be replaced by the Lorentz transformations (Faraoni 2014), in which the characteristic ratio between frame speed and the speed of light appears. It is because of these new relationships between two inertial frames of reference that a clock on a spacecraft moving at constant velocity with respect to an Earth's observer would appear to him/her to run at a different speed than a clock on Earth. In other words, Earth time is *not* spaceship time.

The revolutionary character of *Special Relativity* stems from the fact that there cannot be a "third" or "impartial" observer capable of judging the "right" time between the two. The two frames in relative inertial motion are equally "right," each in its own frame, a consequence that alone can "explain" the *twin paradox* so often cited in connection to relativity (Unnikrishnan 2005). Then, Earth time and ship time are different, but it is Earth time we must be concerned with because that is the time in which the project team is living. H. David Froning has spent a career investigating deep-space travel possibilities, and the authors wish to acknowledge his contribution to this section (Froning 1980, 1981, 1983, 1985, 1986, 1987, 1989, 1991, 2003; Froning et al. 1998; Froning and Barrett 1997, 1998; Froning and Roach 2000, 2002, 2007; Froning and Metholic 2008).

To recall, the Lorentz transformation of Special Relativity (Einstein 1915; Lang 1999) results in a time relationship for the Earth observer and for the spacecraft traveler as follows:

$$t_{\text{Earth}} = \frac{t_{\text{spacecraft}}}{\sqrt{1-\left(\frac{V}{c}\right)^2}} \tag{9.1a}$$

$$t_{\text{spacecraft}} = t_{\text{Earth}} \cdot \sqrt{1-\left(\frac{V}{c}\right)^2} \tag{9.1b}$$

Note that in Galilean transformations (in classical physics), the two times are assumed identical, that is,

$$t_{\text{Earth}} = t_{\text{spacecraft}} \tag{9.2}$$

because the speed of light seemed at that time infinite. This classical result is in fact predicted by the Lorentz transformations in the limit $c \to \infty$.

Then, as the spacecraft approaches the speed of light, the crew's apparent time is shorter than the observer's apparent time on Earth. Both perceive that the event or journey has occurred over an equal duration. It is not until the spacecraft crew returns to Earth that the discrepancy in perceived times becomes apparent. Researchers have derived the relativistically correct equations for a spacecraft journey's duration (t_e) in an Earth-bound observer frame of reference, and for the journey duration (t_{sc}) of that same spacecraft in its own moving reference (Froning 1980). For the simple case of one-dimensional *rectilinear* motion, Krause has derived the expressions for (t_e) and (t_{sc}) for a spacecraft acceleration (a_{sc}) in its own moving frame during the initial half of the total journey distance (S) followed by a constant spacecraft deceleration ($-a_{sc}$) during the final half of the total journey (Krause 1960; Maccone 2008a).

The reader is warned that the relationships below can be derived and are valid only when the motion is rectilinear, i.e., when the space–time continuum is the so-called Rindler space–time (only two-dimensional). This is not a very realistic assumption but one that simplifies this problem. In the fully four-dimensional space–time, or Minkowski's space, the effect of changing velocity (acceleration) is much more complex. There is, in fact, an important consequence with respect to changing velocity, because velocity is a vector. Even simply inverting direction invalidates the consequences of the Lorentz transformations that are strictly valid among *inertial* frames, that is, with constant relative velocity. Because velocity is defined by a magnitude (speed) and a direction, if either changes, then it has to be the result of acceleration. The most common effect of acceleration is a change in the magnitude of the speed. However, a constant speed turn is in fact an acceleration from a continuously varying direction. The direction of the acceleration is perpendicular to the flight path, and pointed at the center of the (instantaneous) rotation. This is the acceleration, the result of any rotation of the velocity vector. Thus, in the spacecraft reference frame, a spacecraft crew in orbit is under a constant acceleration, balanced of course by their gravitational weight. In space, the thrust from a propulsion system is necessary to initiate any acceleration, whether positive or negative. Because there are no aerodynamic forces in space, any motion initiated will continue until it is decelerated by a propulsion force of equal magnitude and opposite direction.

In the two-dimensional continuum assumed in the example by Krause, the two times, crew time and Earth time, are given by the following equations:

$$t_e = 2 \cdot \sqrt{\frac{S}{a_{sc}} \cdot \left(1 + \frac{a_{sc} \cdot S}{4 \cdot c^2}\right)} \tag{9.3}$$

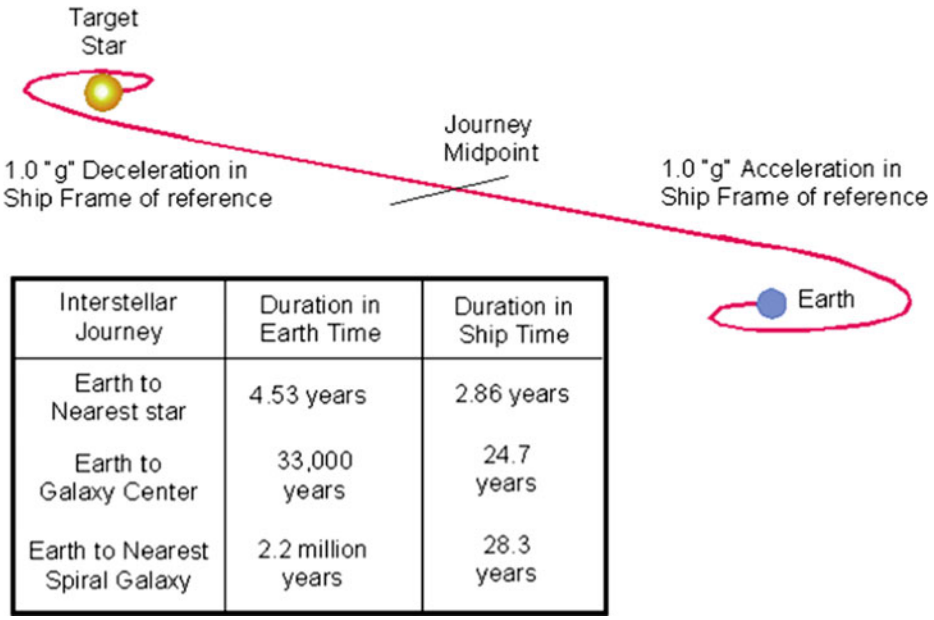
With

$$t_{sc} = \frac{2 \cdot c}{a_{sc}} \cdot \cosh^{-1}\left(1 + \frac{a_{sc} \cdot S}{2 \cdot c^2}\right) \tag{9.4}$$

These equations can be solved for a number of different destinations as a function of spacecraft acceleration and their times compared. The life of a deep-space mission management team (ground team) is probably about 20–30 Earth years. If we wish to travel farther into space, that is, faster relative to the Earth time frame of reference, then we must travel faster.

We have seen in Chap. 8 that accelerated trajectories need tremendous amounts of propellant mass and appear unfeasible at the present state of our knowledge. However, it is interesting to see the consequences of acceleration on travel time if, at some point in the future, propulsion systems other than based on Newton's Third Principle will be discovered.

