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The Enhanced Starshot Concept: Beyond Breakthrough Starshot, towards an Enhanced Framework for Interstellar Travel

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ABSTRACT

Breakthrough Starshot is a project that envisions interstellar travel to the Alpha Centauri star system by accelerating Light sail interstellar probes named StarChip to $15 - 20\%$ is a revolutionary idea. The concept of focusing a light beam from a phased array of ground-based lasers on the Light sails of these StarChips to accelerate them to $15 - 20\%$ speed of light is unparalleled. However, this concept would still take between 20-30 years to complete the journey, and, moreover, traveling to more distant celestial bodies would still remain a constraint. This paper introduces an enhanced version of their concept, which can make interstellar travel more feasible. This new version is named the Enhanced Starshot Concept (ESC) and builds on the original idea by placing a constellation of laser-emission satellites in high Mars orbit and customizing the StarChip's design to have more Light sails. This customized StarChip is named Sailchip-X. The essence of this enhanced concept is to use space-based solar power to accumulate solar energy for these laser-emitting satellites so that the Light sail can have multiple boosts of acceleration, increasing its velocity cumulatively to $40 - 50\%$ speed of light. The Enhanced Starshot Concept improves the original idea by allowing the Sailchip-X to travel at a significantly higher speed, making it more cost-effective and sustainable.

INTRODUCTION

One of the biggest challenges technology has faced is interstellar travel. With today's technology and resources, it is extremely difficult for us to send probes, satellites, etc., to distant celestial bodies. However, the idea proposed by 'Breakthrough Starshot' [1] involves accelerating a very tiny spacecraft named StarChip [1] to 15-20% of the speed of light using a multi-kilometer phased array beam of lasers with a total power of 100 GW for a duration of 3-6 minutes [2], traveling to the Alpha Centauri star system. While it makes interstellar travel feasible, traveling at $15 - 20\%$ speed of light will still take the StarChip 20 years to reach the star system and an additional 4 years to receive the data on Earth.

This paper proposes a concept, similar to the Breakthrough Starshot, that can potentially accelerate the StarChip to $40 - 50\%$ of the speed of light. The Enhanced Starshot Concept (ESC) relies on space-based solar power (which is predicted to be possible by 2045). We use this technology to power a constellation of laser-emitting satellites orbiting Mars, using the laser systems to focus laser beams on the customized StarChip, accelerating it to $40 - 50\%$ the speed of light. With this concept, we can accelerate the customized StarChip multiple times and cumulatively increase its speed to $40 - 50\%$

speed of light, reducing the time it takes to reach the Alpha Centauri star system by a significant amount. Also, we can aim to send more StarChips to distant celestial bodies for future missions.

The Enhanced Starshot Concept is essentially an extension of the Breakthrough Starshot- an enhanced version of their technology- which could potentially revolutionize interstellar travel. It relies on solar power, which we have continuous access to, making it scalable and sustainable not only for Breakthrough Starshot but also for future interstellar missions.

METHODOLOGY

This paper introduces the Enhanced Starshot Concept, building upon the Breakthrough Starshot framework, which could have a substantial advantage over the original concept. This is an exploratory notion and is an attempt to present a concept that could potentially help us reach 50% speed of light. A review of the original framework of Breakthrough Starshot was conducted using various sources, which were cited in the paper and referenced from Wikipedia. A detailed analysis of the StarChip and the Propulsion system was conducted, and based on this review, potential modifications were identified and implemented that could make the project more efficient and sustainable. An evaluation of space-based solar power was done through different publicly available video materials and relevant sources. The calculations and table presented in the paper were independently carried out by the author.

Based on the information evaluated, some assumptions across different sources are also taken into account for this paper. The orbit of Mars is assumed as the staging environment for this project due to its reliable solar power and the fact that human and robotic missions have already successfully reached Mars, demonstrating its accessibility for current space technology. The assumed efficiency of the light sail is 10%, and this assumption is made by accounting for the material properties of the light sail and the thermal energy produced with every burst. This assumption is made for the purposes of theoretical exploration. The value of laser energy per burst is based on Breakthrough Starshot's concept; they have stated using 100 GW of power for about 3-6 minutes. The value mentioned in this paper is 100 GW for 6 minutes, corresponding to approximately 3.71×10^{13} joules of energy.

