Will Science Fiction Always Be Fiction?

Word Count: 2975

The image above is of the black hole Gargantua in *Interstellar*, taken from this web page http://interstellarfilm.wikia.com/wiki/Gargantua, accessed on 06/01/18

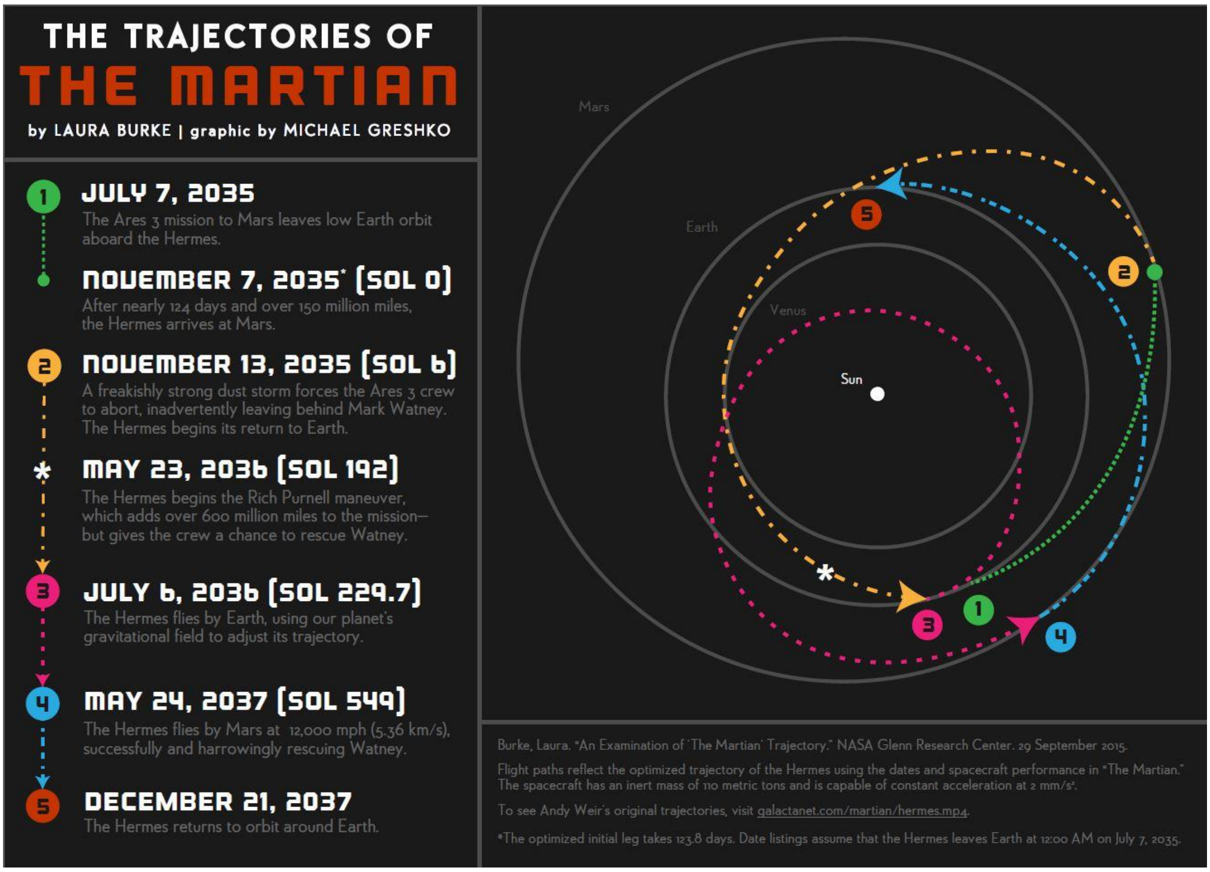
Picture 1865: no Google, no internet, no mobile phones... And at this time, Jules Vernes published his novel "From the Earth to the Moon", which depicts humans attempting a moon landing. Everybody must have thought it was preposterous. People? On the moon? How strange! Yet only a century later, Neil, Buzz and Michael were on their way to it. The wild science fiction dream became a reality. This begs the question: what about today? Are our wild science fiction dreams forever 'doomed' to be science fiction or will they too inspire scientists to strive to make them a reality? Are perhaps some dreams too wild to ever be tamed to abide by the laws of physics?

This article will dissect the physics of different situations from the famous space science fiction *The Martian*, *Interstellar*, *Star Wars* and *Star Trek* and categorise them into possible, plausible and impossible science.