Before discussing travel times, we need to establish the *absolute limit,* or boundary, posed by Special Relativity, that is, when spacecraft speed equals light speed. For such a flight profile, the maximum spacecraft velocity will be assumed to be reached at the journey midpoint only, see Fig. 9.3. From the starting point to the midpoint, the spacecraft has a continuous and constant positive acceleration. From the midpoint to the end point, the spacecraft has a



Interstellar Journey	Duration in Earth Time	Duration in Ship Time
Earth to Nearest star	4.53 years	2.86 years
Earth to Galaxy Center	33,000 years	24.7 years
Earth to Nearest Spiral Galaxy	2.2 million years	28.3 years

Fig. 9.3 Specific examples of Earth versus ship times

continuous and constant negative acceleration. Eugen Sänger derived the ratio of the spacecraft velocity (V) to light speed (c) at the journey midpoint, as given in Eq. (9.5) (Sänger 1956).

$$\frac{V}{c} = \tanh\left[\cosh^{-1}\left(1 + \frac{a_{\mathrm{sc}} \cdot S}{2 \cdot c^2}\right)\right] \qquad (9.5)$$

In Eq. (9.5), the value of the hyperbolic tangent approaches 1 as the value of the hyperbolic arc cosine approaches infinity. So, this solution tells that objects *never reach light speed* unless their acceleration is also infinite. Said otherwise, reaching light speed requires reaching also infinitely large kinetic energy, because V/c tends to 1 and the Lorentz transformation factor (the square root at the denominator) tends to infinity. In Sect. 8.3, we have seen that this is the result of the fact that *potential* energy grows with the Lorentz transformation factor $(1 - V^2/c^2)^{-1/2}$, see Eq. (8.26). However, the hyperbolic tangent has a value of 0.9999, or V is only 0.01% less (30 km/s less) than light speed when the value of the hyperbolic arc cosine function is 70.7. As a consequence, the ($V/c \approx 1$) curve on Fig. 9.4 represents actually 0.9999% of light speed.

Equations (9.3) and (9.4) for Earth time and spacecraft crew time can be solved, for instance, for three sample destinations: (1) For one of the nearest stars, *Proxima Centauri*, 4.24 light-years distant; (2) For the *Galactic Center*, 33,000 light-years away: and (3) For the nearest spiral galaxy, *Andromeda*, 2,200,000 light-years away. Figure 9.4 shows that with the flight profile just assumed for a hypothetical Earth observer, the spacecraft time seems to flow more slowly than Earth time. In terms of spacecraft time, the mission time appears to be approaching a constant value. In the spacecraft, the clock onboard would appear to run slower and slower as the acceleration is increased. To *the crew*, the transit time to final destination continuously decreases as the constant acceleration, a_{sc}, increases, just as expected. Remember, in this discussion, these are one-way missions. However, if the spacecraft were to return to Earth, both the Earth observer's time and spacecraft's crew time would double. These results are shown in Fig. 9.4 on the right, where solid lines are Earth time and broken lines are crew or spaceship time. Each of the Earth observer time curves (solid lines) approaches asymptotically the time corresponding to the distance from Earth, *measured in light-years,* as the spacecraft velocity approaches light speed.

The spacecraft crew time (broken line) breaks away from the Earth observer line above some acceleration threshold. The greater the distance, the lower the value where the spacecraft/crew-perceived acceleration curve breaks away from the Earth observer line. For the nearby Proxima Centauri star, the observer and the spacecraft crew time curves are relatively close until almost 1g acceleration (9.8067 m/s^2). For the two more distant destinations, and for practical accelerations, there are orders-of-magnitude differences between Earth and crew times. In fact, one of the many problems with interstellar travel is the different times predicted by Special Relativity between non-inertial frames. Note again that in these calculations the effect on time due to the non-inertial frames of reference, when the ship accelerates and even inverts its velocity, has been neglected, see Boniolo (1997).

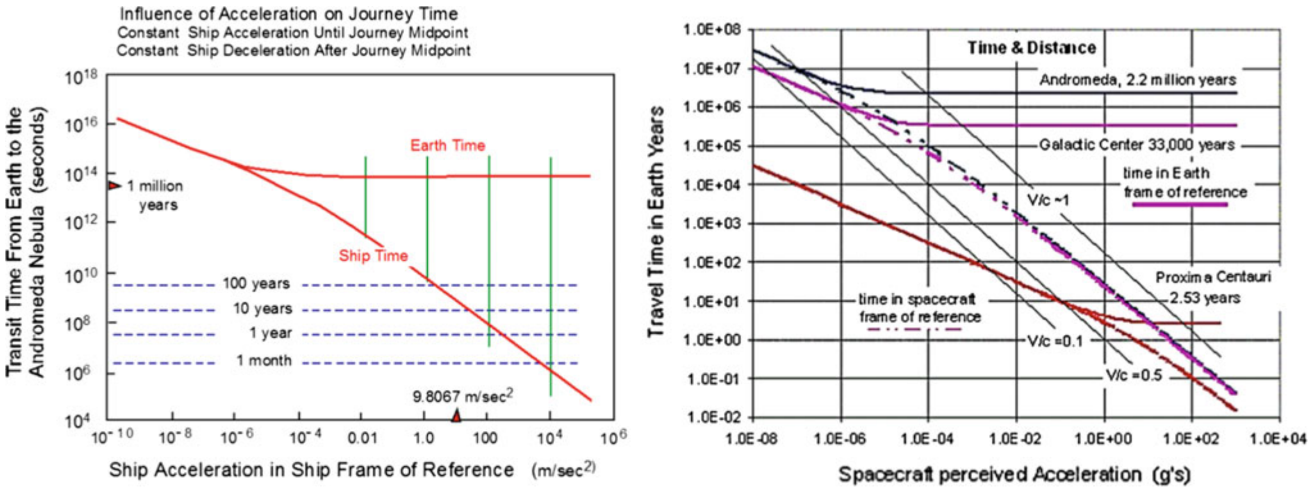


Fig. 9.4 Flight profile and differences between crew and Earth times. Influence of acceleration on journey time (*left*) and the interaction with the three destinations such as the Proxima Centauri, the Galactic Center, and the Andromeda spiral galaxy (*right*)

The ship time to the nearest star *Proxima Centauri* (4.24 light-years) is about 58% of Earth time. The difference is not sufficient to terribly disconcert the arriving crew: The Earth team perceives the trip as 1.86 years longer than the crew. However, as the distance and acceleration increase to reach the *Galactic Center* (center of the Milky Way about 33,000 light-years), the discrepancy in clocks is startling. The ship clock has only registered 24.7 years, while on Earth 30,000 years have gone by. That is more distant to the future than the past Ice Age is to the present! The crew would have no concept of what to expect when returning, and there would be probably no chance of any communication with anything or anyone on Earth. Moving to the nearest spiral galaxy *Andromeda* (2.2 million light-years), the clock on the spacecraft would have only registered 28.3 years, while the Earth clock would have registered 2.2 million years. That is about the time in the past when the first human-like beings appeared on Earth. Then, how do we address the different clock rates so that deep-space exploration can be managed by Earth-based mission teams within their 20 years or so of professional life? This is a very good question for long interstellar travel and it may have become moot by the time such travel is feasible. Whether the spacecraft is manned or robotic, for distant space destinations, there would be no one on Earth that knew *what* was returning to Earth, or *why*.

Putting aside the effects of the Theory of Special Relativity on clocks, it is *time* to discuss the root of the problem, that is, the definition of time or, more correctly, the passing of time. Humans perceive the present moment as having special significance. As the clock ticks, one moment passes and another comes into existence, and we call the process "the flow of time." Physicists, however, argue that no moment, not even the "present," is more special than any other moment. Objectively, the past, present, and future must be equally real. Physicists talk about "absolute past" and "absolute future" in Minkowski's space–time, see Miller (2008), Boniolo (1997), Boniolo and Budinich (2010). That is, all of eternity is laid out in a four-dimensional domain composed of time and three spatial dimensions. What is observed as the *passage of time* is actually that earlier states of the world are different from earlier states of the world we remember. "*… The fact that we remember the past, rather than the future, is an observation not of the passage of time but of the asymmetry of time—a clock measures duration between events much as a measuring tape measures distances between places; it does not measure the 'speed' with which one moment succeeds another. Therefore, it appears that the flow of time is subjective, not objective …*" (Davies 2002). In fact, clocks do not measure time. They only measure the different position of the clock hands. In this view, it is us who connect their positions as a flowing continuum.

