Appendix A Further reading

There are some non-technical books on the topic of interstellar travel. Gilster (2004) is particularly recommended, as well as Johnson (2022). Also very interesting, although now a little dated, is the slightly more technical book by Mallove and Matloff (1989). The book edited by Johnson and Roy (2024) contains some relevant chapters on propulsion, on-board power, and communication.

There are a number of relevant websites that at the time of writing are kept up to date. These include Centauri Dreams,[1] the Initiative for Interstellar Studies (in particular their magazine Principium),[2] the Interstellar Research Group,[3] and the British Interplanetary Society.[4] The latter publishes the *Journal of the British Interplanetary Society* (*JBIS*) in which many articles on interstellar travel appear. Another important journal for this field is *Acta Astronautica*,[5] although relevant articles are spread over many other journals in science and engineering. A useful resource for searching for articles and preprints in the astronomical literature is the SAO Astrophysical Data System.[6] In the following I discuss the main sources used in each chapter as well as some suggestions for further reading.

A.1 Introduction

Evans (2022) provides a detailed history of the Voyager project from precursor proposals through to the early 2020s. Bailer-Jones and Farnocchia (2019) computed the future trajectories of the Voyager and Pioneer spacecraft relative to the nearby stars. References to the Daedalus project are given in the relevant sections below.

A.2 Why travel to the stars?

Some motivations for interstellar travel are discussed by Crawford (2009). The exoplanet science cases for an interstellar spacecraft overlap significantly with the science cases for solar system missions, some examples of which are covered by the references listed under the payloads chapter below.

[1] https://centauri-dreams.org
[2] https://i4is.org
[3] https://irg.space
[4] https://bis-space.com
[5] https://sciencedirect.com/journal/acta-astronautica
[6] https://ui.adsabs.harvard.edu

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

A comprehensive overview of exoplanets and observation techniques is given by Perryman (2018). For a review of exoplanet statistics see Zhu and Dong (2021), although this field is developing quickly. Optical and infrared interferometry is reviewed by Eisenhauer et al. (2023). Space-based interferometry to obtain spectra of rocky exoplanets could be done by the proposed LIFE (Large Interferometer For Exoplanets) mission (Quanz et al. 2018). A milestone paper on the concept of the habitable zone is Kasting et al. (1993). An important update to this was made by Kopparapu et al. (2013), from which I take my definition. Biosignatures and their measurement are discussed by Kiang et al. (2007), Kaltenegger (2017), Meadows et al. (2018), and Schwieterman et al. (2018).

To compile the list of the nearest stars in table 2.1, I started with the CNS5 catalogue of nearby stars of Golovin et al. (2023) then cross-checked against other sources. For the list of planets in this table, I started with Reylé et al. (2021) then updated it with more recent publications on exoplanets around nearby stars. Rather than listing the many articles claiming, confirming, or refuting exoplanet detections, I refer the reader to the NASA exoplanet archive,[7] which compiles much of the information on the planets discussed in section 2.5.1.

Data for the Alpha Centauri system in section 2.5.2 are taken preferentially from Akeson et al. (2021). Dumusque et al. (2012) claimed to have detected a planet around Alpha Cen B via the radial velocity method, but the signal was weak, and later reanalyses of the data show it was probably a false detection (Hatzes 2013; Rajpaul et al. 2016). Some limits on possible planets based on non-detections are given by Zhao et al. (2018). The planet Proxima Cen b was discovered by Anglada-Escudé et al. (2016). The additional candidates c and d were reported by Damasso et al. (2020) and Faria et al. (2022), respectively.

The solar gravitational lens has been explored in some detail by Turyshev and Toth (2020). Helvajian et al. (2023) describe a possible mission to exploit it. The Pioneer anomaly is described by Anderson et al. (1998), and support for the anisotropic radiation solution is presented by Turyshev et al. (2012). References on the science of the heliosphere and the ISM can be found under the interstellar medium chapter below.

A.3 Rockets

The classical rocket equation and its application to rocketry is generally attributed to Konstantin Tsiolkovsky (1857–1935) in 1903 (reprinted in Tsiolkovsky 2004), although it was independently derived in the early twentieth century by other early rocket pioneers such as Hermann Oberth (1884–1989), Robert Esnault-Pelterie (1881–1957), and Robert Goddard (1882–1945). As early as 1810, William Moore (dates unknown) had described rockets and arrived at a closely related expression (Moore 1810). There are some variations on the derivation of the rocket equation in the literature. One can debate whether the velocity of dm relative to the rocket should be $V + dV - v_e$ rather than $V - v_e$ in equation 3.1a (Pinheiro 2004 argues for this), in which case $dVdm$ cancels instead of having to be neglected. But as we are dealing with differentials, it makes no difference for our case. The variable v_e 'perfect' rocket is discussed by Gowdy (1995). The instantaneous and discrete rocket equations are analyzed by Blanco (2019). Two general books on rockets are Turner (2009) and Walter (2018).

