Three Interstellar Ram Jets

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Abstract

The mass ratio problem in interstellar flight presents a major problem[1,[2}; a solution to this is the Interstellar Ramjet[3]. An alternative to the Bussard Ramjet was presented in 1977 [8]. The Laser Powered Interstellar Ramjet, LPIR. This vehicle uses a solar system based laser beaming power to a vehicle which scoops interstellar hydrogen and uses a linear accelerator to boost the collected particle energy for propulsion. This method bypasses the problem of using nuclear fusion to power the ramjet. Engine mass is off loaded to the beaming station. Not much work has been done on this system in last 40 years. Presented here are some ideas about boosting the LPIR with a laser station before engaging the ram mode, using a time dependent power station to keep the LPIR under acceleration. Fishback[4] in 1969 calculated important limitations on the ramjet magnetic intake, these considerations were augmented in a paper by Martin in 1973[6]. Fishback showed there was a limiting Lorentz factor for an interstellar ramjet. In 1977 Dan Whitmire [7] made progress towards solving the fusion reactor of the interstellar ramjet by noting that one could use the CNO process rather than the PP mechanism. Another solution to fusion reactor limitations is to scoop fuel from the interstellar medium , carry a reaction mass , like antimatter, combine to produce thrust [9,10,11]. Limitation issues are addressed, such as structural limitations on the magnetic scoop, radiation losses, drag losses and the accuracy of the pointing of the laser power station. How these limitations affect the dynamic trajectory of the LPIR are also addressed.

1. INTRODUCTION

Three interstellar ramjets are presented, the Interstellar Ramjet, ISR, sometimes known as the Bussard Ramjet, the Laser Powered Interstellar Ramjet, LPIR, and the Ram Augmented Interstellar Ramjet, RAR, see Figure 1.

Project Pluto – a program to develop nuclear-powered ramjet engines – must have been on Robert Bussard's mind one morning at breakfast at Los Alamos. Bussard was a project scientist-engineer on the nuclear thermal rocket program Rover — Bussard and his coauthor DeLauer have the two definitive monographs on nuclear propulsion [1, 2]. Bussard said many times that the idea of the hydrogen scooping fusion ramjet came to him a morning over breakfast. This was sometime in 1958 or 1959 and the SLAM (Supersonic Low Altitude Missile) would have been well known to him. SLAM was a nuclear ramjet, a fearsome thing, sometimes called the Flying Crowbar. Finding a solution to the mass ratio problem for interstellar flight was also something on Bussard's mind. Thus was born the Interstellar Ramjet, published in 1960 [3], Figure 1a.

2. THE INTERSTELLAR RAMJET

The interstellar ramjet scoops hydrogen from the interstellar medium and uses this as both a fuel and energy source by way of fusion reactor. The sun does proton fusion using gravity as the agent of confinement and compressional heating. However, doing fusion in a 'non-gravitational' magnetic reactor makes the process very difficult [3,5,7]. That is, the proton and Deuterium burning is quite difficult to realize on a non-stellar scale. Dan Whitmire attacked this problem by proposing the use of a carbon catalyst using the CNO cycle [7]. The CNO cycle is about 9 orders of magnitude faster than proton-proton fusion. It would still require temperatures and number densities way beyond any technology known at this time.

Bussard noted a number of problems such as losses from bremsstrahlung and synchrotron radiation. He also noted scooping with a material scoop would create a problem with erosion, hinting that magnetic fields might be used, and noting that drag would have to be accounted for.

About 8 years after Bussard's paper, an undergraduate at MIT, John Ford Fishback, took up the problems Bussard had mentioned. He wrote this up for his Bachelor's thesis under the supervision of Philip Morrison. The thesis was published in Astronautica Acta [4] in 1969.