The existence of a time arrow is a major question which was first posed by the British Astronomer Arthur Stanley Eddington in 1927 (Weinert 2004). The time arrow is related to the fact that in any isolated system, entropy cannot decrease (Mackey 1991; Layzer 1975). All the fundamental equations of physics hold irrespective of the time direction, but, in our Universe at least, time seems to be flowing only in one. This troubling issue might be resolved by admitting the existence of a "multiverse," a structure composed of many universes, where each has its own time arrow (Carroll 2008). In such a multiverse, time may flow statistically either way, so that there is no preferential direction. Note that no evidence of multiverses has been found so far. In a special issue of *Scientific American,* the main topic was "A Matter of Time." Davies provides an example of that in his article "That Mysterious Flow" (Davies 2002). An Earthling in

Houston and a person on a spacecraft crossing our Solar System at 80% of the speed of light attempt to answer the question: *"What is happening on Mars right now?"* A resident of Mars has agreed to eat lunch when the clock on Mars reads 12:00 P.M. and transmit a signal at the same time.

The puzzling comparison among times of the events between the Earthling, Martian, and Spaceman is shown in Table 9.1. The real difficulty is that, surprisingly, we really do not have a real definition of time! Astounding as it sounds, we have developed physics over centuries using an undefined quantity. Quoting again from *Scientific American*, *"… Neither scientists nor philosophers know what time is or why it exists. The best thing they can say is that time is an extra dimension akin, but not identical, to space. …"* The physicist Bryce DeWitt has obtained a theory of quantum mechanical gravitation (still the Holy Grail of physics) by eliminating time from the theory itself, as if time was not a physical variable of interest (DeWitt 2003). This is also the opinion of the physicist Julian Barbour (Lemonick 2001), who is convinced that time is an illusion created by our brain, an idea put forward also by Fred Hoyle in the 1960s in one of his fiction books (Hoyle 1957) and mentioned by Gribbin (1992, Ch. 7).

The search for a *quantum gravitation theory* may have a profound influence not only on understanding our Universe's architecture, but also on space travel. A recent suggestion by Ambjørn et al. (2008) postulates that the structure of the Universe may be constructed with simple building blocks or elements, the so-called simplices, using what we already know (gravitation, quantum mechanics, and the principle of superposition), *provided* the principle of causality is added. This elegant constraint, or way out, means time must flow in the same direction for neighbor simplices.

This suggestion is being implemented by its authors in a comprehensive theory that allegedly predicts some of the key features of our Universe, including Einstein's cosmological constant now back in fashion to explain dark energy. If this theory can be validated, a consequence is that wormholes (one of the most used travel devices invented by science fiction writers) may *not* exist. The structure of our Universe would in fact be very smooth (i.e., maintaining the same concept of distance between two points we are familiar with, with no "wormhole shortcuts"). As we shall see, another way out of the time quandary is to travel in another non-time dimension, if such a postulated dimension exists. *If* the space–time continuum is more than four-dimensional (i.e., made of three space coordinates and time), there is a way to reach the most distant star and galaxies in less than human lifetimes.

As we approach the speed of light, another problem is the propellant mass anticipated in Chap. 8. As spacecraft speed increases toward the speed of light, its kinetic energy increases. This is predicted by the Einstein relationships, see Eq. (8.25), and for all practical purposes, it is as if to an observer the vehicle mass becomes infinite at the speed of light. One wonders what is a reasonable mass ratio, M_R, for a long mission carried out at speeds close to that of light. By including relativistic physics, a *minimum* mass ratio needed

Table 9.1 What time is it on Mars?

Time	Observer	Event
Before noon	Earth	Earthling and Martian exchange light signals and determine the distance between them is 20 light-minutes and synchronize clocks
Before noon	Spacecraft	Spaceman and Martian exchange light signals and determine the distance between them is 12 light-minutes and synchronize clocks
12:00 p.m.	Earth	Earthling assumes Martian has begun to eat lunch, and prepares to wait 20 min for verification
12:00 p.m.	Spacecraft	Spaceman hypothesizes Martian has begun to eat lunch, and prepares to wait 12 min for verification
12:07 p.m.	Spacecraft	Signal arrives disproving hypothesis; spaceman infers Martian began eating lunch before noon
12:11 p.m.	Earth	Knowing spacecraft's speed, Earthling deduces spaceman has encountered the light signal on its way to Mars
12:15 p.m.	Spacecraft	Spaceship arrives at Mars and spaceman and Martian notice that their two clocks are out of synchronization, but disagree as whose is correct
12:20 p.m.	Earth	Signal arrives at Earth. The Earthling has confirmed the hypothesis that noon on Mars is noon on Earth
12:25 p.m.	Earth	Ship arrives at Mars
12:33 p.m.	Spacecraft	Signal arrives at Earth. The clock discrepancies demonstrate that there is no universal present moment

Adapted from Davies (2002)

by a very efficient propulsion system (that is, with the highest specific impulse, I_{sp}) can be estimated. The most efficient interstellar rocket ever considered was the photon rocket (Sänger 1956). A photon rocket converts all of its onboard propellant into a perfectly collimated photon (light) beam. Thrust is the recoil due to momentum applied by photons to the spacecraft. The ideal photon rocket has the highest possible $I_{sp} = c$ if the mass consumed to generate light is neglected. Of course photon thrust is tiny. Eugen Sänger (see Sect. 9.2) calculated the mass ratio M_R of this ideal spacecraft performance assuming a trajectory where the spacecraft accelerates at constant a_{sc} until *reaching the speed of light* at the mid-distance $S_{1/2}$ and then decelerates at the same rate $-a_{sc}$ to its final destination:

$$M_R = \exp\left(2 \cdot \cosh^{-1}\left(1 + \frac{a_{sc} \cdot S}{2 \cdot c^2}\right)\right) \tag{9.6}$$

This equation incorporates Einstein's relativistic effects, so the mass ratio approaches infinity as the spacecraft speed approaches light speed. In this trajectory, the mathematical expression calculated by Sänger for the midpoint velocity is as given before by Eq. (9.5). These equations are intriguingly similar to those developed in aerodynamics used to calculate transonic drag, predicting infinite drag at Mach = 1. After WWII this arresting result worried physicists planning to break the "sound barrier," but this "barrier" was in fact due to the linearization of drag by aerodynamicists in order to obtain an analytical solution (Anderson 1997). Therefore, some may doubt whether relativistic effects near $V = c$ are due to a hidden assumption in developing Special Relativity thereby producing a similar mathematical result, or if they are a true physical singularity. The calculation of the mass ratio needed to accelerate to speeds close to the speed of light yields inordinately high values for the mass ratio, just as evaluating aerodynamic drag with linearized aerodynamics near sonic velocity (Mach → 1) yields unrealistically high drag. For most physicists, there is no question: because of the Michelson-Morley experiment in 1887 and accurate measurements of time differences between satellite and Earth clocks, Special Relativity has been validated for good. However, some keep doubting, because the discontinuity when $V = c$ seems a pure mathematical artifact, that is, the effect of the Lorentz transformations based on the invariance of c. Still, almost all physicists are convinced of the validity of Special Relativity.