THE ENHANCED STARSHOT CONCEPT

The Breakthrough Starshot mission intends to launch a "mothership" carrying about 1000 tiny spacecrafts, known as StarChip, to a high-altitude Earth orbit. A phased array of ground-based lasers will then focus a light beam on the Light sails of these StarChips, one by one, to accelerate them to $15 - 20\%$ speed of light. They will deliver 100 GW of power for about 3-6 minutes through the focused light beam, which will accelerate the probe to $15 - 20\%$ speed of light, making the journey to the Alpha Centauri star system possible. Enhanced Starshot Concept introduces an improved and modified version, helping the Sailchip-X (customized StarChip discussed in 3.1) reach $40 - 50\%$ speed of light.

The Enhanced Starshot Concept envisions launching the same "mothership", discussed in Breakthrough Starshot, carrying thousands of Sailchip-X and assumes their deployment in high Mars orbit. Unlike Breakthrough Starshot's concept of a phased array of ground-based lasers focusing a light beam on the sails of these spacecraft to accelerate them to their target speed, the Enhanced Starshot Concept intends to place a constellation of Laser Satellites in the orbit of Mars. These Laser Satellites will include a laser-emission system within them (the design of a Laser satellite is discussed in Section 3.2 of the paper); a phased array of lasers from these laser emission systems will focus a light beam multiple times, as it accumulates solar energy, on the Light sail of Sailchip-X to accelerate the probe multiple times, cumulatively increasing its velocity to reach a target speed of 0.5 c . The amount of power delivered from these phased arrays of lasers to the Light sail will be the same as discussed in the Breakthrough Starshot project, which is 100 GW for 6 minutes or 3.71×10^{13} joules of energy. The Sailchip-X carries multiple Light sails, each used in sequence. A laser beam accelerates the probe via one sail, which is then dropped to reduce mass before the next sail is deployed and struck. Repeating this process enables cumulative acceleration, reaching a final velocity of 0.5 c. Unlike a single boost of acceleration, this concept relies on multiple boosts of acceleration with the deployment of a new Light sail to achieve the target velocity of 0.5c. The detailed process of acceleration of the Sailchip-X is discussed in Section 1.1 of the paper.

A very important requirement for the Enhanced Starshot Concept to accumulate solar energy is through the future technology: microwave space-based solar power [3]. As these laser satellites will be located on the orbit of Mars, they will only receive about $30 - 40\%$ of solar energy relative to what Earth does, and it will take a large amount of time to collect 3.71×10^{13} Joules of energy. For this reason, the Enhanced Starshot Concept intends to take the help of microwave space-based solar power, as it is assumed to generate 1 GW of solar power [3], which will take very little time to accumulate 3.71×10^{13} joules of energy.

THEORETICAL SETUP

Sailchip-X: The customized StarChip

Breakthrough Starshot aims to develop a fleet of Light sail interstellar probes named as StarChip [1], which is a centimeter-sized, gram scale interstellar spacecraft. The Light sail(1g) and other components of StarChip ($\sim 1\ g$) add up to 2 grams [4] of total weight. The components of StarChip include cameras, batteries, photon thrusters, and protective coating. Other than this, it contains a Light sail envisioned to be no longer than 4×4 meters [5]. It is aimed to be made of very thin material and be able to reflect most of the incident light. This design of the StarChip can withstand only one huge laser burst, which is said to be 100 GW for 6 minutes or 3.71×10^{13} joules of energy. The main reason for this is heat management: even if the Light sail reflects most of the light, a small fraction of heat energy is bound to be absorbed, and at this amount of power, multiple laser bursts could vaporize the sail [6] [1]. This design of the StarChip can allow it to attain a maximum velocity of $15 - 20\%$ speed of light, as stated by the Breakthrough Starshot initiatives, whereas the Sailchip-X design proposed in this paper can allow the StarChip to accelerate to 50% speed of light. The modified design involves adding multiple Light sails stacked one after another to the StarChip, so that we can fire multiple huge laser bursts, allowing the probe to gain more acceleration over time, increasing its velocity, and reach a target speed of 50% speed of light. The customized StarChip will be referred to as the Sailchip-X.