Fishback did three remarkable things in his only journal paper: finding an expression for the ‘scoop’ magnetic field, computing the stress on the magnetic scoop sources, and working out the equations of motion of the ramjet with radiation losses. These calculations were done using a special relativistic formulation. Fishback’s most important finding is noticing that when capturing ionized hydrogen to funnel into the fusion reactor, there is a large momentum flow of the interstellar medium which must be balanced by the scooping and confining magnetic fields. Using very general arguments, Fishback showed that sources (magnetic coils and their support) of the magnetic field determine an upper limit on how fast a ramjet can travel. The convenient measure of starship speed is the Lorentz factor

Fisback derived the following expression for the limiting Lorentz factor γ for a constant acceleration, a, Bussard ramjet:

$$(\gamma\beta)_c = \frac{4en\alpha}{aB_0}\frac{\sigma_{max}}{\rho} \quad (1)$$

Where:

β = velocity/c, c = speed of light.

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

e = charge on an electron – 1.6022 x10^{-19} Coulombs

n = average Galactic hydrogen number density -1000/m^3

a = acceleration in g’s

B_0=average galactic magnetic field 1.0x10^{-10} Tesla

∝ = fusion energy yield = 7.1x10^{-3}

σ_{max} = maximum tensile strength of scoop field coils, Pa

ρ = density of ship structural material, kg/m^3

The tensile strength of the scoop field coils is the main limiting constraint as shown in equation (1). At the time, Fishback modeled the upper limit using diamond, because of its shear stress properties, and found that one could only accelerate until the Lorentz factor reaches about 2000 [4]. Tony Martin expanded on Fishback's study [5, 6] in 1971, correcting some numbers and elaborating on Fishback's modeling. Since that time, Graphene has been discovered and has amazing properties, table 1. Graphene has a shear stress that allows a limiting Lorentz factor of about 6000. This in turn implies a range of over 6000 light years when under 1 g acceleration. It does not mean a final range is 6000 light years, but one must travel at a reduced acceleration and then constant speed, which means a longer ship proper time. Table 2 shows some representative values for the Lorentz factor cutoffs. Graphene is close to the upper limit on the maximum tensile strength of a material; however it is possible the theoretical limit may be extrapolated to a limiting Lorentz factor to 10,000. (Note the material Carbyne is approximately twice as strong as Graphene.)

Figure 2 shows a time history of interstellar ramjet acceleration when the overall scoop fields are supported by a structure based on the tensile strength of Graphene. The ship is able to accelerate at 1g for about 10 years before having to throttle back. After about 10 years, ship proper time, the ship is at about 6400 light years distance, of course about 6400 years have elapsed back on earth.

3. OTHER RAMJETS

In 1977 Dan Whitmire and this author published a variation on the Interstellar Ramjet. The vehicle uses a solar system based laser beaming power to a vehicle that scoops interstellar hydrogen and uses this energy to power a linear accelerator boosting the particle energies for propulsion. This method bypasses the problem of using nuclear fusion to power the ramjet. Engine mass is off loaded to the beaming station. Figure 1b.

Another solution to the proton-proton fusion reactor in the Bussard ramjet would be to carry an energy source but extract a 'working fluid' from the interstellar medium by scooping hydrogen. A third ramjet was proposed, the ram augmented ramjet, RAR, Bond [9] and Powell [10], figure 1c. The optimum RAR can be obtained by carrying antimatter and combine with the interstellar medium Figure 3 [11].

One feature of the ISR is that it becomes more efficient at higher speeds [3]. One envisions a mode where the ISR is boosted by the Laser Powered Interstellar Ramjet (LPIR) before engaging the pure ram mode. Figure 5 shows that the instantaneous energy efficiency of the ISR and LPIR cross at roughly a beta of 0.14. At this point there would be a hand off of the two propulsion modes.

A tri-mode is also possible. The start trajectory would be to deploy a sail [12], push the vehicle to a high speed, transition to the laser powered ramjet mode and transition to the interstellar ramjet at high beta.

Such a vehicle might be schematically represented by figure 4. The para-sail acts as a plain radiation pushed sail and then an absorber for the pushed and the powered mode. Because of the remarkable electrical, thermal and strength properties of Graphene such a sail would have multiple uses. After the ‘boost’ phases the sail could even be consumed as source of carbon catalyst when in the interstellar ramjet mode.