Combining Tsiolkovsky's rocket equation (Tsiolkovsky 2004) and the M_R equations, one can estimate the average I_{sp} needed for a specific mission, as given below. In the simple flight profile chosen by Sänger, for example, when the mass ratio approaches infinity, the specific impulse I_{sp} approaches zero. For speeds less than 91% of the speed of light, the limit M_R and I_{sp} (here in seconds) are given by

$$M_R = \exp\left(2 \cdot \cosh^{-1}\left(1 + \frac{a_{sc} \cdot S}{2 \cdot c^2}\right)\right) = \exp\left(\frac{\Delta V}{g_0 \cdot I_{sp}}\right) \tag{9.7}$$

$$I_{sp} = \frac{\frac{\Delta V}{g_0}}{2 \cdot \cosh^{-1}\left(1 + \frac{a_{sc} \cdot S}{2 \cdot c^2}\right)} \text{(s)} \tag{9.8}$$

When the spacecraft speed is in the vicinity of light speed, as measured by the difference

$$\Delta c = c - V_{sc} \tag{9.9}$$

an approximation for the mass ratio M_R and I_{sp} is:

$$M_R = \frac{599{,}475}{\Delta c} \tag{9.10}$$

$$I_{sp} = 1{,}373{,}120 \cdot \Delta c^{0.076744} \text{ (s)} \tag{9.11}$$

with

$$\Delta c = 299{,}796 - V_{sc} \tag{9.12}$$

A value Δc = 5994.75 km/s makes the absolute speed 97.85% of light speed, and the mass ratio to achieve that, M_R = 100, may be tractable. The corresponding I_{sp} is 2,676,900 s. That is about three orders of magnitude greater than the best (electric) space engines can provide today.

Traveling close to light speed, even with reasonable M_R, requires either dramatic improvements in propulsion or radically new ways of conceiving propulsion and space travel. Some are discussed below.

9.3 Black Holes and Galactic Travel

The time, energy, and logistic limits posed by traveling in reasonable times to our closest stars (let alone to Galactic destinations) motivate the search for propulsion means alternative to those based on current physics (Newton's Third Principle). This is an endeavor common to science fiction writers and scientists alike.

The measurements taken from scientific satellites indicate that the space–time continuum of the Theory of General Relativity (Minkowski space–time) is nearly flat. If space–time were "warped," that is curved, the force and energy available from gravitation would be much larger than predicted by the simple Newton's Law. Then a new propulsion system would, in principle, be possible (Alcubierre 1994; Obousy and Cleaver 2008). Such a system has been proposed by Millis (1996) and is examined in Ford and Roman (2000), Minami (2008). Feasibility is for the moment speculative, due to the mathematical complexity of the tensor calculus required when manipulating General Relativity equations (Maccone 2008b), but at least Relativity or any other basic physical principle does not appear violated. Contrary to popular belief, General Relativity allows for a number of effects that are positively unexpected or "strange," some far stranger than fiction. The fundamental equations of physics, including General Relativity, tell what cannot be achieved or done (i.e., all that is forbidden). They do not tell us anything about what is actually possible to do. They behave like the old joke about what is lawful and what is not in England, Germany, Russia, and Italy: *"In England all is permitted, except what is explicitly forbidden. In Germany all is forbidden, except what is explicitly permitted. In Russia all is forbidden, even what is explicitly permitted. In Italy all is permitted, even what is explicitly forbidden."* General Relativity would then be an English Law. Solving the General Relativity equations is difficult, and obtaining results (some quite unexpected) has been and still is a step-by-step process, each sometimes correcting or modifying the previous one.

Among the most interesting of these results are those concerning black holes. By now, the work of Stephen Hawking and Roger Penrose, publicized by books, movies, and the popular press, has made black holes a well-known term and even a metaphor (deGrasse Tyson 2007). Its "strange" and disconcerting properties are still being investigated by theoreticians, and they are far from having been completely explored. Their relevance to propulsion is that they carry significant implications for space travel. In some far future, the physics of black holes may conceivably result in replacing the very idea of *space travel* with the more physically consistent idea of *space–time travel* (Gribbin 1992). Note that the number of "primordial black holes" (those created by the big bang) is estimated in the trillions, their average mass of order 10^{12} kg. They are theorized to evaporate in a process called "Hawking radiation" producing antimatter (mostly positive electrons). This process might explain the so-called dark matter invoked to justify the missing mass of our Universe.

A black hole is a true discontinuity in the space–time continuum. A black hole is not "made" out of matter, although it attracts and collects matter. Then it is not another exotic star such as a neutron stars or pulsar either. It may be defined simply in terms of four-dimensional space–time topology as a purely geometric concept, characterized by a center and a surface (Kaufmann 1992). It is theorized that black holes are the final products of massive stars at the end of their life cycle. If their mass is too big to end as a white dwarf or neutron star, the gravitational force compressing a spent star matter is no longer compensated by the pressure developed by thermonuclear reactions. Then, mass keeps compressing and shrinking, density increases, and so does gravitation, until not even light may escape. The radius of the collapsing star at this point is called the Schwarzschild radius, and defines the so-called event horizon. The German astronomer Karl Schwarzschild was the first to discover this effect when solving Einstein field equations of General Relativity in 1916 (Schwarzschild 1916). Beyond this distance, an external observer cannot see any longer inside the collapsing star, and optically speaking the star disappears. Most recently, in August 2016, Jeff Steinhauer, from the Technion Department of Physics, announced results of an experiment where laboratory-sized black holes may have been generated, results finally proving that the Hawking radiation exists (Weiner 2016).

Inside the collapsing star, gravitation curves space–time more and more till a "hole" is punched in its fabric. The star matter is swallowed by this singularity, as (for a *static* hole at least) density and gravitational force become infinitely large. The sharply increasing curvature of space–time when nearing a black hole is perfectly equivalent to that created by mass gravitation. For this reason, a black hole is also characterized by a mass, that is, the *equivalent* mass that would have the same gravitational effect. Inside the event horizon, the pull of the black hole singularity cannot be overcome by any force or thrust, and gravitation bends even photon trajectories. Outside the event horizon, space–time tends to become gradually flatter, and the pull decreases, tending to that of an equivalent ordinary mass. For instance, a black hole with mass equal to that of ten times our Sun would start behaving like a star of that mass from a distance of order three or four AU (Kaufmann 1992).

In 1939, Oppenheimer and Volkoff (1939) calculated the limit mass of a star beyond which the star would collapse into a singularity. In 1971, the Uhuru satellite, designed to monitor space X-ray emissions, was launched from the Italian "San Marco" platform off the Kenyan coast. This X-ray astronomy satellite observed a strong source of X-rays from a supergiant blue star in the Cygnus constellation, later found in fact to be a binary system. The other star, named Cygnus X-1, had a mass estimated at more than ten times that of our Sun, but compressed within a 300 km diameter, was (and still is) invisible. In the Harvard College Observatory, the giant star took the catalog name HDE 226868. We do know now its companion, Cygnus X-1, is very likely a black hole. Much progress in this field has been made since the 1970s. At present, black holes are considered the natural final evolution of massive stars and their estimated average distribution density is significant. For instance, statistically, there should be a black hole within 15 light-years from our Sun, although it cannot be observed directly (DeWitt and DeWitt 1973; Lasota 1999).

Meanwhile in 1963, Kerr had already calculated some properties of a *rotating* black hole, and the work by Newman in 1965 had explored the properties of *charged* black holes. Their joint solutions of the theory of General Relativity are called now the Kerr–Newman solution, to which theoretician Paul Davies added later quantum mechanics effects. So far, all these results were obtained by solving Einstein's field equations. No rotating black holes has been deduced from observational astrophysics yet. However, this fact has not deterred theoreticians from investigating more and more features of these objects. For instance, when Carl Sagan decided to write his novel *Contact* (Sagan 1985), he asked Kip Thorne, the leading gravitation physicist at CalTech, to help him in checking mathematically whether black holes could be exploited for space–time travel (Gribbin 1992). The answer was positive (Thorne 1995).