The Possible: Ion Propulsion, Trajectories and Slowing Time

The recent book *The Martian* by Andy Weir depicts a series of near-future missions to Mars in which a space vessel named the Hermes is used to ferry astronauts between Earth and Mars – this vessel implements ion propulsion. Ion propulsion is a technology that allows spacecraft to change velocity or direction over time by ionising a propellant (often xenon) by electrically charging it [1]. The resulting ions are accelerated out of the spacecraft to produce thrust. This technology is not only entirely feasible, but in fact presently used in satellites and NASA's Dawn spacecraft, which is currently orbiting Ceres and Vesta (two of the largest asteroids in the asteroid belt). Ion propulsion has been described to be the "enabling technology" [2] of the Dawn mission, as it provides all the velocity variation (delta-V) required following the launch. The total delta-V the ion propulsion system in Dawn can offer is 11km/s [3]. This is in fact comparable to the delta-V from the mission's launch vehicle, Delta II [2], which uses traditional chemical propulsion i.e. fuel. This goes to show that ion propulsion can provide just as strong an overall force as chemical propulsion (although over longer periods of time). The power of ion propulsion lies in that with a tiny acceleration, a spacecraft can be sped up to massive speeds over a long time. Ion propulsion also enables trajectories to be fine-tuned, which is of particular use over longer missions where the spacecraft may have to perform flybys, gravity assists, enter low orbit and more. This is exploited in the book, particularly in the 'Rich Purnell Manoeuvre', a trajectory which includes all these as well as hyperbolic trajectories (a trajectory where the object is travelling fast enough to escape the central body).

The spacecraft trajectories in *The Martian* were ran through simulations by both Andy Weir and NASA, making them highly accurate and fascinating. All the trajectories used in the book are shown in the image below [4], created by Laura Burke, a mission designer at NASA who verified the trajectories and found them to be accurate [5]. The first orbit is a Hohmann transfer (an elliptical orbit between Earth and Mars) occurring at an astronomical synod. A synod is an alignment of Earth, Mars and the Sun which enables the quickest and easiest trajectory possible between the two planets by only orbiting the Sun once [6] (this is the green and yellow path in the image). As the Hermes approaches Earth and begins the Rich Purnell manoeuvre, it accelerates using its ion engines and uses Earth's gravity to slingshot into a hyperbolic trajectory leading to Mars (see the pink path in the image). The Hermes then performs a Mars flyby, as it would be going too fast to fall into orbit [7], and returns to Earth (see the blue path). However, one issue with the trajectory is its safety for the crew; the manoeuvre requires the Hermes to travel well within Venus' orbit, exposing the crew to vast amounts of radiation and heat from the Sun [5]. Furthermore, Mark Watney is also following a hyperbolic trajectory when attempting to meet the rest of the crew in space during the climactic rescue. A hyperbolic rendezvous is very risky as after the crossover point, their two paths will never cross again due to the nature of a hyperbolic trajectory.



Let's have a look at a different instance of possible science. In Christopher Nolan's *Interstellar*, three astronauts visit a distant planet (named Miller's planet) which orbits the supermassive black hole Gargantua. One of the astronauts states that for every hour on Miller's planet, 7 years pass on Earth, i.e. time flows 60,000 times slower than on Earth. Is this possible? In one short word: yes. In a few more 'short-ish' words: yes, with the right conditions.

Einstein's theory of general relativity demonstrates that close to objects of very large mass, time slows down as spacetime is warped. The classic analogy is to picture a heavy ball placed on a rubber sheet; the ball will deform the sheet just as a large mass deforms spacetime. There have been highly accurate experiments proving this to be true; for example, in 1959 Bob Pound and Glen Rebka measured the flow of time at the basement and penthouse of a 73-foot tower and found that time flowed more slowly in the former by 210-trillionths of a second [8]. So general relativity can be seen even on a human scale; in fact, if not for corrections made using general relativity, GPS would not work.

We've seen that due to general relativity gravity does have the effect of slowing time, however can this happen to the extent that it does in the movie? We must consider some of the properties of the planet and the black hole to answer this. Miller's planet is placed as close to Gargantua as it can be without being pulled into it [8], in a position where the gravitational force from the black hole is balanced by the centrifugal force that the planet feels from orbiting it. Miller's planet also feels a tidal force from Gargantua – a tidal force is exerted when there is a difference in gravitational field strength at two different points of the same body [9] – which stretches it towards and away from Gargantua, as the side closest to the black hole will experience a stronger force. If a black hole's mass increases, so does its circumference [8] and in this case the tidal force decreases as there is less difference in the force exerted on different parts of the planet. Kip Thorne, the scientific advisor for the film, calculated that Gargantua would have to be 100 million times more massive than the Sun in order to not create a tidal force so strong that Miller's planet was ripped apart.

