Traveling to another body in our Solar System requires an immense amount of planning, preparation, and resources. When plotting the Journey to the Moon in the 1960s, NASA committed to years of research and development, studying not only spacecraft designs, but also mission profiles. All of this culminated in the creation of all the necessary components that led to the historic Moon Landing on July 20th, 1969. With our eyes now fixed on Mars and other planets in the Solar System, similar planning has to be made.

When plotting a journey to Earth's only satellite - which lies at an average distance of 384,399 km (238,854.5 mi) from Earth - required a huge commitment in resources and energy. Mars, on the other hand, made its closest approach to Earth in 2003, at a distance of 56 million km (34.8 million mi). Because of this, getting there will be much more taxing. So the question is, when looking to Mars and beyond, how much energy will it take for a spacecraft to make the journey?

Potential Targets:

As mentioned already, Mars and Earth were at their closest in 2003. But due to the nature of our orbits around the Sun - Earth's being interior to Mars, and Mars having an eccentric orbit around the Sun - this distance varies considerably. The two planets make their closest approach - what is called "opposition" - every 26 months, when Mars is at perihelion (closest to the Sun) and Earth is at aphelion (farthest).

At this time, they can be as close as 55 million km, which is why space agencies try to take advantage of this window to launch missions to the Red Planet. On the other side of things, Earth and Mars are at their greatest distance from each other when their positions are reversed - Earth being at perihelion and Mars at aphelion. At this point, which described as the planets being at "conjunction", Earth and Mars are a distance of 225 million km (140 million mi).

However, Mars is not Earth's closest neighbor. That honor goes to Earth's "Sister Planet", Venus, which lies at a distance of 41 million km (25.5 million mi) when it is at its closest. This happens when Venus orbits between Earth and the Sun - what is an inferior conjunction - which occurs every 584 days (1.6 years). When Venus and Earth are on
opposite sides of the Sun - a superior conjunction - they are nearly 257 million km (159.7 million mi) apart. Because of this, Venus would not only take less time and energy to travel to, but the launch windows would occur more often.

Mercury is similarly located between earth's orbit and the Sun, which means its distance varies between it being at an inferior and a superior conjunction. At an inferior conjunction, Earth and Mercury are an average of km 77.3 million km (48 million mi). When it is at superior conjunction, it is 221.9 million km (137.88 million mi). Mercury is at an inferior conjunction to Earth every 116 days, or approximately once every four months.

Next up, Jupiter, king of the planets! As an planet of the outer Solar System, its distance from Earth is significantly greater than any of the inner Solar plants. Case in point, when Jupiter and Earth are at their closest (opposition), Jupiter is at an average distance of 588.5 million km (365.68 million mi) from us.

That's over twice as far as Mercury and Mars are at their most distant. And when it is at its most distant (conjunction), it is 968.1 million km (601.55 million mi). However, despite its distance and its rather wide orbit around the Sun, it only takes about 399 days (1.09 years) for it to experience a conjunction with Earth. This would allow for a decent launch window, provided a ship can get their speedily to catch Jupiter before it moves too far away.

Saturn, another gas giant prominently occupying the outer Solar System, takes slightly less than a year to experience a conjunction with Earth. At its closest, it is 1195.5 million km (742.85 million mi) from Earth; and at its most distant, it is 1.658 billion km (1.03 billion mi) distant. Again, a relatively good launch window, but the distances involved complicate things.

When we get to the gas/ice giants, things become even more interesting. At its closest to Earth, Uranus is an average of 2.58 billion km (1.604 billion mi) distant, which only occurs once every few decades. At its greatest distance, Uranus is 3.157 billion km (1.96 billion mi) from Earth.

Neptune, the most distant of the planets, is a whopping 4.3 billion km (2.67 mi) from Earth when it is at opposition, which takes 367.5 days on average. When it is at conjunction, that distance does not vary significantly, reaching a distance of 4.7 billion km (29.2 billion mi) from Earth.
Animated diagram showing the spacing of the Solar Systems planet’s, the unusually closely spaced orbits of six of the most distant KBOs, and the possible “Planet 9”. Credit: Caltech/nagualdesign

To break these numbers down, no planet is ever at the same distance from Earth at any given time. The fact that they are also revolving around our Sun means their distance from us varies considerably, which in turn means we cannot travel to them in a straight line. Hence why missions to distant planets often have to take indirect routes, and rely on "gravity assists" from other planets.

**Potential Methods:**

Thanks to decades of space exploration, we have a pretty good framework for determining how much energy it would take to get to neighboring planets. Essentially, we have sent missions to every planet that orbits the Sun, and even some of the dwarf planets and moons. So determining how much energy would be involved using current methods involves very little guess-work.