In fact, General Relativity solutions for static black holes had already shown the existence of channels ("wormholes" is their popular name) punched by black holes between different regions of space–time. This means that black holes may be the entrance into channels leading to places in our universe, or even to a *different* universe. These General Relativity solutions are the so-called Rosen-Einstein bridge solutions and, if confirmed by observation, would imply interstellar travel may be possible. This same class of solutions, however, predict that *neutral* and *static* black holes must evolve and last only for an instant, while space–time inside shrinks to a mathematical point. The difference between *rotating* or *charged* Kerr–Newman black holes is that the latter allow finite size and duration of wormholes. The singularity predicted at the center of Kerr–Newman black holes is not a point but rather a ring. If the black hole is sufficiently large and massive, objects of finite size may enter and travel without being torn apart by the gravitational tidal forces associated to smaller black holes inherently possessing sharper space–time curvature (Gribbin 1992). In principle, these General Relativity solutions suggest a spaceship may go through a massive black hole and emerge in a different part of our universe in a transit time much shorter than covering the same distance along the ordinary (nearly flat) space–time continuum while not exceeding light speed. In other words, the transfer from one part of the universe to another does not violate the light "speed limit." The ship would simply take a shortcut (the wormhole) created by the intense curvature of space–time near a singularity.

However, there are caveat associated with this. The trip through a rotating or a charged black hole is one-way, unless the charge (or angular velocity) of the black hole is so large that the singularity at its center, still annular, becomes in the language of gravitation "naked." Naked singularities are predicted by General Relativity and are singularities where the event horizon does not exist. By using this class of black holes, traveling both ways becomes possible in space but not in time. Then, the spaceship would be able to return to its point of departure, but the time would precede departure time! This disconcerting fact can be shown using the so-called Penrose diagrams, and it is due to the extreme effects typical of singularities in space–time. Space and time can no longer be kept separate as in our ordinary, locally nearly flat space–time (Kaufmann 1992; Thorne 1995).

Are there such rotating or charged black holes? As said, none has been "observed." An inference shared by many astrophysicists, however, is that quasars *may* be such objects. Quasars are indeed massive, a fact that can be deduced by their enormous rate of electromagnetic energy release, and they rotate. If this is indeed so, quasars are natural connections to other space–time regions.

A second caveat about using black holes as shortcut entrances between regions of space–time is the fact that any material object must have a speed less than that of light. When the spaceship enters a black hole it is preceded by the isotropically emitted gravitational waves traveling at light speed. This gravitational radiation may be amplified by the black hole to the point of perturbing the space–time curvature in front of the ship itself, thus preventing entrance. Phrasing this problem differently, the question is how sensitive, or stable, a black hole is to external perturbations? Indeed, the exact Kerr solution does show the solution is sensitive. However, it is precisely this solution "weakness" when facing any practical application that presents an opportunity. If the black hole is unstable, its equilibrium may be in some way altered in the direction of favoring entrance, not exclusively preventing it. This viewpoint looks at black holes as the next major step in space travel.

In fact, work on the ship mass effect on the Kerr–Newman black hole, spurred by C. Sagan's questions to Kip Thorne, showed that black holes may be born naturally (and are therefore common), so that, in some way, perturbations must either dissipate or be insufficient to "close" a black hole. Researchers working with Kip Thorne aimed at finding answers to C. Sagan's questions decided to engineer black holes to meet the objectives of the plot in *Contact,* an instance of fiction motivating a theory (Morris et al. 1989). The team at CalTech did what is called "reverse engineering" of a black hole. In other words, they assumed the features such a wormhole should have in order to be a practical means of transportation, and then set out to find what was necessary to make it based on what is known from General Relativity (Morris et al. 1988; Morris and Thorne 1988). Perhaps, the most important result they obtained is, that matter inside the black hole must be capable of exotic properties (either anti-gravity or negative pressure) in order to keep the wormhole steady and to prevent it from contracting during the spaceship transit. Such exotic matter may, for instance, consist of cosmic strings. All these properties, hard to even conceive in ordinary matter, are nothing radically new. The Casimir effect indicates such exotic properties are not only theoretically possible, but can be also theoretically observed. String theories have been investigated since the 1980s (Greene 1999).

An intriguing proposal in this quest was advanced by Visser (1989). Visser proposed a space-gate unlike the ones discussed so far. The major problem with conventional black holes is the distortion of space–time, subjecting travelers and their ships to intense gravitational tidal forces. These forces become moderate only for very large (massive) black holes, where gravitation is distributed over a vast enough portion of space, overall resulting in a mild space–time curvature. Relaxing the assumption of rotating or charged holes, where exotic matter would prevent the ring inside from closing due to the gravitational disturbance generated by the transiting ship, Visser envisaged a star-gate in the shape of a flat-faced cube. A spaceship can cross such gate without feeling any force induced by space–time, and without touching the matter holding the gate together. This solution is predicated on the ability to keep the space–time cube flat by using exotic matter to delimit its edges. Note that all the associated complex physics is still the outcome of solutions of the field equations developed by Einstein in his General Relativity theory, indicating that his theory is reliable. In fact, after much mathematical and experimental testing, nothing has been found to challenge this theory to this day.

9.4 Breakthrough Physics and Propulsion

In juxtaposition, efforts are under way to find *new* physics, physics that would enable us to bypass limitations such as the speed of light. It is this limit that is assumed to be the main issue blocking our path toward the exploration of stars and of our Galaxy. In this context, it must be said that certainly we have *not* explored all there is to know in our understanding of physical laws. After all, what we know has been found by looking at a very small portion of our universe. Are the laws we know everywhere the same? Do they change with time? Some physicists think so (Smolin 2013).

After the two probes, *Pioneer 10* and *Pioneer 11* (also *Galileo* and *Ulysses*, as found later), showed a tiny but measurable deceleration, the so-called Pioneer Anomaly, that could not be explained by any of the mechanisms proposed, some physicists began to conjecture that gravitation, or inertia, was changing with distance (in this case, from the Sun) (Anderson et al. 1998). However, the painstaking analysis of all Pioneer data by S. Turyshev's team at the Jet Propulsion Laboratory in 2012 showed that the effect could be explained by photon thrust due to the dish antenna heated by the RTG nuclear generator (Turyshev et al. 2012). Similarly, many physicists thought that the experiments in the Large Hadron Collider (LHC) at CERN (Anon. 2008) would result in changing our current understanding of physical laws and trigger another revolution (Quigg 2008). In fact, the sought-for Higgs particle (Higgs boson) was indeed detected in 2013, but not its wished for "twin," so that no revolution appears likely any time soon. This dampened hopes, for the time being, for new physics that could broaden the understanding of the Universe and weaken or remove existing limits.

Nevertheless, the fact is that we have barely scratched the prediction potential of the General Relativity equations. Dark matter, dark energy, inertia, the equivalence between inertial and gravitational mass, quantum entanglement, and the relationship between quantum mechanics and gravitation —these aspects are still unexplained by the Standard Model ('t Hooft 2007). New quantum gravity theories are frequently proposed, e.g., Kane (2003), Smolin (2004), Barceló et al. (2009), Lisi and Weatherall (2010). Hopes to circumvent inertia or gravitation remain.

Probably, the single most severe shortcoming in efforts to exploit the potential of General Relativity is our limited conception of space and time. In particular, time is more and more frequently questioned or questionable; we still are at loss to *define* time. As mentioned, we should abandon our concept of space travel in favor of space–time travel. Besides the questions above, related to the very fabric of the Universe we know, there are also more mundane problems connected with the energy needed for such travel. These questions and attitudes motivate the search for still undiscovered laws, or connections between laws, constituting what has been given the catchy name of "breakthrough physics" (Hamilton 2000) and "breakthrough propulsion" (Millis 1996, 1998). These are nicknames given by scientists and engineers frustrated by the constraints posed by "known" physics, and should be understood to mean "physical principles beyond the ones we know"; they might be part of currently unknown physics, or developments from General Relativity, or from the Standard Model, that we still have not explored.