Given that Gargantua is large enough and Miller's planet is as close as it can be to it, then the extreme time dilation is possible (although unlikely) if Gargantua is also spinning fast enough. In fact, to create this slowing of time, Gargantua would have to be spinning at almost its maximum possible speed [8]. So next time you think that time is flying, direct yourself towards the nearest black hole.

The Plausible: Antimatter, Invisibility Cloaks and 'Cool Space Stuff We've Never Seen But Seems Pretty Likely'

This section will discuss science that is plausible or perhaps speculative in science fiction.

The famous show *Star Trek* is rife with creative and interesting uses of technology and was quite ahead of its time. Notably, the crew on spaceships would use 'communicators' to speak to each other [10], very much like our mobile phones today. Some other technologies demonstrated on the show, we'll only be able to achieve with more time and research.

The *USS Enterprise* in the show utilises matter-antimatter reactions as its source of power. From Einstein's mass-energy relationship, we know that a matter-antimatter annihilation will produce 9×10^{16}J of energy for every kilogram of reactant, which is a huge amount. In fact, this is 300 times the energy produced by the nuclear reactions at the Sun's core [11]. This immense amount of energy would greatly increase the variety of space missions humans could accomplish, namely ones that require a large characteristic velocity, such as reversing the direction of orbit of a spacecraft (this would require 'cancelling out' the angular velocity of the body the spacecraft is orbiting as well as having additional velocity).

However, there are two significant problems with this method of propulsion: production and storage. Antimatter has only been formed in very small amounts by accelerating protons to near the speed of light and then colliding these with atoms in a metal. The loss of kinetic energy of the protons is converted into the mass of new particles, some of which may be antiparticles. This has been done at CERN and the Fermi laboratory but to the order of nanograms annually [11]. Furthermore, for obvious reasons the antimatter formed must not come into contact with any matter. This is often prevented via magnetic confinement of the antimatter if the particle is charged, for example an antiproton or positron. This can be done in a Penning trap, which uses a combination of an electric field and a homogeneous magnetic field. The ion is trapped axially via a potential difference (which creates a saddle point) and then radially due to a magnetic field, which forces the ion into a circular orbit on a plane due to the Lorentz force, which keeps the ion in the trap [12].

Due to these problems, the USS Enterprise engine is categorised as 'plausible' rather than 'possible'. Although the theory is sound, the practicality of a matter-antimatter annihilation powered engine is too difficult for our current technology.

Another plausible *Star Trek* technology is the cloaking device, used to project a 'cloaking shield' that can hide a space vessel by bending light around it. Primal cloaking devices have actually been created today by scientists such as John Pendry using layers of 'metamaterials', substances whose properties are described by their interior structure rather than their chemical composition [13]. This means that their nano-structure can be fine-tuned to create the desired effect. Pendry has proposed using these metamaterials to bend electromagnetic fields (light) to render objects effectively invisible [14]. The analogy used to explain the process is that of a stick in a river: the water will part around the stick and then regroup as if there had been no obstacle; the water flow represents light rays. However, so far, these real cloaking devices can only be used to cloak very small objects of a small frequency (colour) range [10], not enormous spacecrafts.

Moving on to the next plausible science, a crowning achievement of the film *Interstellar* was the representation of black holes and Einstein-Rosen bridges – or wormholes. Not only are they stunning, the images containing these were created by physics simulations using Einstein's equations of relativity [8] and so are scientifically accurate to our best knowledge. The warped light around Gargantua and the wormhole is due to gravitational lensing, a phenomenon predicted by Einstein that states that since black holes distort spacetime, they also distort the light behind them. This effect is common to any objects with masses large enough to significantly bend spacetime. For Gargantua, as black holes emit no light, this warped light comes from Gargantua's accretion disk and the galaxy where it is located [8]. In the film, a wormhole is explained by folding a piece of paper and piercing a hole through both sides [15]; in that example, space is depicted as two dimensional, which is why the mouth of the wormhole is a circle. However, space is three dimensional and so it would make sense for the entrance of the wormhole to be a sphere, as shown in the film. While the depictions of these are likely, the creation of a wormhole is not.