[7] https://exoplanetarchive.ipac.caltech.edu/index.html

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

A.4 Orbital mechanics

I cover only the basics of orbits along with some specific details used in later chapters. There are many books and pedagogical articles on various aspects of orbits. A good general reference is Curtis (2014).

In discussing the escape velocity as a function of planet size, I have made a number of crude approximations, such as very fast mass expulsion from the rocket and a fixed mass–radius relation for planets. These issues are addressed in more detail in several papers, in particular Gonzalez (2020).

The Hohmann transfer is named after the engineer Walter Hohmann (1880–1945), who published it in Hohmann (1925). The principle of the Oberth effect was published by Hermann Oberth in Oberth (1929). Orbital escape manoeuvres with two and three boosts are analyzed by Blanco and Mungan (2021). In my discussion of the efficiency of the bielliptic transfer orbit vs the simpler Hohmann transfer, I have used the threshold values from Curtis (2014). Technical details of the Voyager 2 gravity assists at the outer planets can be found in Cesarone (1989).

A.5 Thermal rockets

General overviews of thermal rocket engines can found in Turner (2009) and Walter (2018). The former also discusses propellants. Isentropic flows and the convergent–divergent nozzle are discussed in most text books on aerodynamics, such as Anderson (2016). Tajmar (2003) and Frisbee (2003b) discuss advanced propellants such as atomic or metallic hydrogen. Details of the Saturn V and Ariane 6 rockets can be found on the NASA and ESA websites.

A.6 Ion engines

My presentation of the principle of the gridded ion engine follows that given by Turner (2009). The Dawn ion propulsion system using NSTAR is described by Brophy (2011). More details of the Dawn spacecraft can be found in Thomas et al. (2011). Some of the variants on ion engines are discussed by Frisbee (2003b). An early paper for using nuclear electric propulsion for interstellar missions is Aston (1986).

A.7 Relativistic motion

There are many text books on special relativity at a range of levels with diverse approaches. Readers are advised to try out different ones if any one doesn't meet their needs. Some texts do not cover acceleration, which may explain the widespread misconception that special relativity does not apply to accelerating systems. There are also many didactic articles in

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

the literature explaining various aspects or promising new insights. An excellent article that inspired my coverage of the journey to Alpha Cen is Müller et al. (2008).

The relativistic rocket equation goes back at least to Robert Esnault-Pelterie in 1928, but a more general derivation was provided by Ackeret (1946). There are several other derivations, including those of Forward (1995) and Walter (2018) (their section 1.4). The proper speed (rapidity) is discussed by Walter (2006). My discussion of the general matter–photon rocket draws on material from Walter (2006), Westmoreland (2010), and Walter (2018) (their sections 1.4.2 and 1.4.3). An earlier presentation along similar lines can be found in Vulpetti (1985). Note that Westmoreland (2010) identified an error in Walter (2006) in the derivation of the effective exhaust velocity. The latter neglected the factor of γ_m in the momentum of the matter particles in equation 7.36. This is corrected in section 1.4 of Walter (2018). Frisbee (2003a) claims that the relativistic rocket equation itself, and not just the expression for effective exhaust velocity, is different when there are mass losses, but they don't expand on the claim, which is criticized by Niang (2020).

A.8 Nuclear rockets

The data quoted for the uranium-235 reaction is from De Sanctis et al. (2016).

The NERVA programme is described in various technical reports available online, such as Robins and Finger (1991). Its predecessor project, ROVER, is described by Finseth (1991). Liquid and gas core nuclear thermal rockets are discussed by Thomas et al. (2021) and Frisbee (2003b), respectively. My outline of fission fragment rockets is based on Clark and Sheldon (2005) and Werka et al. (2012). An earlier description with a different design was given by Chapline et al. (1988).

Fission pulse rockets are described in various technical reports and articles, such as Platt and Hanner (1965) (which was originally classified), Martin and Bond (1979), and Schmidt et al. (2000) (the source of my quoted v_e values). The latter two also give a historical review of NASA's Project Orion. Platt and Hanner (1965) and Martin and Bond (1979) argue that the internal combustion arrangement – detonating nuclear bombs within your spacecraft – would be infeasible.