4. CONCLUSTION

In conclusion one notes many questions about the interstellar ramjet: (1) Could one really make the whole ship out of Graphene?(Or something like it?). (2) Will one always be γ limited by strength of source of magnetic field? (3) Does the CMB limit the sail acceleration [13]? (4) Bremsstrahlung and Synchrotron scoop radiation losses need further refinements. (5) Need to explore the Interstellar Ramjet reactor in more detail. (6)Even at 100% efficiency will waste heat melt the ship?

The ‘laser’ powered ramjet needs to be looked at again. The antimatter augmented ram scoop needs a revisit. The SETI observables need a look: The laser or microwave ‘booster stations’ can we see them? Beamed waste heat? Decelerating ramjets in stellar atmospheres or high density regions?

Acknowledgment: Figure 3 by Douglas Potter.

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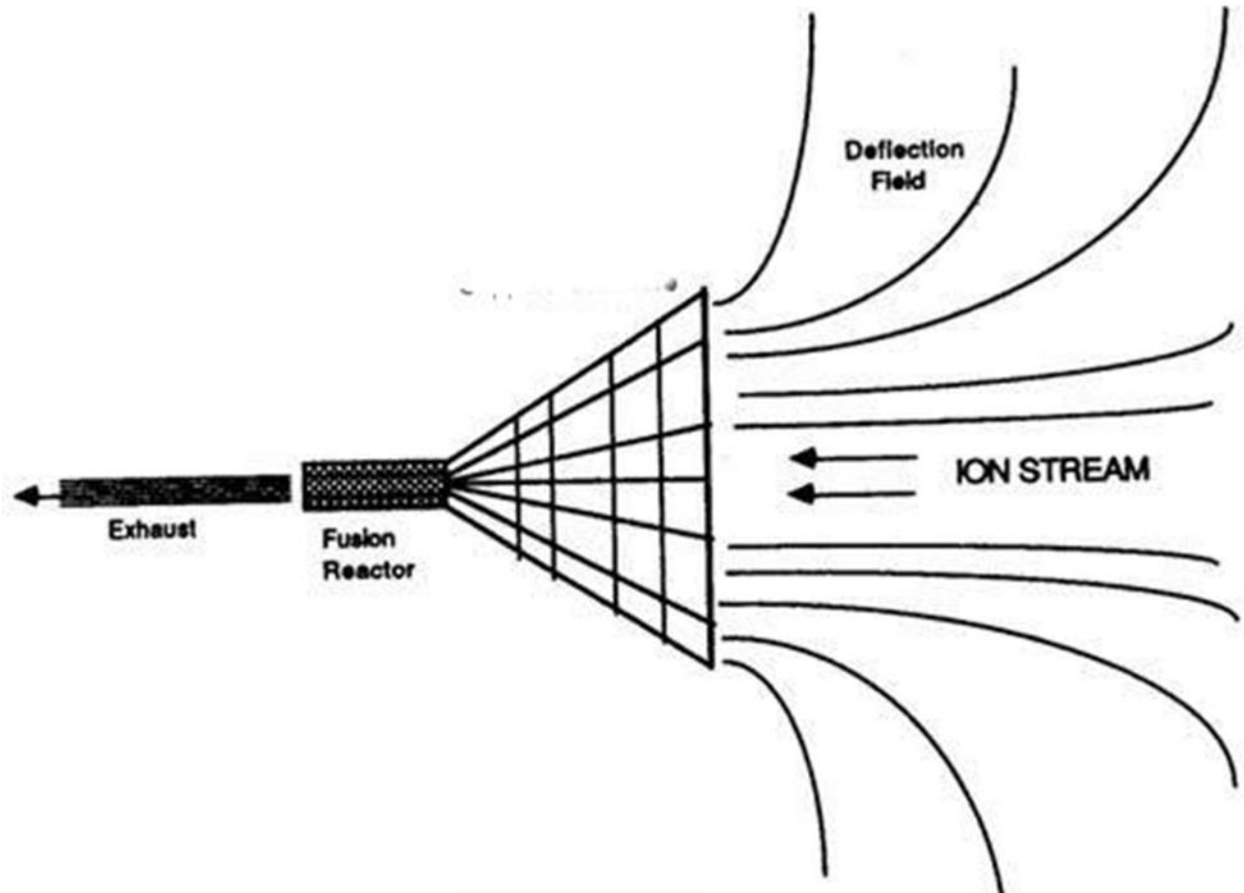
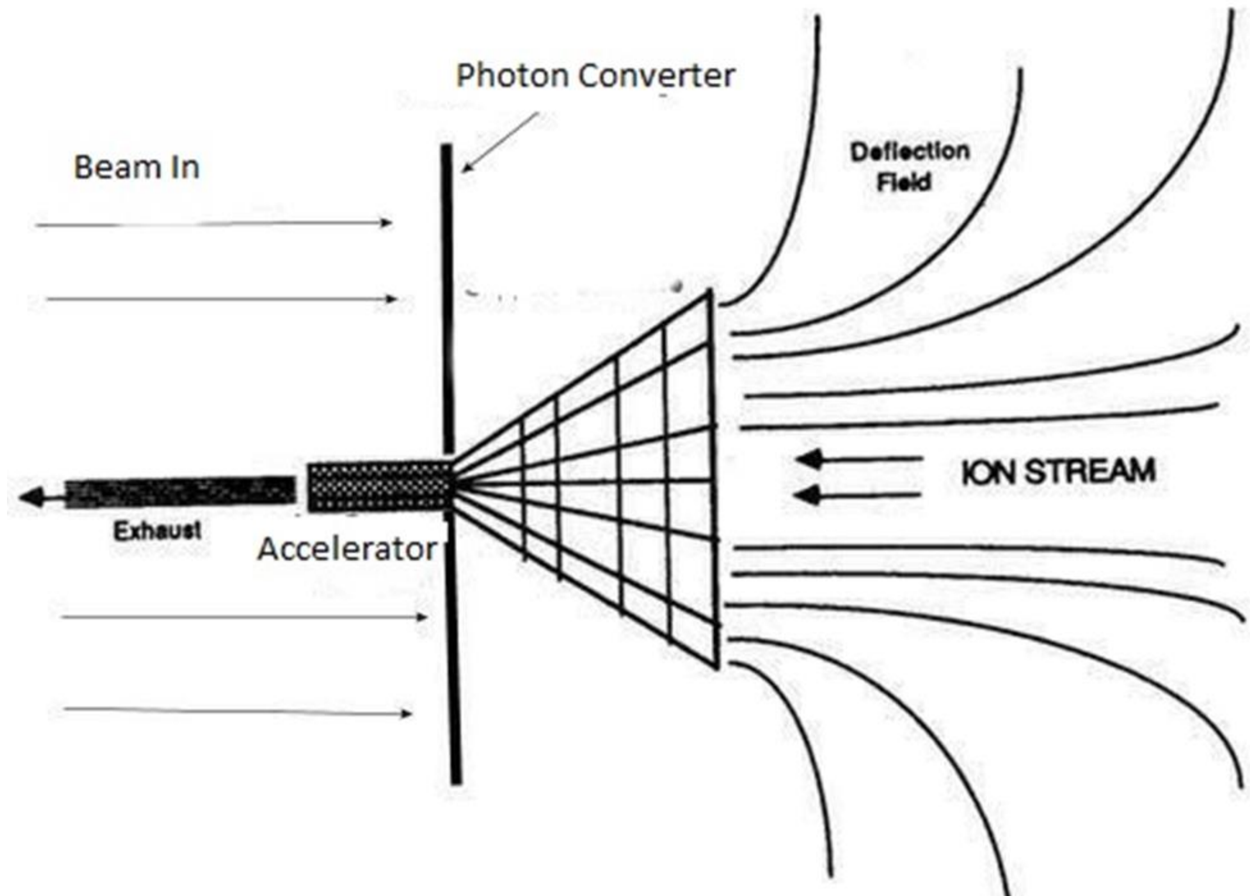
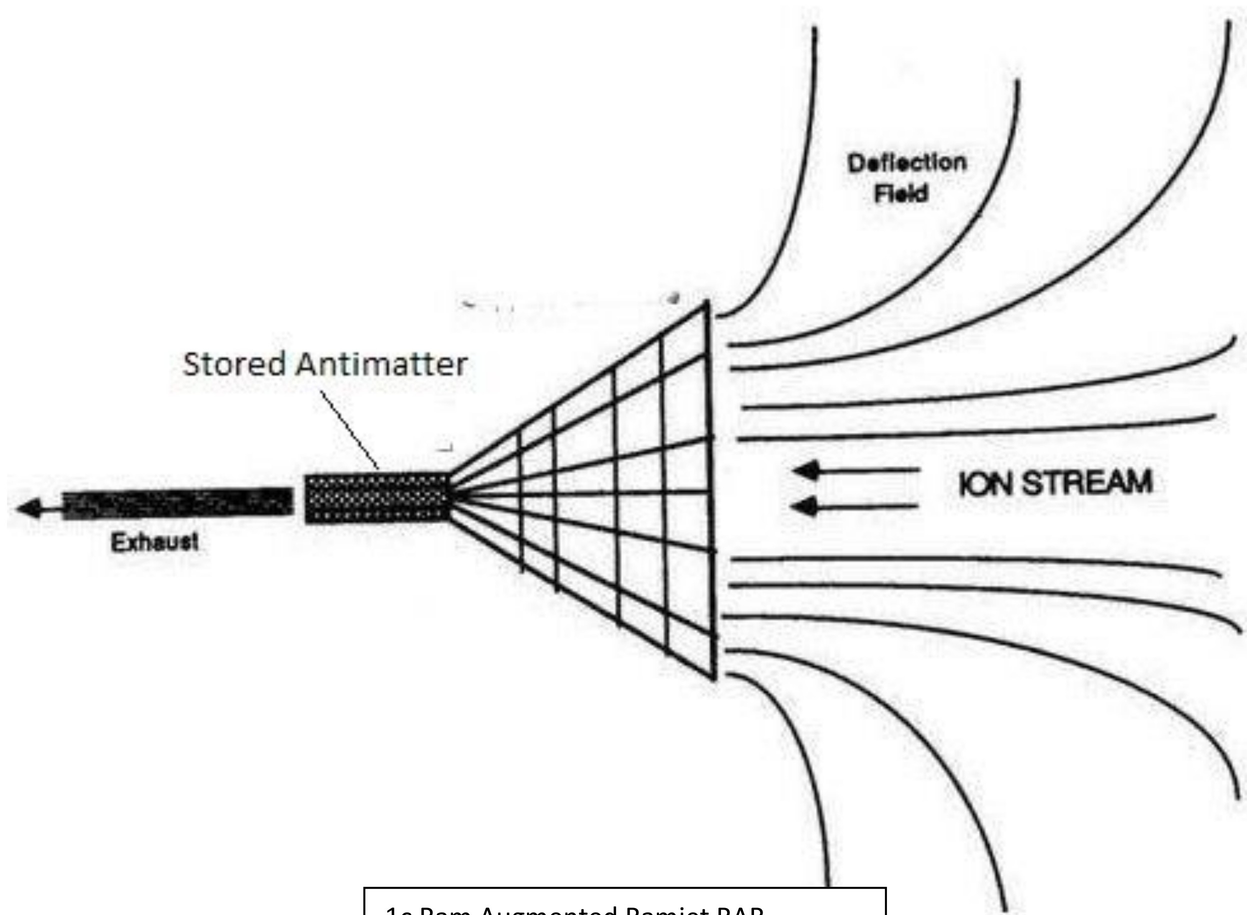
Tables and Figures:



1a Interstellar



1b Laser Powered Interstellar Ramjet



1c Ram Augmented Ramjet RAR

Figure 1: Three interstellar ramjets

Material	Copper	Graphene	
Tensile Strength*	.22	130.0	GPa
Thermal Conductivity	.385	3-5	10^3 W/m-K
Max current density	~106	>1x10^8	A/cm^2
Melting Point	1356	3800	K

Table 1 : Comparison Copper and Graphene

Structural Material	**σ/ρ** dyn cm^{-2}/gcm^{-33} 10^{10}	**γβ**$_c$ Proton	Range LY
Aluminum	.062	8.6	12.6
Stainless Steel	.261	36.2	7.5
Diamond	15.2	2110	3550

Graphene	600.0	6628.0	6418.0

Table 2: Lorentz factor cut-offs and range of the Bussard Ramjet accelerating at 1g. Interstellar medium 1/cm-3 using the p-p fusion reaction.

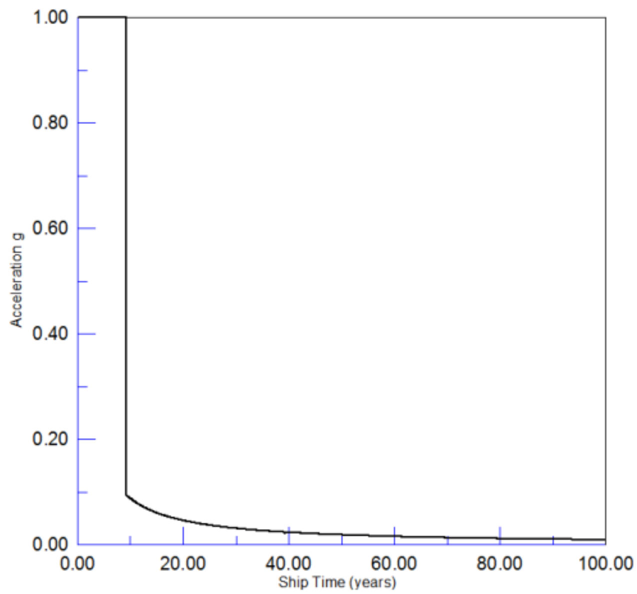


Figure 2: Ramjet acceleration profile due to stress on the magnetic scoop field sources.

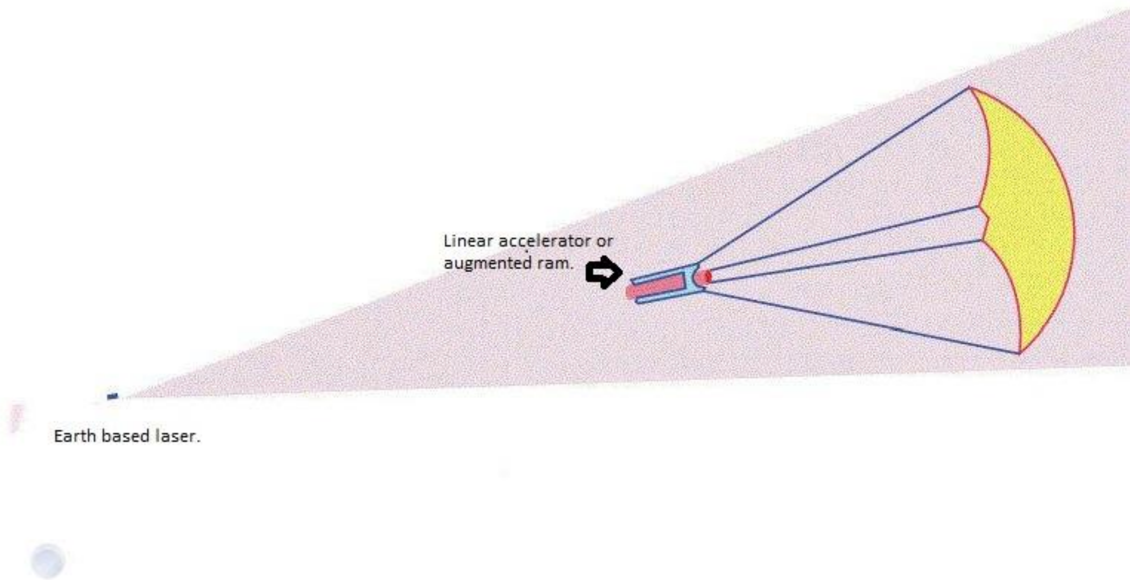


Figure 3. Schematic of Laser Powered or Augmented Ramjet.