The Impossible: Creating Wormholes and Faster Than Light Engines

This section discusses the 'impossible' situations of science fiction. It is not meant as a criticism to the creators of the various shows and films, who were more than likely aware of the laws of physics that they were breaking. This category should, in fact, be more suitably called "Imaginary Science", science fiction where the authors know that their creation meddles with the laws of physics but either decide that this science may become possible one day or that it is necessary for a plot point [16]. After all, these are films made to entertain the audience, not encyclopaedias made to bore them. Nevertheless, it is interesting to dissect the physics in these situations.

In speculative cosmology, we speak of the 'brane' and the 'bulk'; the brane is short for membrane and is our friendly four-dimensional spacetime as we know it and the bulk is a strange five-dimensional spacetime hyperspace that the brane resides in [8]. *Interstellar* uses a wormhole, which can be described as a tunnel in the bulk connecting two different locations on the brane; it is a plausible theory and predicted by Einstein's equations of relativity [17]. However, the formation and maintenance of a wormhole is not plausible within our current imagination as the wormhole would usually collapse before even light could pass through it [8]. To keep the wormhole open, one would need very large amounts of 'exotic matter', matter that has negative mass and energy [18]. Needless to say, it doesn't look like we'll be finding or using a wormhole anytime soon.

FTL engines are used in many science fiction shows and films to make them more exciting and to enable the characters to travel to galaxies far far away without taking up the whole film. The postulates of relativity state that the speed of light must be the same everywhere and that nothing can travel faster than this – that makes faster than light (FTL) engines impossible by definition.

Star Trek adopts an FTL engine called warp drive, which involves bending spacetime to travel faster than the speed of light. Warp drive is a possibility if a spaceship could be created that had a ring made of exotic matter around it. This exotic matter would cause the warping of spacetime by contracting the spacetime ahead of the ship and expanding the spacetime behind the ship, while the spaceship itself would remain in an un-warped 'flat' spacetime [19]. The physics loophole exploited here is that spacetime itself is 'allowed' to travel faster than the speed of light, for example as it did in the beginning of the universe [20]. As the ship itself is in flat spacetime, this supposedly does not violate the laws of relativity, as it is the spacetime that is moving faster than the speed of light not the spaceship itself. However, this spacecraft would require massive amounts of energy, at least as much as the mass-energy of Jupiter [19], which is why this method of propulsion would likely be unfeasible.

In *Star Wars*, the FTL engine is called hyperdrive. The difference between hyperdrive and warp drive is that the former involves the use of an alternate dimension whereas the latter involves bending spacetime. This means warp drive would be slower than hyperdrive, as can be seen in *Star Wars*, where journeys are of the order of hours and days and in *Star Trek* where they are of the order of years and decades.

A spaceship in *Star Wars* is said to use its hyperdrive to 'jump into hyperspace', an alternate dimension in which a spacecraft can somehow travel faster than the speed of light. This can be 'explained' in a few ways: perhaps the hyperspace does not follow relativity and so does not have a speed barrier or maybe a route in hyperspace is smaller in distance than a route in realspace. However, the result is that no time dilation occurs, so the theory of special relativity is contradicted. When in hyperspace, a spaceship maintains its mass-energy profile and also casts a 'mass shadow', meaning that hyperdrive courses had to be planned out so that the ship did not explode as it flew across a planet or other massive object (as seen in the recent *Star Wars* film *The Last Jedi*). This suggests that there is an important spatial connection between hyperspace and realspace, which should mean that distances in hyperspace cannot be smaller than in realspace. The science is fuzzy to say the least; for this reason (as well as the mind control), I'd have to label *Star Wars* science-fantasy rather than science-fiction.

Where To Now?

Science fiction can be seen as an extrapolation of science; it uses a scientific truth and stretches it to its maximum capacity, sometimes even further. Yet it cannot be denied that while science is the origin of science fiction, science fiction does act as an inspiration to scientists. It depicts technology that we can aspire to create and it increases the younger generation's enthusiasm and interest in science which is of key importance.

Science fiction in space is particularly awe-inspiring, as it gives us a sense that there is something greater than ourselves; it meshes physics and philosophy and asks the questions that everybody wishes to know the answer to: where do we come from? Is there more than this? What is time? This type of science fiction asks the big questions and physics helps to answer them.

So, will science fiction always be fiction? I would say no, as the science-fantasy of today can become the reality of the next century. In any case, I hope that this article has drawn more light to this question. The point of science fiction is to make everybody dream a little bit, and maybe along the way, someone with crazy hair and an even crazier mind will be inspired. Maybe in a few centuries, everybody will have a *Millenium Falcon*.

