Kent University

Physics Foundation Year

STAR TREK Propulsion systems

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Research, development and use of antimatter to propel space craft

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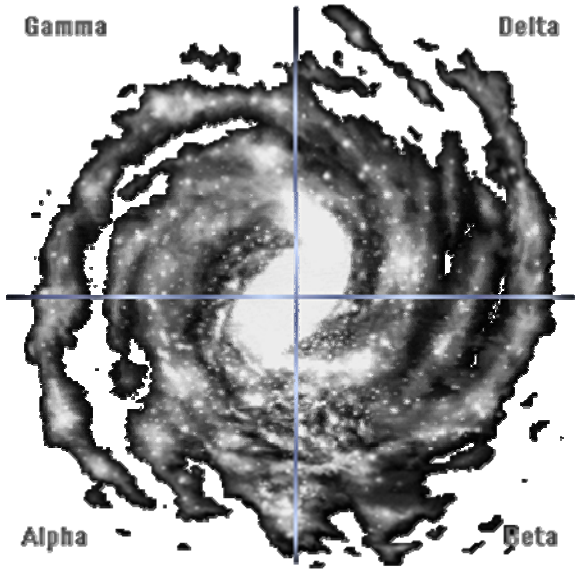
Introduction

“Warp 7 engage“, “get us out of here, warp 2” (1) are phrases well known in the star trek community. But what does it mean? What is warp power and antimatter? What is matter and antimatter annihilation? Can we use this process to propel spacecraft? Is there any “real science” behind phrases like this and if yes are there any useful applications for today`s and future propulsion systems?
This essay will try to find some answers to those questions and hopefully gives some understanding of how present research and development impacts on technology dreamed up by science fiction writers decades ago.

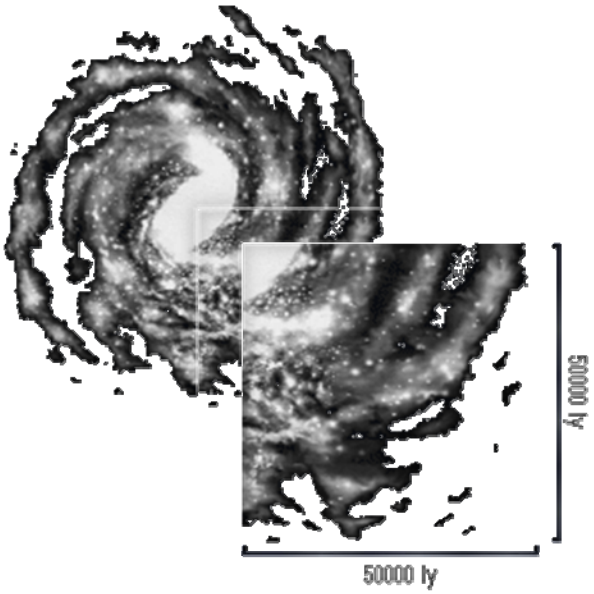
What is Warp drive and how does it work?

To understand the warp propulsion system according to Star Trek, first of all it is necessary, to understand why we need a warp drive and explain the theory behind faster than light travel. The problem becomes quite obvious if you look at the story line of Star Trek. Looking at the images in Diagram I, it becomes a necessity to travel faster than light just because of the sheer distances between two points in the galaxy.