Further details of the fusion reactions I discuss can be found in any good textbook or review article. Ball (2019) discusses in greater depth the catalyzed deuterium reaction for use in rockets. Wittenberg et al. (1992) outline the sources of helium-3 from the Earth and Moon and how to extract it.

While various governments are investing in fusion projects, the most noteable being ITER [8] there are numerous commercial ventures. Their approaches and status are reviewed by Meschini et al. (2023)

There were various designs for the fusion pulse rocket Daedalus. My description uses data from Bond and Martin (1978) and Long et al. (2011). Long (2022) reviews concepts for fusion engines that use inertial confinement fusion, including the lower-mass Icarus design mentioned in the chapter, and provides many references on earlier studies. The z-pinch variation of Icarus is described by Freedland and Lamontagne (2015). The direct fusion drive

[8] https://iter.org/

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

is described in several articles, including Razin et al. (2014) and Cohen et al. (2019). There is little concrete material available on either the helicity drive or the fusion drive rocket, but some details are available from You (2020) and Slough (2024), respectively (both conference proceedings).

My derivation of the effective exhaust velocity for the antimatter (hydrogen–antihydrogen) rocket follows Westmoreland (2010) using data from Frisbee (2003a). Antimatter rockets (including thrust augmentation) were explored in some detail in a series of articles in *JBIS* in 1982, in particular Cassenti (1982), Forward (1982), and Morgan (1982). A more recent reference is Semyonov (2014). An approach to using antimatter-induced fission to decelerate a spacecraft is discussed by Jackson (2022).

A.9 Relativistic optical effects

Derivations of aberration and the Doppler effect can be found in many textbooks. My derivations are inspired by those in Christodoulides (2016). Greber and Blatter (1990), Lagoute and Davoust (1995), and Kraus (2000) discuss several of the optical effects I discuss in this chapter. Kraus (2000) provides a good derivation of the brightness effects (spectral radiance etc.).

Different authors use different conventions for the definition of the direction angle (α in my notation), namely whether it is the direction from the source to the observer or vice versa. The angle can therefore differ by 180°, which results in a difference in the sign before the cosine of the angle.

The Terrell–Penrose rotation is named after the works of Terrell (1959) and Penrose (1959). Kraus (2000) shows that it is often unobservable in practice. Beig and Heinzle (2008) examine in detail the counter-intuitive effects of aberration on the appearance of an object as an observer accelerates away from it. Greber and Blatter (1990) and Yurtsever and Wilkinson (2018) show the impact of aberration and the Doppler effect on the appearance of the cosmic microwave background.

A.10 Solar sails

There are a lot of books and articles on solar sailing. A good overall reference for many aspects is McInnes (1999). This, as well as McInnes and Brown (1990), discuss the impact of the extended size of the Sun on a sail's dynamics.

The logarithmic spiral orbit dates back at least to 1959 (Bacon 1959, Tsu 1959) and is further covered by Bassetto et al. (2018), McInnes (1999), and other authors. Tsu (1959) also mentions briefly the energy of this non-Keplerian orbit. McInnes (1999) gives the expression linking γ to α and λ. Bailer-Jones (2021b) examines the sundiver combined with the Oberth effect.

Forward (1990) looks at imperfectly reflecting (grey) solar sails in some detail. Sail material properties is a very active area of research, with many publications. Kezerashvili

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

(2008) looks at the skin depth and the thickness of metallic sails. References discussing non-conducting sail materials are given in the chapter on laser sails below.

The LightSail 2 mission is described by Spencer et al. (2021). A summary of the experience from the DLR Gossamer programme is given by Spietz et al. (2021). The IKAROS mission is described by Tsuda et al. (2013); more information can be found on the eoPortal website.[9] JPL's concept for a large interstellar sail is described by Liewer et al. (2000), and ESA's heliopause probe is presented by Lyngvi et al. (2005). Macdonald (2014) provides a collection of articles on various aspects of the science and technology of sails. Ancona and Kezerashvili (2024) review some more recent developments presented at an international solar sailing conference in 2023, and Turyshev et al. (2023) discuss some of the science that can be done in and near the solar system with solar sailcraft.

A.11 Laser sails

The literature on laser sails goes back to not long after the development of the first lasers in the 1950s. Ever since, there have been debates in the literature about both the exact mathematical expressions and the interpretations of the phenomena. As this can be confusing for someone new to the field, I try now to give some overview.