In detail, this idea works as follows: Assuming that the Sailchip-X initially has X number of Light sails; A focused light beam from the phased array beam of lasers would strike the Light sail, allowing it to accelerate at a certain speed. After gaining acceleration, we drop the Light sail, which was struck by the light beam, decreasing the total weight of the StarChip. Next, another focused light beam from the phased array beam of lasers would strike the next Light sail in order, boosting the Sailchip-X's acceleration to achieve a greater speed. Repeating this process allows the StarChip to gain acceleration after each strike, increasing its speed, and reaching a target velocity of 0.5c. The total number of Light sails required to reach the target velocity is discussed in Section 4 of the paper.

Laser-emmision system

This section presents an exploratory notion about the laser-emission system. The Enhanced Starshot concept envisions a constellation of satellites orbiting Mars. The reason for having a constellation of satellites is that, as we have access to continuous solar power, this process can be repeated several times for multiple acceleration phases of the Sailchip-X. A ground-based laser system, as discussed in Breakthrough Starshot, can face challenges such as interference of the laser beam with atmospheric particles, which
would deflect the laser beam's direction.
As this is just an exploratory notion, only the two main components required in the satellite's design are discussed: a fiber laser-emission system and rectennas. The idea is to have each satellite equipped with a fiber laser-emission system, and each of these satellites would emit a laser beam that would combine into one phased array of lasers with a combined power of 100 GW . A fiber laser-emission system is a preferable option, due to high power and efficiency, and produces a high-quality, stable beam.

As mentioned earlier, the main source of power for the satellites is solar power, but solar power is less efficient on Mars, receiving about 43% less sunlight than Earth. Hence, accumilating 3.71×10^{13} joules of energy, equivalent to 100 GW for 6 minutes, becomes a time-consuming task. The main source of energy for the satellites will be microwave space-based solar power. As Microwave space-based solar power are envisioned to generate 1 GW of power, given rectennas spanning across several kilometers are the receivers. [3], they can be the primary source of power for satellites. Accordingly, rectennas, instead of conventional solar panels, should be integrated into the satellites for efficient microwave absorption. These rectennas will absorb energy in the form of microwaves and convert it to DC, which shall be the power input for the fiber laser emission system. Each satellite should be equipped with rectennas, and the constellation of satellites together shall form a grid of rectennas spanning several kilometers to absorb microwaves, as shown in Figure 1.

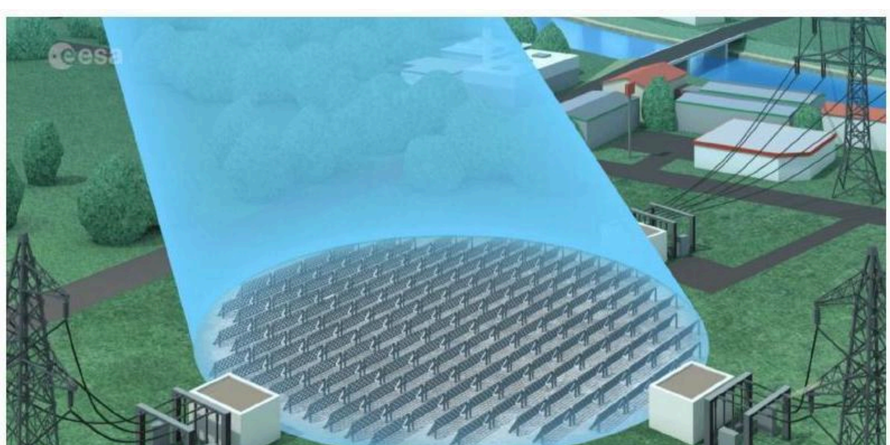

Figure 1: Rectennas present on Earth recieving microwave space-based solar power (the image is provided for the reader to help visualize the staging environment). [7]

Technological Challenges

The concept discussed above also has many technological limitations. The fiber laser emission system at an industrial scale can produce 24 KW of power, and with this power output, we would require millions of satellites to have a combined output of 100 GW . As the satellites need to accumulate 100 GW of power and then emit it to the Sailchip-X, there will be a lot of thermal energy and heat produced. For this purpose, we would also require efficient heat management and cooling systems in the satellite to manage the huge amount of heat produced with each laser burst. The heat management systems shall also be capable of handling continuous cycles of energy as the concept relies on multiple bursts. It should also be able to manage temperature spikes during the 6 minutes of energy accumulation of energy accumulation.