For the record, when we talk about potential methods, we are talking about those that either rely on existing technology, or those that do not yet exist, but are technically feasible. In just about all cases, they present a possible, but time-consuming means of
getting to another planet. How much energy they will consume in the process, that depends on the method.

**Conventional Rockets:**

This form of propulsion, which is the most time-honored and widely used, involves igniting solid or liquid chemical propellants, and then channeling the resulting combustion through nozzles to generate thrust. It was this very technology that powered the Saturn V rockets and the spacecraft that were used by the Apollo Program to put astronauts on the Moon also relied on a combination of chemical and liquid propellants.

For instance, the first stage of the Saturn V used a combination of refined kerosene and liquid oxygen, while its upper stages used liquid hydrogen. The Command/Service and Apollo Modules - which made the flight to the Moon and landed the crew on the surface - relied on a series of jets that used a combination of chemical propellant and oxidizer, as well as stored helium to pressurize them. Using this technology, the Apollo 11 mission took about three days, launching on July 16th and achieving orbital insertion on July 19th, 1969.

A more contemporary example of this would be the engine system on the New Horizons mission – which consisted of 16 thrusters fueled with hydrazine monopropellant. Using this technology, New Horizons reached the Moon in a mere 8 hours and 35 minutes before heading off towards Pluto.
The New Horizons probe also passed the orbit of Mars on April 7th, 2006 (79 days after launch) while the probe was moving at a speed of roughly 21 km/s (76,000 km/h; 47,000 mph). It then reached the Jovian system in 2007, where it conducted a close flyby to pick up a gravity boost on its way to Pluto. Its closest pass to Jupiter happened on February 28th, 2007 - roughly 1 year, 5 weeks and 5 days (405 days) after launch.

Similarly, the Voyager 1 mission launched from earth on September 5th, 1977 and arrived around Jupiter on March 5th, 1979. All told, it took the spacecraft 1 year and 26 weeks (547 days) to make the trip. Voyager 2 launched a few months later, on August 20th, 1977, and arrived around Jupiter on July 9th, 1979 - 1 year, 10 months, and 19 days (688 days).

**Ionic Propulsion:**

Currently, ionic propulsion is the slowest form of propulsion, but also the most fuel-efficient. And its only been in recent years that the technology to support ion engines has moved from theory to practice. A good example of this is the ESA’s SMART-1 mission, which successfully completed its mission to the Moon after taking a 13 month spiral path from the Earth.

SMART-1 used solar powered ion thrusters, where electrical energy is harvested from its solar panels and used to power its Hall-effect thrusters. Only 82 kg of xenon propellant was used to propel SMART-1 to the Moon. 1 kg of xenon propellant provided a delta-v of 45 m/s. This is a highly efficient form of propulsion, but it is by no means fast.
Ionic propulsion is currently the slowest, but most fuel-efficient, form of space travel.

Credit: NASA/JPL

One of the first missions to use ion drive technology was the Deep Space 1 mission to Comet Borrelly that took place in 1998. DS1 also used a xenon-powered ion drive, consuming 81.5 kg of propellant. Over 20 months of thrusting, DS1 was managed to reach a velocity of 56,000 km/hr (35,000 miles/hr) during its flyby of the comet.

And then there was NASA's Dawn mission, which relied on an ion engine similar to the SMART-1 mission to reach the Asteroid Belt. After launching from Earth on September 27th, 2007, the probe achieved an orbit around Ceres on March 6th, 2015 - 7 years 25 weeks (2555 days) later.

Ion thrusters are more economical than rockets, as the thrust per unit mass of propellant (a.k.a. specific impulse) is far higher. But it takes a long time for ion thrusters to accelerate spacecraft to any great speeds, and the maximum velocity it can achieve is dependent on its fuel supply and how much electrical energy it can generate.

**Gravity Assist Method:**

The fastest existing means of space travel is known the Gravity Assist method, which involves a spacecraft using the relative movement (i.e. orbit) and gravity of a planet to alter its path and speed. Gravitational assists are a very useful spaceflight technique, especially when using the Earth or another massive planet (like a gas giant) for a boost in
velocity.

Artist’s concept of Voyager 1 in interstellar space. Credit: NASA/JPL-Caltech

The Mariner 10 spacecraft was the first to use this method, using Venus’ gravitational pull to slingshot it towards Mercury in February of 1974. In the 1980s, the Voyager 1 probe used Saturn and Jupiter for gravitational slingshots to attain its current velocity of 60,000 km/hr (38,000 miles/hr) and make it into interstellar space.

However, it was the Helios 2 mission – which was launched in 1976 to study the interplanetary medium from 0.3 AU to 1 AU to the Sun – that holds the record for highest speed achieved with a gravity assist. At the time, Helios 1 (which launched in 1974) and Helios 2 held the record for closest approach to the Sun. Helios 2 was launched by a conventional NASA Titan/Centaur launch vehicle and placed in a highly elliptical orbit.