"Breakthrough" physics sometimes adopts General Relativity equations, and sometimes modifies them to suit a particular goal, or replaces them with something else that often does not stand the test of time and peer reviews. It is hard to judge the merits of ideas or models based on completely "new" physics that should, in the best intentions of the authors, suggest new means of propulsion, e.g., see Puthoff (2010). As for alternative energy sources, much has been made of the zero-point energy (*ZPE*) discovered by Einstein and Stern. This energy is often associated with Planck's length (a scale arbitrarily formed by using three fundamental physical constants). The zero-point energy field is tied to so-called quantum mechanical vacuum energy fluctuations. The existence of quantized energy fluctuations is responsible for the experimentally proven Casimir force (Casimir 1948; Ball 2007).

The consequences of zero-point energy have been investigated for several years. In propulsion its appeal derives from the fact that, while its absolute magnitude is extremely small, its scale should be just as small (e.g., the Planck's length just defined is of the order of 10^{-36} m). By implication, the estimate for the zero-point energy associated with a sizable volume yields extremely large values, in fact so large as to curve space, a fact not observed and theoretically obscure (Garattini 2008). Besides, nobody would know how to extract this energy (Yam 1997), but myths abound. This difficulty has not discouraged suggestions to use it for a propulsion device of some sort.

An example is the so-called EmDrive, Q Drive, RF Resonant Cavity Drive, or Cannae Drive, depending on the groups that built and tested the concept. This was conceived in the UK by R. Shawyer in 2008–2009 and tested at his SPR Ltd company, at NASA Johnson Research Center (Eagleworks Laboratories), by chemical engineer Dr. Guido Fetta in the USA, and at China's Northwestern Polytechnic University. A chronology and downloadable papers are available from SPR Ltd. An early picture of the device, as built by SPR Ltd, is shown in Fig. 9.5. It consists of a cone frustum where a standing EM wave of frequency in the MHz range is introduced. No mass and (apparently) no radiation is released by the device, but thrust may have been measured varying between micro-N and milli-N, depending on radio frequency (RF) power applied at the experimental facility. All explanations provided so far fail to satisfy fundamental physics, such as conservation of momentum and energy, but the initial observation that thrust was measured appears inconclusive (Tajmar and Fiedler 2015). Tajmar and Fiedler conclude: *"… To this end it was successful in that we identified experimental areas needing additional attention before any firm conclusions concerning the EMDrive claims could be made. Our test campaign therefore cannot confirm or refute the claims of the EMDrive but intends to independently assess possible side-effects in the measurement methods used so far. …"* Whether or not thrust has been measured, the EmDrive experiments have made researchers invoke zero-point energy or inertia reduction for possible explanations. In an article by MacDonald (2015), Eric W. Davies, physicist at the Institute for Advanced Studies at Austin, pointed to a possible flaw in the experimental setup.

A second aspect of the existence of zero-point energy is its postulated association with gravitation. As shown in the definition of the Planck length, theories of inertia and presumed ways of reducing inertia, and of shielding or altering gravity go under the name of "electro-gravitics" breakthrough physics. In this case, the claims tend to be experimental, but most such experiments have not been independently reproduced, casting doubts on their accuracy. In this context, skepticism is in order, mainly because understanding of gravitation is incomplete (Maggiore 2007; Cook 2002; Thorne 1995). This said, the detection of gravitational waves by the team of scientists that designed and built the LIGO Laser Interferometer Gravitational-Wave Observatory) project (Overbye 2016) not only confirms the dynamic nature of space–time as postulated by Einstein, but may contribute to explain the relationship between gravitational and inertial mass. Note that no inertia "constant" exists in physics except through the puzzling equivalence between gravitational and inertial mass. As defined, the Planck length does not involve inertia.

Other energy sources have been derived by either postulating or deriving new relationships from the equations of General Relativity. To date, however, it is very difficult to check the consistency and validity of any of these developments, as they are couched in often abstruse mathematics that in most cases requires considerable analytical skills to be manipulated (if understood). Some of these predictions, if verified by experiments, would have dramatic implications not only for propulsion and space travel, but also for power generation in general. In this context, there is much anecdotal but hard-to-substantiate "evidence" on the Internet. Dr.

Fig. 9.5 EmDrive tested at SPR Ltd. *Courtesy* SPR on *left* and kindle e-book by R. Walker *right*

Martin Tajmar, now at TU Dresden (Germany), and Dr. Marc Millis, formerly at NASA, have done much to debunk the mystique and the exoteric claims of proposals to exploit breakthrough physics concepts (Tajmar 2003; Millis and Davis 2009). The effect of hypothetical gravity and inertia shielding on specific impulse of chemical rockets has also been studied (Bertolami and Tajmar 2005; Tajmar and Bertolami 2005). Curiously, in this last case, the effect has been investigated only insofar the molecular weight of the exhaust from a rocket is concerned, not the spacecraft mass itself; predictably, the impact on I_{sp} was found negligible. Nevertheless, these two references are very useful to assess the state of breakthrough physics, containing a wealth of citations of recent work on this subject. Even after much sifting, one or two experiments are still baffling, resisting explanations based on standard physics. Experimental and theoretical evidence is suggesting a fourth force, e.g., see Tajmar et al. (2008a, b). Millis and Davies (2009) critically analyze many recent theories and experiments allegedly supporting conceptual revolutionary propulsion.

Dark matter and dark energy are another source of inspiration when looking for unconventional energy. Dark matter is believed to make up to 85% of all matter in our Universe, and it is possible to conceive it as a means of propulsion. In fact, the existence of dark matter is so far presumptive, and most physicists think it is not ordinary matter at all (Hogan 2007). Dr. Marla Geha, at Yale Observatory, identified the Segue-1 dwarf spheroidal galaxy. Segue-1 has the same mass of 450,000 Suns, but is extremely dim, some 350 times less than expected, suggesting it is mostly composed of dark matter (Courtland 2008). Supersymmetry theory predicts that each particle known in the Standard Model must have a non-standard and heavier counterpart. The lightest counterpart has been named “neutralino.” When two neutralinos collide they annihilate and the decay products eventually produce high-energy electrons and positrons. Preliminary data from the European PAMELA satellite showed the ratio p^{-}/p^{+} reaching a peak 0.0002 at about 10 GeV, then declining to 0 at higher energies. One explanation was initially based on collisions between dark matter particles predicted by supersymmetry (Brumfiel 2008a, b), but the decay at high GeV eventually provided conventional explanations.

A new area of investigation in physics, negative matter, may be utilized to construct propulsion machines. Negative matter was proved to be compatible with General Relativity by Bondi (1957). That inertial matter may behave as a negative quantity, therefore accelerating in the direction opposite to applied force, has been observed for neutrons in crystals, e.g., see Raum et al. (1995). The original suggestion to build a self-accelerating mass dipole (Forward 1990) has been further developed recently by Tajmar (2014). The mass dipole consists of an ordinary (+) mass, also positively charged, and of a *negative* mass, negatively charged, connected by a spring. The Coulomb force between the two charges attracts the two masses, but because one is negative, they both accelerate in the same direction, that is, the direction going from the positive to the negative mass. If negative mass can be produced in some way, the magnitude of the effect should be quite significant, because the forces are electrostatic, not gravitational. This investigation is continuing.