In 1966, Marx published a paper on the basic principle of a laser-propelled sail and derived an expression for the efficiency of the energy transfer (Marx 1966). A year later, Redding claimed in a half-page response paper that Marx had made an error (Redding 1967). More than two decades after this, Simmons and McInnes (1993) published a terse but detailed derivation of the sail kinematics that leads to the expression for the velocity of the sail in terms of the energy supplied (equation 11.7) and the equation of motion in terms of retarded time (equation 11.25). The authors of this paper denounced Redding's correction of Marx as 'nonsensical', attributing it to Redding having mixed up coordinate time and retarded time. They state that Marx's mathematical solution was right, but for the wrong reasons, and go on to provide a corrected interpretation.

Another two decades later, Kipping (2017) examined the basic physics of laser sail kinematics and claimed that the results in an earlier paper – Kulkarni et al. (2016) – had assumed the incident and reflected photon energies were equal, thus leading to a 10% error in the final velocity of the sailcraft. The authors of the 2016 paper refuted this in Kulkarni et al. (2018) and gave a more detailed analysis of the problem, highlighting the error in the criticism, which was again related to mixing up coordinate and retarded time. Kipping conceded the error in an erratum (Kipping 2018). My derivation in section 11.1.3 does not assume the reflected photon has the same energy as the incident photon (see equation 11.12). Parkin (2018) too published a detailed analysis of laser sail kinematics. Both this paper and Kulkarni et al. (2018) agree on the equation of motion in terms of coordinate time (equation 11.16), and the latter paper also gives its integral explicitly (equation 11.19). Parkin (2018) goes on to use this model to describe the kinematics of a laser-accelerated sail in some detail, some of which I summarize in the chapter. (This model was updated and extended in Parkin 2024.) This paper also makes some economic calculations and sail optimizations.

[9] https://eoportal.org/satellite-missions/ikaros

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

My derivations of the laser sail kinematic equations in chapter 11 are based on – and are a synthesis of – Simmons and McInnes (1993), Kulkarni et al. (2018), and Parkin (2018). Kulkarni et al. (2018) extend my results in section 11.1.4 to take into account diffraction losses in a simplified way. Diffraction losses, also for synthesized apertures, are treated in more detail by Haas (2025).

A review of optical and infrared interferometry as used in astronomy is given by Eisenhauer et al. (2023). Aperture synthesis is discussed more specifically by Saha (2011), and Davies and Kasper (2012) review adaptive optics in astronomy. Peretz et al. (2022) discuss the idea of using an orbiting laser beacon to correct the atmospheric distortions when synthesizing a large laser aperture on the Earth's surface.

The properties of various candidate materials for laser sails are discussed by Matloff (2013) (graphene), Hein et al. (2017) (layered dielectrics), Mecklenburg et al. (2012) (aerographite), and Atwater et al. (2018) and Brewer et al. (2022) (2D photonic crystals). The stability and optimal shape of sails is discussed by several authors, for example, Popova et al. (2017), Gao et al. (2024), and Campbell et al. (2022). The last of these looks into an overall optimization of the curvature of a spherical sail together with other characteristics of the sail and laser system.

The mission concepts or sail designs mentioned in the chapter are described in Frisbee (2004), Hein et al. (2017), Parkin (2018), and Häfner et al. (2019). The Project Dragonfly competition workshop is summarized on the Initiative for Interstellar Studies website.

A number of other authors have published analyses of laser sails, either theory or specific mission profiles, including Forward (1984), Perakis et al. (2016), and Lubin (2016) (see also the two-volume mathematical book of Lubin 2022a,b). Some more advanced considerations are contained in Fuzfa et al. (2020). The idea for braking at the target star using a separable outer sail comes from Forward (1984), and the photo-gravitational assists for deceleration in the Alpha Cen system are studied by Heller and Hippke (2017).

A.12 The interstellar medium

The properties of the solar wind are summarized by Kallenrode (2004) and Owens (2020). More background material on the heliosphere and its boundary to the ISM appears in the review article by Zank (2015), and details on the ISM near to the Sun are provided by Crawford (2011) and Frisch et al. (2011). The quoted space density estimate of ISOs of $0.2\,\mathrm{au}^{-3}$ was derived by Do et al. (2018). The Voyager 1 crossing of the heliopause is reported by Gurnett et al. (2013). Articles that describe some of the science studies that an interstellar spacecraft could undertake of the heliosphere, its boundaries, and nearby interstellar space include McNutt et al. (2019), Brandt et al. (2022), and Brandt et al. (2023).