Due to the large eccentricity (0.54) of the 190 day solar orbit, at perihelion Helios 2 was able to reach a maximum velocity of over 240,000 km/hr (150,000 miles/hr). This orbital speed was attained by the gravitational pull of the Sun alone. Technically, the Helios 2 perihelion velocity was not a gravitational slingshot, it was a maximum orbital velocity, but it still holds the record for being the fastest man-made object regardless.

Nuclear Thermal and Nuclear Electric Propulsion (NTP/NEP):

Another possibility for interstellar space flight is to use spacecraft equipped with nuclear engines, a concept which NASA has been exploring for decades. In a Nuclear Thermal Propulsion (NTP) rocket, uranium or deuterium reactions are used to heat liquid hydrogen inside a reactor, turning it into ionized hydrogen gas (plasma), which is then channeled
through a rocket nozzle to generate thrust.

![Artist's concept of a Bimodal Nuclear Thermal Rocket in Low Earth Orbit. Credit: NASA](image)

A Nuclear Electric Propulsion (NEP) rocket involves the same basic reactor converting its heat and energy into electrical energy, which would then power an electrical engine. In both cases, the rocket would rely on nuclear fission or fusion to generates propulsion rather than chemical propellants, which has been the mainstay of NASA and all other space agencies to date.

Compared to chemical propulsion, both NTP and NEC offers a number of advantages. The first and most obvious is the virtually unlimited energy density it offers compared to rocket fuel. In addition, a nuclear-powered engine could also provide superior thrust relative to the amount of propellant used. This would cut the total amount of propellant needed, thus cutting launch weight and the cost of individual missions.

Although no nuclear-thermal engines have ever flown, several design concepts have been built and tested over the past few decades, and numerous concepts have been proposed. These have ranged from the traditional solid-core design – such as the Nuclear Engine for Rocket Vehicle Application (NERVA) – to more advanced and efficient concepts that rely on either a liquid or a gas core.

However, despite these advantages in fuel-efficiency and specific impulse, the most sophisticated NTP concept has a maximum specific impulse of 5000 seconds (50 kN·s/kg). Using nuclear engines driven by fission or fusion, NASA scientists estimate it would could take a spaceship only [90 days to get to Mars](https://example.com/mars-trip-duration) when the planet was at “opposition” – i.e. as close as 55,000,000 km from Earth.
Electromagnetic (EM) Drive:

Another possible method of travel comes in the form of the Radio Frequency (RF) Resonant Cavity Thruster, also known as the EM Drive. Originally proposed in 2001 by Roger K. Shawyer, a UK scientist who started Satellite Propulsion Research Ltd (SPR) to bring it to fruition, this drive is built around the idea that electromagnetic microwave cavities can allow for the direct conversion of electrical energy to thrust.

Whereas conventional EM thrusters are designed to propel a certain type of mass (such as ionized particles), this particular drive system relies on no reaction mass and emits no directional radiation. Such a proposal has met with a great deal of skepticism, mainly because it violates the law of Conservation of Momentum – which states that within a system, the amount of momentum remains constant and is neither created nor destroyed, but only changes through the action of forces.

However, experiments conducted in the past few years have apparently yielded positive results. Based on calculations performed using the NASA prototype, which yielded a power estimate of 0.4 N/kilowatt, a spacecraft equipped with the EM drive could make the trip to Pluto in less than 18 months (126 days). That's one-sixth the time it took for the New Horizons probe to get there, which was traveling at speeds of close to 58,000 km/h (36,000 mph). Naturally, further experimentation is needed to confirm that this is truly possible.

As you can see, there are a few means of getting around the Solar System, ranging from the gas-guzzling but rapid, to the slow and steady. In all cases though, it comes down to a
massive expenditure of energy. While some are all about using it quickly to achieve high acceleration, others apply the energy in small amounts over a long period of time.

Other means are still on the shelf, but could very well be assembled using today's technology. These (ranging from the EM Engine to Nuclear power) emphasize tackling the problem with increasingly sophisticated forms of technology. And while they do offer shorter trip times and a more energy-efficient mode of travel, some serious development needs to happen before they can be considered readily available.

We have written many interesting articles on space travel here at Universe Today. Here's How Long Does it Take to Get to the Moon?, How Long Does it Take to Get to Mercury?, How Long Does it Take to Get to Venus?, How Long Does it Take to Get to Mars?, How Long Does it Take to Get to Jupiter?, How Long Does it Take to Get to Saturn?, and How Long Does it Take to Get to Pluto?

For more information, check out The Planets and Windows to the Universe's pages on planetary distances.

Astronomy Cast also has some good episodes on the subject, like Episode 84: Getting Around the Solar System, Episode 171: Solar System Movements and Positions and Episode 413: Navigating Near

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