Other attempts to provide solutions, or at least suggestions on how interstellar and galactic travel could be realized, consist in simplifying or modeling in a simpler way some of the results that have been extracted from General Relativity. Although the language may not be rigorous, or the description not completely consistent with the formalism of General Relativity and in any case highly speculative, these attempts are often useful as they may make easier to understand what the equations predict while possibly suggesting further avenues of investigation. For instance, the complexity of describing the Kerr–Newman solution may be simulated (albeit in one dimension) by introducing a “hyperspace,” replacing the four-dimensional metric of the field equations. This is the attempt D. Froning made in using his *K*-tau hyperspace in Sect. 9.5

9.5 Superluminal Speed: Is It Required?

At subluminal speeds (based on Newton’s Third Principle), we have shown that round-trip travel to distant galactic destinations cannot be accomplished within the lifespan of an Earth-bound project team. But what if the spacecraft can exceed the speed of light? Some investigators have postulated the possible existence of faster-than-light (superluminal) entities (Tanka 1960; Bilaniuk 1962). There is a mathematical approach to the Lorentz transformations that avoids violating Einstein’s Special Relativity and that involves introducing the imaginary square root of minus one (*i* is its mathematical symbol). The consequence is that all results become real numbers (and not complex in the mathematical sense) only if the speed of the spacecraft is *greater* than the speed of light.

If the spacecraft speed could be much greater than the speed of light, then time, the distance divided by speed, becomes vanishingly small, even over enormous distances. Thus, destinations that are millions of light-years distant from Earth could be reached in short intervals of time if the ship acceleration could be quite large and the speed of the spacecraft many times the speed of light. But even if the ship speed is many multiples of the speed of light, the duration in spacecraft time is the distance divided by the speed of light, and that determines the spacecraft time elapsed during the mission and the physical aging of the crew (Jones 1982).

Thus, even with an 80-year lifespan of the spacecraft crew, the crew could only reach and return from stars that are less than 40 light-years distant from Earth.

Then, for *less-than-light-speed* (subluminal) travel, it is the lifespan of the Earth-bound observers that is the limitation. For *greater-than-light-speed* (superluminal) travel, it is the lifespan of the spacecraft crew that is the limitation. In both cases, the limitations are equally severe. If we assume round-trip travel without a radically different approach to propulsion or to the concept of spacecraft, we are confined to the region around our Solar System. This would change drastically if interstellar travel were to be considered in the context of colonization, where trips may become one-way missions.

The passing of time within a spacecraft will appear to slow down to zero to a hypothetical "inertial" observer of the spacecraft as it reaches the speed of light. Thus, in effect, all sense of time will seem to the observer to vanish when looking at beings that reach the speed of light. But let us imagine that this vanished sense of something is replaced with something that has nothing to do with either time or distance. Although the essence of this something is as yet a postulate unknown, it has been given the designation tau (τ) (Froning 1983). Tau has no correspondence with time or distance; its essence cannot be measured in terms of spatial or temporal separations. It is a dimensionless quantity devoid of any units involving distance or time. Just as it is possible to multiply a time by a constant (such as $c \cdot t$) that gives it the unit of distance, it is also possible to multiply tau (τ) by a constant K that results in a term ($K \cdot \tau$) that is also in distance units. Although the metric of $K \cdot \tau$ can be made the same as $c \cdot t$, it must be measured along an axis that is perpendicular to the (x-$c \cdot t$)-plane, as tau represents something that is neither time nor distance, as shown notionally in Fig. 9.6.

In a sense, devising such τ is akin to simplifying the field equations of General Relativity for illustration purposes, as they cannot yet predict what really happens when a spacecraft enters and passes through the wormholes in Sect. 9.3. Since when traveling at the speed of light no apparent time elapses, the spacecraft would arrive instantly and simultaneously at all locations along the flight path. Along this path of flight, to the crew on the spacecraft all spatial separations would collapse to zero without relativistic time dilatation, as all spatial separations are transverse to the light-speed spacecraft flight. The spacecraft in effect "jumps" into a dimension "perpendicular" to the normal three spatial dimensions and time. In order to accomplish this jump, the spacecraft must achieve light speed and fly a specific flight path. There is a specific trajectory that can be determined to accomplish the jump (Froning 2003).

Thus, the first constraint to travel in this way is that the spacecraft must achieve light speed and fly a specific trajectory. In a sense, the spacecraft "soars" over space and time of the *x*-*ct* plane. The flight segment in this hyperspace can be represented as a parabolic-like trajectory over the *x*-*ct* plane and in the x-$K\tau$ plane, see Fig. 9.6. The spacecraft then returns to light speed and an inverse trajectory returns the spacecraft to the physical *x*-*ct* plane. There is no material motion associated with the spacecraft travel in the x-$K\tau$ plane, because the plane contains no time. The spacecraft travel along the x-$K\tau$ plane would be imperceptible to the slower-than-light-speed observers as the travel occurs within a plane of event/existence that is at a "right angle" to the *x*-*ct* plane. Thus, the spacecraft would disappear after reaching light speed, followed immediately by its reappearance trillions of miles away in the proximity of the target star, when the spacecraft returns to sub-light speed. As the spaceship travels in the x-$K\tau$ plane, the "unfolding of tau" is not the same as the "passage of time" in the *x*-*ct* plane. Here, our classical concept of time is perceived as an inexorable movement toward the "future" from the "past." As cited from Davies (2002), this perception has no mathematical or

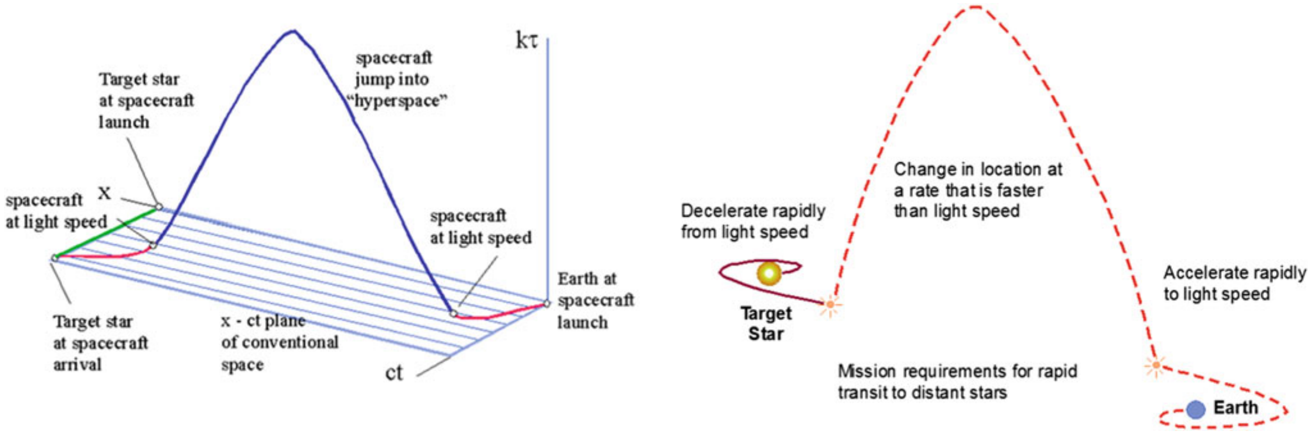


Fig. 9.6 Ship jumps out of conventional space into Einstein space–time

physically based reality. By contrast, the essence of tau must be such that $K\tau$ both increases and decreases during the spacecraft's travel in the x-$K\tau$ plane. Of course, spacecraft navigation in the x-$K\tau$ plane is impossible unless position and direction can be determined for each increment of tau, as tau unfolds with the spacecraft. Froning (1983) gives the details of the mathematical derivation of this strange journey.