The relativistic stopping formula was derived by Bethe (1930); an earlier non-relativistic version was derived by Niels Bohr (1885–1962). For plotting figure 12.4 I adopt the same dependence of I on Z as used by Lubin et al. (2022). My consideration of the damage done by ions and dust particles to an interstellar spacecraft draws on results presented by Hoang et al. (2017) and London and Early (2018). Early and London (2000), Lubin et al. (2022), and Long (2023) also discuss impacts. Martin (1972) and Hoang (2017) consider in more detail the drag caused by ISM particles.

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

The Bussard ramjet is named after Robert Bussard (1928–2007), who first introduced the idea in Bussard (1960). My treatment of the ramjet's acceleration follows that of Blatter and Greber (2017), with some minor changes in the derivations. Semay and Silvestre-Brac (2004) go into more mathematical depth for the mass jet case, giving also the analytic expressions for the time and distance. Schattschneider and Jackson (2022) examine using a magnetic scoop to collect ISM particles (referred to as the Fishback ramjet). Whitmire (1975) discusses using the CNO cycle and the electromagnetic recovery of the kinetic energy of the ISM.

A.13 Magnetic and electric sails

The dipole magnetic sail was introduced by Andrews and Zubrin (1990). Its general concept and use are described by Zubrin and Andrews (1991), Funaki and Yamakawa (2009, 2012), Gros (2017), and Djojodihardjo (2018). My derivations follow the more comprehensive mathematical treatment in Freeland (2015), who also comments on the results derived in several of the earlier papers. The numerical values in section 13.1.2 are taken from Zubrin and Andrews (1991). Häfner et al. (2019) looked at using a magnetic sail to decelerate a high-mass laser sail.

The M2P2 concept was introduced by Winglee et al. (2000) and criticized by Khazanov et al. (2005). Other authors also conclude the M2P2 acceleration would be much less than claimed, because much of the momentum from the solar wind is lost by accelerating the plasma instead of the spacecraft.[10] Further development of the M2P2 concept has been carried out by Funaki and Nakayama (2012).

Electric sails were introduced by Janhunen (2004). My presentation of the theory is based on Janhunen and Sandroos (2007); see also Janhunen et al. (2014). A follow-up study by Janhunen (2009) found that the thrust may be five times higher than the model on which I base my results. Wiegmann (2017) outlines a concept for an electric sail accelerated by the solar wind to explore the outer solar system.

Perakis and Hein (2016) compare magnetic and electric sails and using them together for braking with the ISM. The combined effect of photon radiation pressure and magnetic fields for decelerating a charged interstellar spacecraft is analyzed by Forgan et al. (2018).

A.14 Navigation

For some historical background on navigation on the Earth, Alder (2014) gives an excellent account of mapping France by triangulation in the late eighteenth century.

The DOR and delta-DOR techniques are covered by a number of papers, for example James et al. (2009) and Iess et al. (2014). Some more history and technical details are given by Curkendall and Border (2013). The navigation of New Horizon's flyby of Pluto is described in Miller et al. (2005).

[10] For example https://space.fmi.fi/~pjanhune/papers/eMPii_final_1.3.pdf

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

The Gaia satellite has measured accurate parallaxes (as well as proper motions and radial velocities) for hundreds of millions of stars. The content of its third data release is summarized in Gaia Collaboration (2023). The technique of astrometric star navigation to determine the position and velocity of a relativistic spacecraft in interstellar space (section 14.4) from the angular separation of stars (or their radial velocities) is described and simulated by Bailer-Jones (2021a) (see also Yucalan and Peck 2021). A non-relativistic demonstration of this using observations from New Horizons when it was 47 au from the Sun is described by Lauer et al. (2025). Estimating just the velocity from aberration is investigated by Christian (2019) for the case of a spacecraft near to the Sun, and by Calabro' (2011) when using distant quasars.

A lot has been written about pulsar navigation, for example Sheikh et al. (2006), Becker et al. (2013), and Shemar et al. (2016). The pulsar navigation results that I report are from Shemar et al. (2016), Huang et al. (2019), and Yu et al. (2020). Ashby (2002) provides a non-technical overview of GNSS.

A.15 Communication

Various derivations of the Friis transmission equation can be found in the literature. They make a range of assumptions – perhaps implicit – and sometimes end up with different numerical factors, but all agree on the general dependencies. The correction for relative motion detailed in section 15.2 is only mentioned by a few authors, such as Parkin (2020).