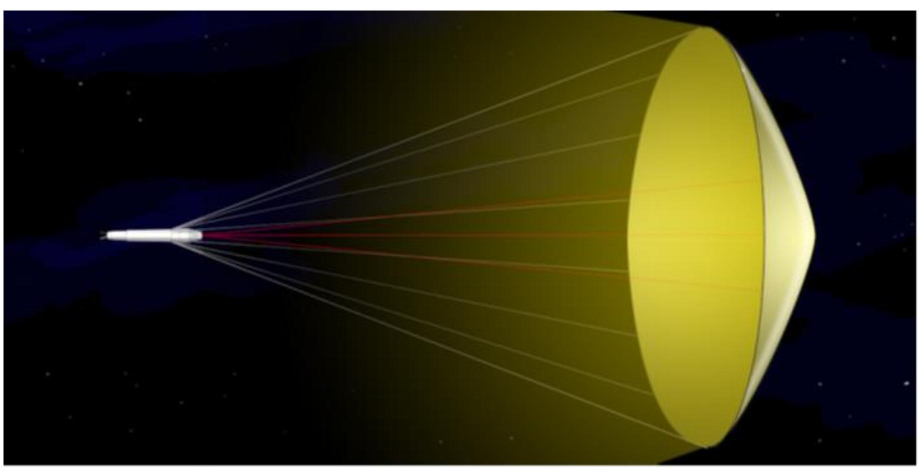


Figure 4. The ‘para-sail’ laser collector hybrid interstellar ramjet, before transition to interstellar ramjet mode. The graphene sail could be eaten as fuel.

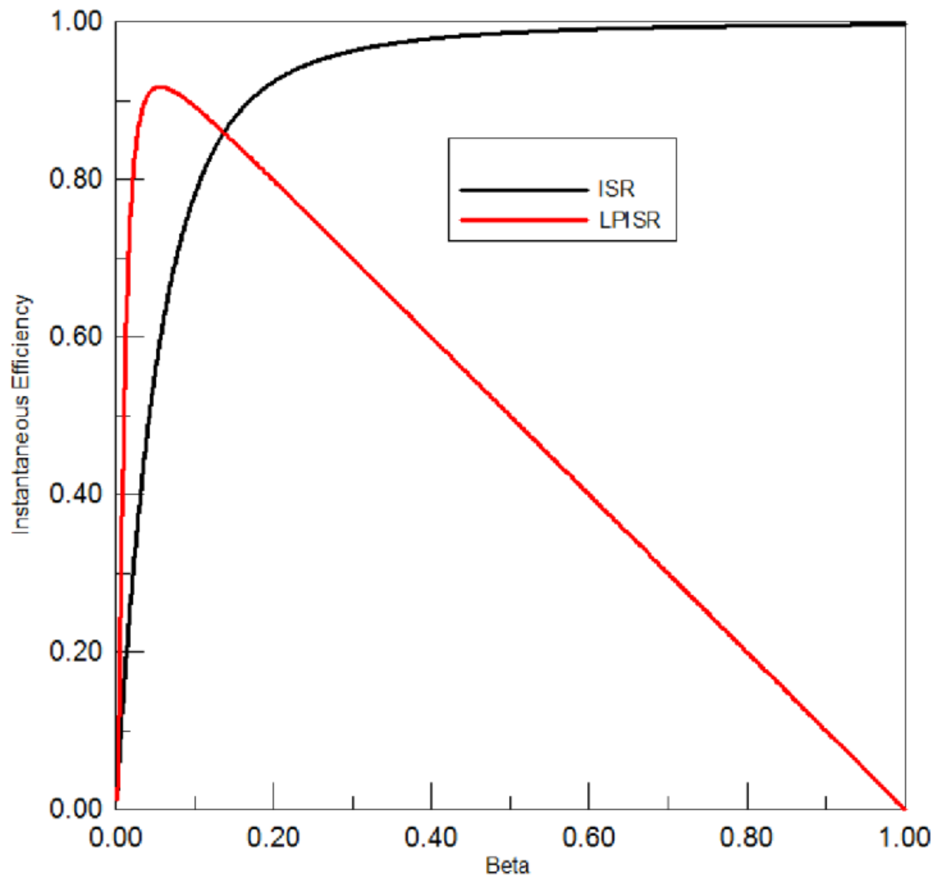


Figure 5: Ramjet efficiency vs beta = v/c.