As the Sailchip-X travels farther at an immense speed, there will be certain difficulties in beam pointing and sail alignment; this difficulty also worsens as the Sailchip-X travels towards distant bodies. Hence, the laser beam shall be tighter and focused in order to provide maximum power and momentum to the Light sail.

LASER-POWERED SAILCHIP-X KINETIC ENERGY AND LIGHT SAILS REQUIRED CALCULATIONS

For the purposes of this study, we assume a total probe mass of 2 grams, consistent with the target mass of the StarChip as outlined in Umrigar and Anderson (2025) [4].

Light sails required

Required Values and details

- Speed of light: $c = 3 \times 10^{8} m/s$
- Laser energy per burst: $E_{laser} = 3.71 \times 10^{13} J$
- Assumed efficiency of the Light sail: 10%
- Kinetic energy per burst: $KE_{burst} = 0.1 \times E_{laser} = 3.71 \times 10^{12} J$
- The calculations assume ideal conditions:

1. Constant efficiency of the light sail (10%)
2. There is no beam divergence
3. There is no structural degradation
4. Perfect reflectivity of the light sail

Calculating the number of Light sails required:

- Each laser burst gives the probe:

$K_{burst} = 3.71 \times 10^{12} J$

which is 10% of $3.71 \times 10^{13} J$ laser input energy.

- You perform x bursts (one per sail), so the total kinetic energy after all bursts is:

$K_{tot} = x \cdot K_{burst}$.

- Final mass (probe + last sail) is:

$m_f = 2\,g = 0.002\,kg$.

- Use relativistic kinetic energy:

$K = (\gamma - 1)mc^2$

where:

$\gamma = \frac{1}{\sqrt{1-(v/c)^2}}$

- Goal: find the smallest integer x such that:

$v \geq 0.5c$.

Find required γ for $v = 0.5c$

$\gamma_{req} = \frac{1}{\sqrt{1-(0.5)^2}} = \frac{1}{\sqrt{0.75}} \approx 1.154700538$

Let the value of γ after the outcome of all bursts be considered as γ_{final}

So we need, $\gamma_{final} \geq \gamma_{req}$

or, $\gamma_{final} \geq 1.154700538$.

Relate γ to total KE at final mass

$\gamma_{final} = 1 + \frac{K_{tot}}{m_f c^2} = 1 + \frac{xK_{burst}}{m_f c^2}$

Require:

$1 + \frac{xK_{burst}}{m_f c^2} \geq \gamma_{req}$

Rearrange for x :

$x \geq \frac{(\gamma_{req} - 1) m_f c^2}{K_{burst}}$

Input values

$\gamma_{req} - 1 \approx 0.154700538$ $m_f c^2 = 0.002\ kg \times (3 \times 10^8\ m/s)^2 = 1.8 \times 10^{14}\ J$ $K_{burst} = 3.71 \times 10^{12}\ J$

So

$x \geq \frac{0.154700538 \times 1.8 \times 10^{14}}{3.71 \times 10^{12}} = \frac{2.78460968 \times 10^{13}}{3.71 \times 10^{12}} \approx 7.50$

Since x must be an integer(a fractional burst/sail is not physically meaningful), the minimum integer satisfying this is:

$x = 8.$

Short verification

- Eight bursts deliver $8 \times 3.71 \times 10^{12} = 2.968 \times 10^{13}\ J$ total KE .
- With final mass 0.002 kg , that corresponds to $\gamma \approx 1.165$ and $v \approx 0.513c$, which exceeds $0.5c$.
- Seven bursts would only give $7 \times 3.71 \times 10^{12}\ J$, which yields $\gamma < 1.1547$, so $v < 0.5c$.

Kinetic energy and cumulative velocity calculations for multiple boost phases

Required Values and details(Restated) with Relativistic formulas.