Modulation methods are discussed in standard texts on signal processing. A foundational paper on information theory is Shannon (1948) and a good introduction to information theory and error-correcting codes is given by MacKay (2003). Moision and Farr (2014) show that the $1/r^2$ dependence of the channel capacity with distance r, as expected from the Friis transmission equation, can degrade to $1/r^4$ under certain circumstances.

The technique of coronagraphy is described by Rouan (2011) and Kenworthy and Haffert (2025). An example of its use to look for faint sources – in this case exoplanets – near Proxima Cen is reported in Gratton et al. (2020).

Early work on the introduction of quantum effects into information theory was done by Gordon (1962). Giovannetti et al. (2013) and Giovannetti et al. (2014) summarize the Holevo formulation for the channel capacity in the limit of photon counting. Farr et al. (2013) and Kanth Dacha et al. (2025) demonstrate achieving 10–15 bits of information per incident photon. The latter give more background on the quantum information paradigm and on using PPM for low photon rate communication. Several papers discuss the application of the Holevo bound for interstellar communications, including Hippke (2019) and Messerschmitt et al. (2023).

Single photon counting for optical communication between the Earth and an orbiting satellite was demonstrated by Villoresi et al. (2008). Biswas et al. (2024) summarize the optical communication channel using the DSOC on the Psyche satellite, which has since sent optical signals back to the Earth from a distance of 3 au.

Measurements of the brightness of emission sources from and beyond the Earth's atmosphere across the spectrum are presented by Leinert et al. (1998). Sources of airglow are discussed by von Savigny (2017).

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019

Interstellar communications are discussed in numerous papers. Fridman (2011) and Shostak (2011) both discuss the application of the Friis transmission equation and the Shannon–Hartley theorem, as does Messerschmitt (2015), who also looks at the energy requirements and discusses channel coding. Messerschmitt et al. (2020b) provide an overview of the challenges of communication from a low-mass spacecraft.

The communications system of the New Horizons spacecraft is summarized by Fountain et al. (2008). The communication concept for Icarus is presented by Milne et al. (2016). Their optical alternative for Icarus evolves an earlier concept of Lesh et al. (1994) developed for Daedalus. Those concepts more appropriate for lighter sailcraft mentioned in the chapter are summarized by Parkin (2020), Lubin (2016), and Hippke (2019). Bazzani et al. (2023) outline the use of a phased array antenna as an optical transmitter on the spacecraft.

A.16 Payloads

The following articles summarize the science instruments carried by various interplanetary missions: Cardesin-Moinelo et al. (2024) (Mars Express); Pappalardo et al. (2024) (Europa Clipper); Grasset et al. (2013) (JUICE, to Jupiter and its moons); Weaver et al. (2008) (New Horizons to Pluto and the Kuiper belt). The instruments suggested for an interstellar precursor mission to explore the heliosphere and the nearby ISM are described by Brandt et al. (2023).

The idea of relay spacecraft is investigated by Messerschmitt et al. (2020a). One proposal for a swarm of satellites to synthesize a large transmitting aperture is presented in Eubanks et al. (2023). Nesnas et al. (2021) discuss past and future automation in solar system missions.

A.17 Outlook

The Alcubierre warp drive was introduced by Alcubierre (1994). Bobrick and Martire (2021) generalize the concept and discuss some alternative relativistic solutions, including a subluminal warp drive that works with a positive energy density. An accessible account of black holes and wormholes is given by Morris and Thorne (1988); this provided the means of travel in Carl Sagan's novel *Contact*. Lingam and Loeb (2020) investigate deploying electric sails and light sails near to extreme astrophysical objects as a means of achieving large velocities. Tajmar et al. (2022) give an overview of the theory and claimed measurement of one type of propellantless propulsion concept (the EMDrive), and provide an experimental refutation. The final chapter of Tajmar (2003) looks briefly at some breakthrough propulsion ideas.

The progress or incentive trap in the context of interstellar travel is discussed by Kennedy (2006).

Some ideas for interstellar precursor missions include: a 2 m-sized chemical rocket-propelled spacecraft to explore the heliosphere out to 550 au over a period of 50 years (Brandt et al. 2023); a solar sail made of aerographite that travels to Pluto's orbit within three years (Heller et al. 2020); laser sails that travel to Mars within a few days (Lubin and Hettel 2020); and solar and laser sails to chase interstellar objects (Lingam et al. 2023).

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 17 Nov 2026 at 21:10:57, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009700429.019