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Article Plan **Possible Title**: Will Science Fiction Always Be Fiction?

In this article, I intend to write about the science in various situations from science fiction, discuss their plausibility and then divide them into 3 categories: science that is possible or even in use right now, science that is plausible one day and lastly science that is not (within our realistic imagination) possible. Science fiction is very broad so I intend to focus only on recent films in space so that I can discuss my chosen examples in detail. Science fiction not based in space, although fascinating too, will not be included in this article so that I can stay in the word limit. This article will focus more on the qualitative explanation of the science and will include only necessary equations (if any) and will not include mathematical explanations of phenomena such as general relativity.

Introduction: Discussing the history and importance of science fiction in our society as a source of inspiration, for both people to become scientists and scientists themselves; the science fiction of the past can become the reality of the future, or even the present! For example, in 1865 Jules Verne wrote about people attempting to land on the moon in his novel "From the Earth to the Moon" and a century later, humans did just that.

Section 1: The possible/in use right now

- Ion propulsion of the Hermes in 'The Martian'. Currently used in NASA's Dawn Spacecraft
- Effects from general relativity near Gargantua in 'Interstellar'
- Orbital paths taken by the Hermes in 'The Martian'

Section 2: The plausible one day – generally situations where the theory makes sense but it is not reasonably practical; also includes speculation

- Matter/anti-matter engine of the USS Enterprise in 'Star Trek'
- Cloaking devices in 'Star Trek'
- The representations of black holes and Einstein-Rosen bridges in 'Interstellar'

Section 3: Not possible – a smaller section including situations of science fiction that break fundamental laws of physics.

- Hyperdrive in 'Star Wars', warp drive in 'Star Trek' and generally faster than light engines
- 'Slingshotting' around Gargantua and using a neutron star to slow down in 'Interstellar' (interestingly, this could have worked with an Earth-sized black hole, as discussed in Kip Thorne's book)
- Creating a wormhole as done by the 'They' from 'Interstellar'

Conclusion: Reiterating the importance of science fiction as a source of inspiration. Space is the source of much discussion based on both physics and philosophy and good science fiction manages to include both of these. Science is constantly progressing; barely a century ago, the idea of a human on the moon would have been almost outrageous. Science fiction helps us ask the big questions, and physics helps us answer these.

Research Material: The NASA website has articles on the science in particular movies and TV shows which I will read. Also, Kip Thorne worked with Christopher Nolan on the science in 'Interstellar' and then wrote a book about this, which will also be very useful.

Plan Feedback:

Hello!

Thank you for sending back your plan for the Year 2 Scientific Article. As promised, here are a few thoughts/ ideas.

As I mentioned during/ after your presentation, this a brilliant idea and I am very excited to read the paper. The main theme of your article seems to be science fiction in film – do you think you could expand to literature? (i.e. Kurt Vonnegut, who wrote a tonne of surreal physics focussed short stories: https://www.jstor.org/stable/24777181 , and whose brother was a scientist: https://en.wikipedia.org/wiki/Bernard_Vonnegut, or Tom Stoppard, a famous English playwright who was obsessed with physics – and whose son studied it at university - https://www.newscientist.com/article/dn26878-the-hard-problem-is-stoppards-problem-with-science/ , https://physics.weber.edu/carroll/honors/HONSYL14.pdf).

I really like the breakdown into real, eventually real and never going to happen. IT would be great to have links to contemporary science covering these topics (Pendry's cloaking device: http://www.bbc.co.uk/news/science-environment-23081852). Section Three could be expanded to include action movies that defy the laws of physics (a bit here: http://www.denofgeek.com/movies/18022/10-action-sequences-that-defy-the-laws-of-physics , http://www.intuitor.com/moviephysics/) – or just point out that this discussion is on going.

If possible, you should have a chat to Dave Clements (who I emailed you about before!) and also try and meet the team in Science Communication at Imperial - https://www.imperial.ac.uk/study/pg/science-communication/science-communication/ . They have a module on physics and film which would be perfect for you to include. Also, the Sloan film program http://scienceandfilm.org/film .

Changes from the plan and response to feedback:

Due to the word limit, I could not write about the science in literature and had to omit the 'slingshotting' paragraph in Section 3 that I had mentioned in my plan. Although I was not able to meet Dave Clements face-to-face we did exchange emails and he kindly sent me links to resources such as the science fiction encyclopaedia, which was useful for learning terms like 'imaginary science'.