How will we receive signals from interstellar probes like Starshot?

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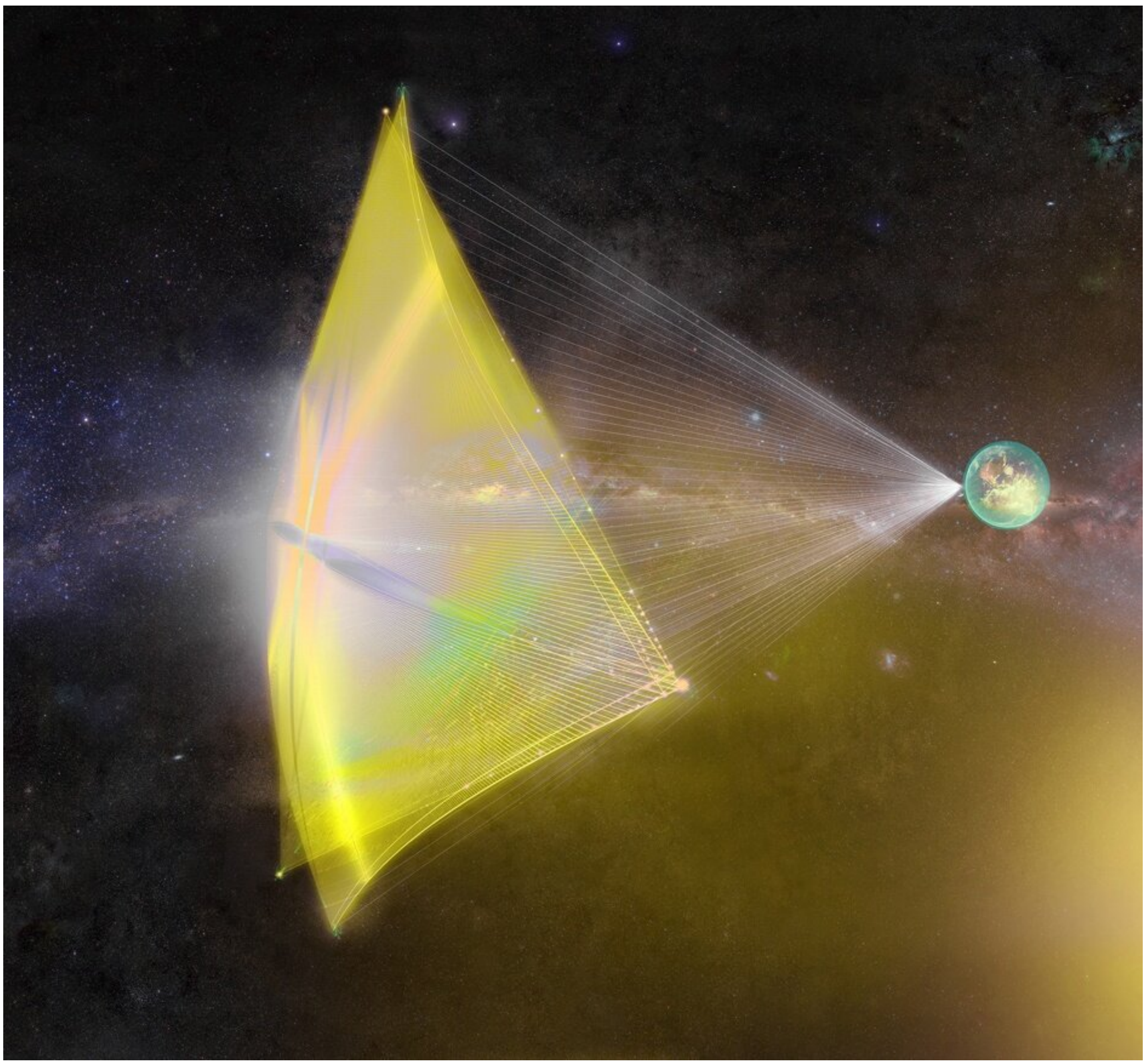


Credit: Breakthrough Starshot

In a few decades, the Breakthrough Starshot initiative hopes to send a sailcraft to the neighboring system of Alpha Centauri. Using a lightsail and a directed-energy laser array, a tiny spacecraft could be accelerated to 20% the speed of light (0.2 c). This would allow Starshot to make the journey to Alpha Centauri and study any exoplanets there in just 20 years, thus fulfilling the dream of interstellar exploration within our lifetimes.