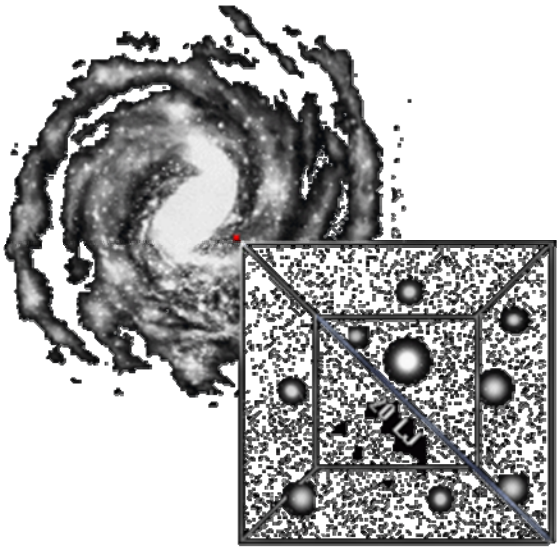
The subdivision into quadrants

Image 1



The dimensions of a quadrant

Image 2



The dimensions of a sector

Image 3

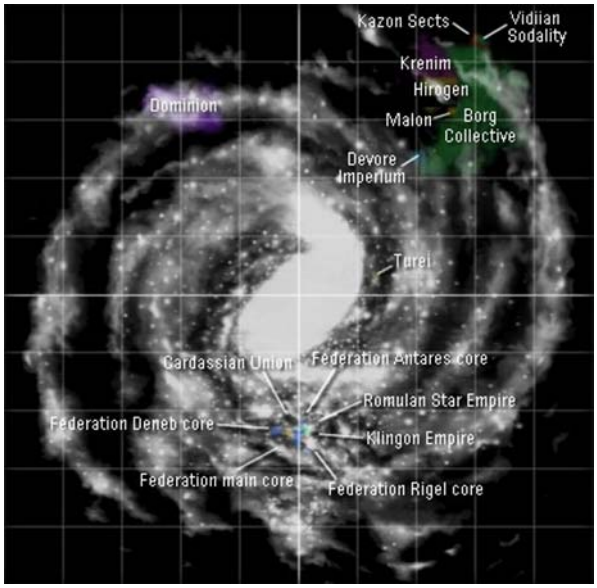


Image 4

Diagram I: Image 1 shows the subdivision of the galactic plane into 4 quadrants. Image 2 shows the dimension of one quadrant in ly (light years)[1]. Image 3 shows the subdivision of a quadrant into sectors and its dimension. Image 4 shows a political map according to Star Trek. (2)

[1] Distance travelled by light in one year

Warp factor	Speed (c) [2]	5 ly (to next star)	20 ly (through a sector)	100000 ly (through the galaxy)	2000000 ly (to Andromeda galaxy)
Standard orbit	0,000008 (9600km/h)	400000 years	2×10^{6} years	$1{,}11 \times 10^{10}$ years	$2{,}234 \times 10^{11}$ years
1	1	5 years	20 years	100000 years	2000000 years
6	392	5 days	19 days	255 years	5096 years
9,9999	199516	13 minutes	53 minutes	6 months	10 years

Table I: (3-4)

The Data in Diagram II illustrates the situation of interstellar travel even more.

Having established the need for the warp drive, it is important to highlight its function.

The Warp drive is defined as the primary propulsion system used by most faster than light interstellar spacecraft. Warp drive systems employ the controlled annihilation of matter and antimatter, regulated by dilithium crystals, to generate the tremendous power required to warp space and travel faster than light. (5) Diagram II shows the components of a warp drive system.