- Speed of light: $c = 3 \times 10^8\ m/s$
- Laser energy per burst: $E_{laser} = 3.71 \times 10^{13}\ J$
- Assumed efficiency of the Light sail: 10%
- Kinetic energy per burst: $KE_{burst} = 0.1 \times E_{laser} = 3.71 \times 10^{12} J$
- The mass reduction of 0.001 kg after every burst is due to sail shedding, as clarified in section 4.1.
- Relativistic formulas:

$\gamma = 1 + \frac{KE_{cumulative}}{mc^2}$ $v = c\sqrt{1 - \frac{1}{\gamma^2}}$

Energy and Velocity Table

Burst	Mass (kg)	E_{laser} (J)	KE_{burst} (J)	$KE_{cumulative}$ (J)	γ	$v(\ m/s)$	v/c
1	0.009	3.71×10^{13}	3.71×10^{12}	3.71×10^{12}	1.00	2.86×10^{7}	0.095
2	0.008	3.71×10^{13}	3.71×10^{12}	7.42×10^{12}	1.01	4.27×10^{7}	0.142
3	0.007	3.71×10^{13}	3.71×10^{12}	1.113×10^{13}	1.02	5.57×10^{7}	0.186
4	0.006	3.71×10^{13}	3.71×10^{12}	1.484×10^{13}	1.03	6.89×10^{7}	0.230
5	0.005	3.71×10^{13}	3.71×10^{12}	1.855×10^{13}	1.04	8.36×10^{7}	0.279
6	0.004	3.71×10^{13}	3.71×10^{12}	2.226×10^{13}	1.06	1.01×10^{8}	0.336
7	0.003	3.71×10^{13}	3.71×10^{12}	2.597×10^{13}	1.10	1.23×10^{8}	0.410
8	0.002	3.71×10^{13}	3.71×10^{12}	2.968×10^{13}	1.16	1.54×10^{8}	0.513

DECLARATION OF CONFLICT OF INTERESTS

The author declares that there are no conflicts of interest regarding the publication of this article.

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CONCLUSION

In this paper, the Enhanced Starshot Concept (ESC), which is an enhanced framework of Breakthrough Starshot, is discussed. ESC envisions the probe reaching $40 - 50\%$ of the speed of light and focuses on the concept of multiple acceleration boosts to cumulatively increase the probe's speed. For this purpose, ESC fosters changes in the design of the StarChip, naming the design Sailchip-X, and also discusses a constellation of satellites placed in the orbit of Mars as the laser-emission system. The laser-emission system has certain benefits, such as sustainability due to its main source of power being microwave space-based solar power, but it also has certain technological challenges, as discussed in the paper. This concept can also be helpful in accelerating it to much higher speeds as well, potentially allowing us to reach extremely distant bodies in a reasonable time frame. In summary, the Enhanced Starshot Concept mainly talks about some improvements made in the initial framework of Breakthrough Starshot, which could potentially make interstellar travel more achievable and efficient.

REFERENCES

[1] Paul Gilster. Breakthrough Starshot: Mission to Alpha Centauri - Centauri Dreams - centauri-dreams.org. https://www.centauri-dreams.org/2016/04/12/breakthrough-starshot-mission-to-alpha-centauri, 2016. [Accessed 11-062025].
[2] Avi Loeb. Breakthrough Starshot: reaching for the stars.https://lweb.cfa.harvard.edu/~loeb/Loeb_Starshot.pdf, 2016.
[3] adminMP. Space-based solar power (SBSP) and prospects for the development of alternative energy in orbit - Max Polyakov - maxpolyakov.com. https://maxpolyakov.com/space-solar-power-as-a-type-of-alternative-energy-source/#:~:text=The%20energy%20production%20of%20one,orbital%20stations% 20and%20ground%20bases. [Accessed 16-06-2025].
[4] Tyler A. Anderson C. J. Umrigar. Energy needed to propel a tiny spacecraft to Proxima Centauri, and, an unstated assumption in Einstein's 1905 paper - arxiv.org. 2025.
[5] Breakthrough Initiatives - breakthroughinitiatives.org. https://breakthroughinitiatives.org/forum/5?page=2. [Accessed 03-07-2025].
[6] Neel V. Patel. The Starshot Breakthrough Light Beam Is Really a Million Lasers, Which Is Insane inverse.com. Inverse article, 2016. [accessed 16-7-2025].
[7] European Space Agency. Receiving rectenna on the ground. https://www.esa.int/ESA_Multimedia/Images/2022/08/Receiving_rectenna_on_the_ground, 2022. [Online; accessed 11-09-2025].