With more conventional propulsion, the solution to the aging of the crew problem is to accelerate at very high rates. That, of course, would crush occupants and equipment. Trained pilots can stand a $3g$ acceleration for only ten or fifteen minutes (this was the time and acceleration sustained to orbit by the Space Shuttle during the ascent). Then, the underlying discovery that could enable deep-space exploration by both humans and machines is an anti-inertia shield, something that would reduce the inertial mass opposing acceleration. Clearly, the accelerations required to explore the Galaxy are significant. Figure 9.7 shows the effect of increasing the acceleration of the spacecraft with respect to the Earth frame of reference. A nominal 2-year trip at conventional $1g$ acceleration shrinks to a 1.7-h trip at $10{,}000g$, i.e., a reduction to one ten-millionth of the 2-year mission. With that shrinkage, the 30-year mission to the Galaxy center would take just 2.9 years! Then, the key to rapid travel to distant destination is not super light speed, but super-fast or steady accelerations (Long 2009). That requires the discovery of an anti-inertia/anti-mass system to permit the human body and physical structures to withstand such accelerations and loads.

At this point in time, no one appears to have the energy source nor the anti-inertia or anti-gravity approach that would permit such accelerations or the flight speeds that approach light speed. According to physicist and philosopher Ernst Mach's conjecture, inertia is due to the mass present in the Universe (this is *Mach's principle*). Accelerating a mass would affect all other masses via changes in gravitational forces. If so, an inertial time lag should in principle be detected moving a mass fast enough for relativistic effects to take place. Such an experiment would be hard to perform, and, if successful, would rule out any chance of finding anti-inertia or inertia-less propulsion systems. Experiments to check the Mach principle and a theory for the origin of inertia have been proposed by Woodward (2001, 2004). Other theories have proposed that inertia is due to the interaction of an accelerating mass with vacuum energy (Yam 1997; Rueda and Haisch 1998). An explanation of the *Pioneer anomaly* based on inertia modification at large scales was tested and seemed to work (McCulloch 2008) before being replaced by the more prosaic one based on the thrust due to heat radiation (Betts 2012; ten Boom 2012). Results by Woodward seem to indicate that his theoretical explanation of inertia may be right. Since it uses electromagnetism, it would open the door to anti-inertia devices based on manipulating magnetic fields.

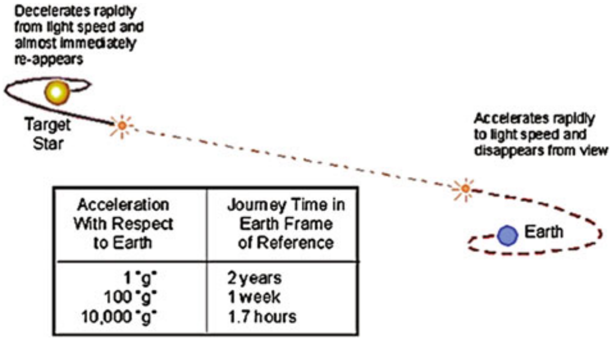


Fig. 9.7 High acceleration shortens Galactic travel times

In summary, rapid transit to distant stars and galaxies would involve the spacecraft accelerating to light speed at rates quite beyond present human or material limitations. It would require the understanding of, and then the ability to control, inertial mass. When so, the spacecraft would be disappearing from human sight. Almost "immediately," in terms of spacecraft clock, the spacecraft would reappear billions of kilometers away close to the target star or galaxy. During those moments when the spacecraft disappears, the spacecraft would have "jumped" over the so-called space–time continuum in an "arching" flight path. If theories and postulates are correct, the maximum speed necessary to achieve is, at most, light speed, and *superluminal speeds would be of no time benefit.*

If our Cosmos possess a greater spatial dimensionality than three (length, height, and width) and one-dimensional time, then a spacecraft may be able to "soar" above the time and space realm of existence and travel great distances in only the time required to accelerate to light speed and then decelerate from light speed to the target destination. The key requirement is to be able to achieve light speed and *no greater*. Clearly, there is hope that in some future time and place, a space-faring civilization might learn to journey round-trip through space to further stars.

In a similar vein, if our Universe has extra dimensions, as posited by string theory, Richard K. Obousy and Gerald B. Cleaver at Baylor University, Texas, claim that manipulating the 11th dimension in the so-called m-theory (a development of string theory), the cosmological constant could be made to change *locally* by using the Casimir effect, forcing space to "warp" (i.e., to contract) in front of a spaceship and expand behind it (Obousy and Cleaver 2008). Warping was originally put forward by the physicist Alcubierre (1994). A ship inside the warped space "bubble" would not move and would not violate the c limit. Instead, space would stream by at a speed depending on "warp" intensity. Since there is no relativistic constraint on the expansion speed of space–time, a spacecraft could arrive at its destination much faster than a light beam connecting the departure and arrival points. Calculations indicate that a 1000 m^3 warp bubble would need about 10^{28} kg of annihilating matter-antimatter to form. At the same time, the space-streaming speed would be orders of magnitude larger than c. In fact, choosing the limit value estimated for the cosmological constant (10^{40} Hz), the energy required to form the bubble would increase to 10^{99} kg of matter-antimatter, but the space-streaming speed would become $10^{32}c$. This would mean that the entire Universe could be crossed in 10^{-15} s.

If these numbers can be taken seriously, in the far future the higher dimensionality of space–time may be the true key to fast interstellar travel. If this higher dimensionality does not exist, the stupendous gulf of cosmic space appears to be an insurmountable barrier.

There is a final question that may leave a little room for doubting this pessimistic remark. Quantum mechanics *entanglement* is an *"… observed phenomenon where a physical property of a particle (or even a larger system) becomes instantly dependent on the properties that are being measured on another particle, regardless of how far apart the particles are …"* (Rudolph 2008; Albert and Galchen 2009). While entanglement does not involve matter motion, it still seems to violate the spirit of the relativistic c limit. The lower bound for the speed at which this phenomenon occurs has been estimated to be *at least* of the order of 10^4 to 10^5 c (Salart et al. 2008). Entanglement of two electrons has been experimentally confirmed at Delft University (Hensen et al. 2015). What is at the heart of this, *"… spooky action at a distance …"* as Einstein called it (Friedman 2014), is a mystery fostering hope that, at some point, the c barrier may be overcome.

9.6 Conclusions

A legitimate question is whether the ideas for traveling to destinations in our Galaxy discussed in this chapter may be considered even remotely practicable. Among facts that may give some hope, in the sense that they are promising and based on established physics, are the possible existence of wormholes and quantum entanglement, enabling intra-galactic or extra-galactic travel. Wormholes are predictable from General Relativity, and quantum entanglement has been demonstrated and is the foundation of current work on quantum computing. Furthermore, subject to progress in the physics we already have at our disposal, wormholes may be designed by again using General Relativity. As wormholes depend on the existence of black holes, they appear at the moment impossible to build in an engineering sense. However, the relative abundance of them in our Sun's immediate neighborhood gives hope appropriate ones may be found.

Skepticism concerning these concepts is justified, and this was also the case with learned savants that in the 1500s were exposed to the drawings of parachutes and flying machines by Leonardo da Vinci. Much more recently, on January 13, 1920, Robert Goddard was ridiculed by the "New York Times" when he proposed to reach the Moon using rockets (Kuntz 2001). In this age today "we know better," admire Leonardo's farsightedness, pity his naiveté, and shy away not only from his boldness, but also that prevalent in the 1950s and 1960s. With future hindsight, some of the ideas discussed about using gravitation, space–time curvature, and topology, space travel may eventually become practical. Certainly, they form the only established body of physics we can use now and for the predictable future, and they solve or bypass questions connected with time paradoxes and causality. Backed by General Relativity, it appears the precautions time travelers must take to avoid accidentally killing one's ancestors may be unnecessary. Rather than travelling in space and then putting up with, or fixing, the many problems caused by time, understanding Einstein's space–time may provide ways of reaching stars. So, the answer to the question opening this chapter and this section is, literally, *Time will tell*.

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