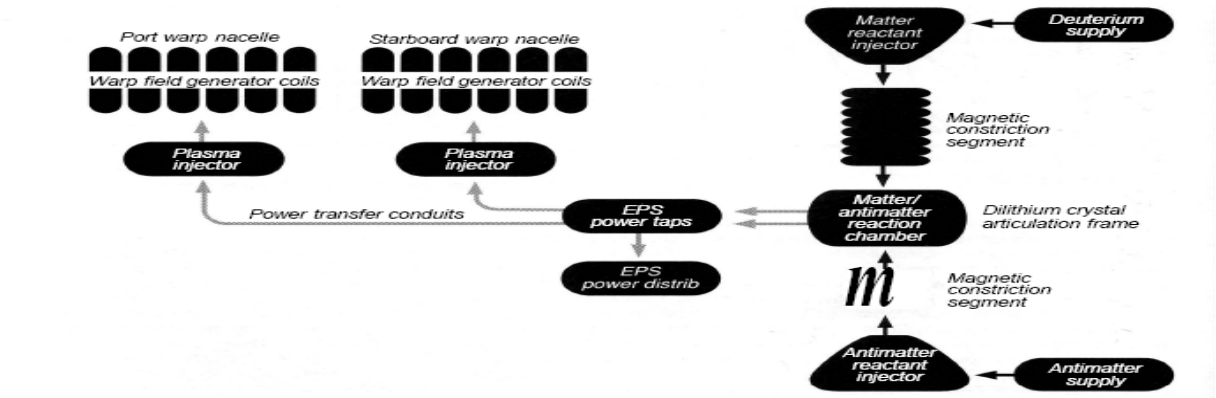


Diagram II: Warp Drive System (6)

[2] c = speed of light = 299793 kms^{-1} (7)

The whole idea of a warp drive is based on the idea of bending normal space / sub space.

The warp drive generates a distortion in the space – time – continuum, which compresses the space in front of the space craft and stretches the space behind it. This process requires a fast amount of energy, which is produced by the matter / antimatter annihilation.

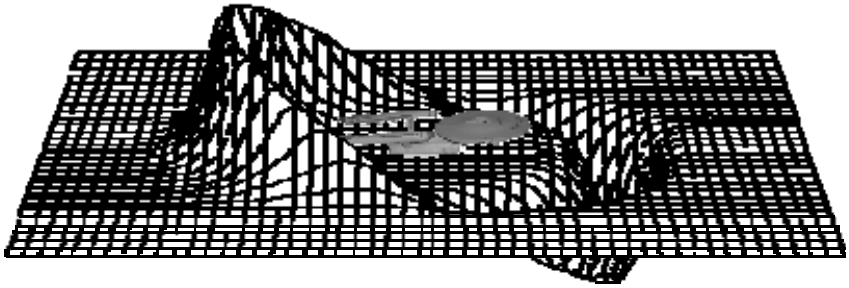


Diagram III: Image of the Distortion of subspace and the space – time – continuum, created by the warp drive (8)

What is matter / antimatter and matter / antimatter? annihilation?

The British physicist Paul Dirac predicted the existence of antimatter already in 1928.

He formulated a quantum theory for the motion of electrons in electric and magnetic fields.

$$E^2 = p^2c^2 + m^2c^4$$ [3]

Equation I: relativity equation (9)

[3] E = energy of particle, p = momentum of particle, m = mass of particle, c = velocity of light

Using this equation of the relativistic relation between energy, momentum and mass, Dirac found that not only positive energy solutions exists, but negative ones as well. Assuming correctly, he postulated the existence of positive charged electrons. This was formulated in the following 4x4 matrices.

$$\gamma_1 = \begin{pmatrix} 0 & 0 & 0 & -i \\ 0 & 0 & -i & 0 \\ 0 & i & 0 & 0 \\ i & 0 & 0 & 0 \end{pmatrix} \quad \gamma_2 = \begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$\gamma_3 = \begin{pmatrix} 0 & 0 & -i & 0 \\ 0 & 0 & 0 & i \\ i & 0 & 0 & 0 \\ 0 & -i & 0 & 0 \end{pmatrix} \quad \gamma_4 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

Equation II: 4x4 matrices of electron`s spin[4] (9)

Two of the four matrices explain the electron`s spin, while the two other matrices explain the behavior of the antielectron, like the opposite charge and spin, where `i` is the complex root and the representation of the antiparticles. (9) The American physicist Carl Anderson discovered the positron, the antimatter counterpart of the electron, using his cloud chamber experiment in 1932. (7) Today, it is clear that every particle of matter has its own counterpart in the "antimatter world". Annihilation takes place when a particle comes in contact with its antiparticle. This creates energy, in form of light, according to Einstein`s formula $E = mc^2$.

[4] Electron spin = intrinsic angular momentum

When a proton p and antiproton $\bar{p}$ annihilate the products are charged and uncharged pions π according to the reaction I. The number of neutral pions π^0 and charged pions $\pi^{\pm}$ created are approximately equal with m 2 and n 1,5. Reaction II is showing that the uncharged pions are decaying immediately into gamma rays, while reaction III and IV are showing the decay of the charged pions into muons μ and associated neutrinos ν_μ.

Reaction I: $\bar{p} + p \rightarrow m\pi^0 + n\pi^+ + n\pi^-$

Reaction II: $\pi^0 \rightarrow \gamma + \gamma$

Reaction III: $\pi^+ \rightarrow \mu^+ + \nu_\mu$

Reaction IV: $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$ (10)

Antimatter, production, costs, efficiency

The preferred annihilation is the proton – antiproton annihilation because the products of this process are neutral and charged pions. These charged pions can be confined and directed magnetically. They then can be used as thrust. For this purpose anti molecular hydrogen, anti -H_2, is used which doesn't exist naturally. These atoms are produced in facilities like CERN, the Organisation for Nuclear Research in Switzerland, or FermiLab, the National Accelerator Laboratory in the United States. This process involves accelerating protons to velocities near the speed of light and collide them into a metal, for example tungsten. These high energy protons are slowed down or stopped in the collision with nuclei of the target. This creates various subatomic particles and some are antiprotons. These antiprotons are electromagnetically separated and contained in an electromagnetic field in high vacuums.

Diagram VI shows a schematic drawing of that process while Diagram VII shows a schematic drawing of a storage device build and tested by Penn State Laboratories. The current production rate of antimatter is around 10^{16} antiprotons or 10 nanograms (ng) per year. (11) The production and storage of antimatter is complicated and highly energy consuming, making the estimated costs for antimatter reach up to $ 62,5 trillion per gram. (12)

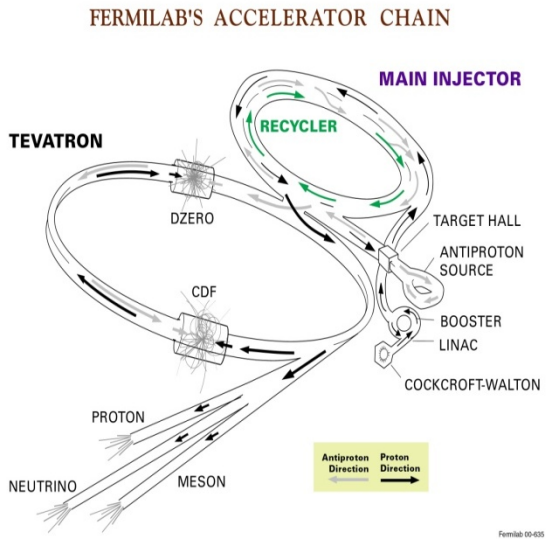


Diagram V (13)

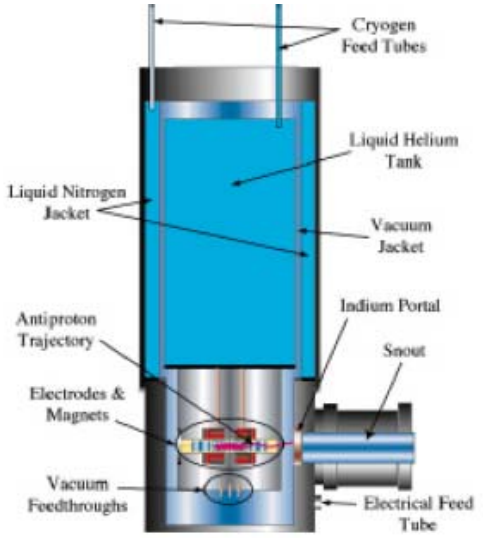


Diagram VI (14)

Problems arising from matter / antimatter and the potential use for future space travel

Using matter / antimatter annihilation in spacecraft propulsion systems leads to various problems. After mentioning the high costs of antimatter, the next problem that will be discussed is the transportation and storage of antimatter. One current concept to store antimatter is the neutral antimolecular hydrogen (anti-H_2) ice, suspended in an electromagnetic trap.

If production of liquid or solid anti-H_2 can be achieved, only initial steps have been demonstrated so far, the next problem lies in the need to store the anti-H_2 as a very cold (1-2 K)[5] solid to prevent evaporation, because in its gaseous form it cannot be contained magnetically. The anti-H_2 would then drift to the storage container walls and annihilate, starting a chain reaction. (11)

Another problem is the gamma radiation created in the annihilation process. Because of the short lifetime of the neutral pion, $7x10^{-17}$ seconds (15), it moves only about 0,06 micrometers before decaying into high energy gamma rays, with approximately 200 MeV (Mega Electron Volt) each. In contrast to that, the charged pions move around 21 m and their decay products, charged myons, move another 1,85 km before decaying.

All the problems aside, using antimatter for propulsion purposes has its positive sides as well. Having a specific Impulse (Isp) of 10^{11} - 10^{16} seconds[6] and a Thrust to Weight Ratio of 10^{-8} - 1, [7] it becomes quite clear why matter / antimatter annihilation is preferred to propel spacecraft. Its energy, efficiency and size make it the leading replacement for current solid and liquid fuel systems. (9) Proposed designs for antimatter propelled spacecrafts include for example ICAN.

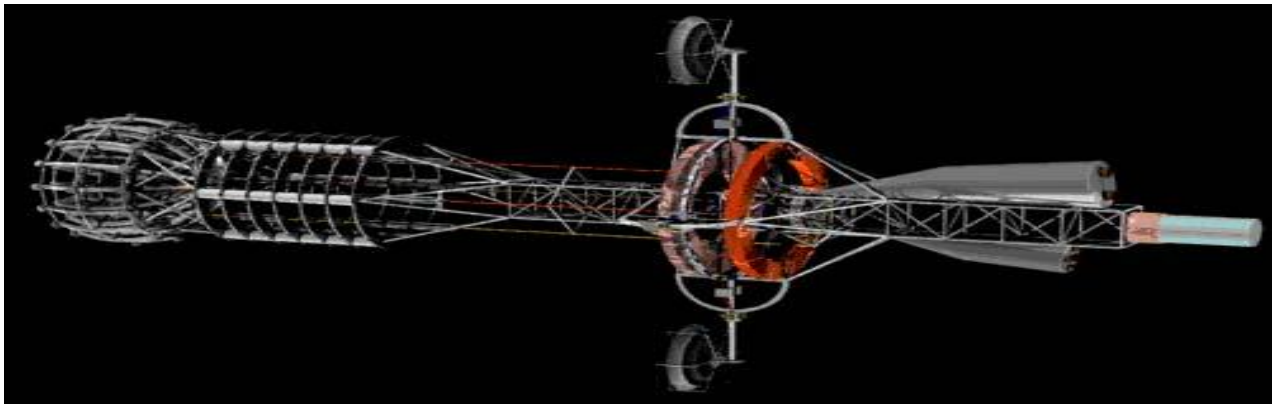


Diagram VII: ICAN Spacecraft (17)

[5] K=Kelvin

[6] Isp - ratio of the thrust produced to the weight flow of the propellants (16)

[7] Thrust to weight ration – indication of thrust efficiency of engine (16)

Conclusion

Going back to the Star Trek example I chose in the beginning, it becomes apparent that even with the relatively fast 25km/s cruising velocity, of the ICAN spacecraft (17), mankind is not able to match anything close to the velocities shown in those science fiction programs, for now. Using imaginary propulsion subsystems like dilithium crystals for bending the space- time-continuum may work in films, but is no use in our reality. Encouraging physicists to engage in research in this field, the British Interplanetary Society was setting up a conference entitled “Faster than Light: Breaking the Interstellar Distance Barrier” on November 15, 2007. (18)

Engaging young physicists in research like that, now and in the future, will make sure that the current problems regarding the antimatter technology will be solved, rather sooner than later. Looking at the tremendous development regarding manmade flight in the last 100 years and use this as a prediction for the future of space travel, who knows where mankind will stand in two or three generations time. Maybe the stars will be in our reach and interstellar travel becomes reality.

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