Naturally, this plan presents a number of engineering and logistical challenges, one of which involves the transmission of data back to Earth. In a recent study, Starshot Systems Director Dr. Kevin L.G. Parkin analyzes the possibility of using a laser to transmit data back to Earth. This method, argued Parkin, is the most effective way for humanity to get a glimpse of what lies beyond our solar system.

The author of the study, Dr. Kevin Parkin, has served as systems director of Breakthrough Starshot since 2016. Prior to this, he was awarded the Korolev Medal by the Russian Federation of Astronautics and Cosmonautics for his groundbreaking work in microwave thermal propulsion. He also founded the San Francisco-based aerospace company Parkin Research, which specializes in the development of cost-saving technologies.

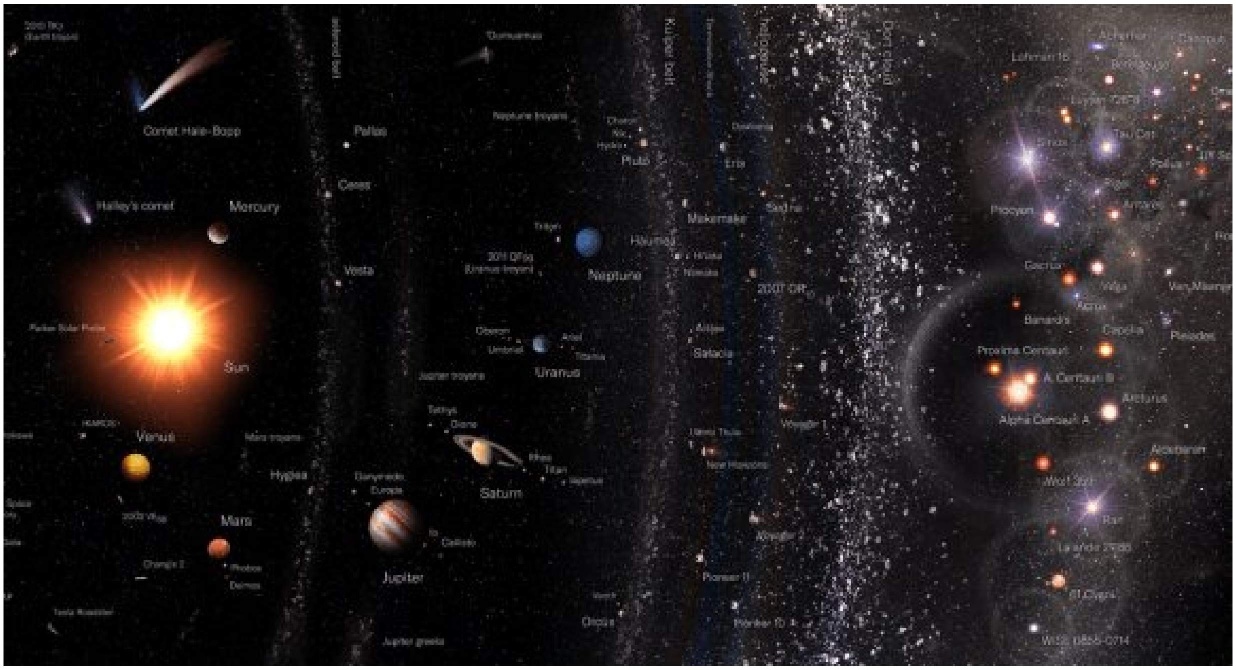
Addressing the issue of a communications downlink, Dr. Parkin sought to calculate the best option for an integrated sail and spacecraft (sailcraft). To this end, he considered the possibility of a tight-beam laser transmitter aboard the 4.1-m (13.45 ft)-diameter Starshot sailcraft, which would begin transmitting to a 30-meter (~100 ft) telescope on Earth once it reached Alpha Centauri.

This array would take the form of a 100-watt optical phased array (embedded in the sail itself) that uses lasers to transform power from the interstellar medium (ISM). Dr. Parkin envisions that the array would transmit data at a wavelength of 1.02 micrometers, which would then be received at 1.25 micrometers by the telescope—which places the transmissions in the near-infrared/near-ultraviolet spectrum.

This type of downlink presents many advantages over communications that rely on radio wave or microwave transmissions. As Dr. Parkin told Universe Today via email:

"Relative to microwaves, lasers have a thousand-fold shorter wavelength, and so form a much tighter beam from Alpha Centauri to Earth… The advantage of transmitting 100 watts over the full area of the sailcraft is that the Earth-based receiver shrinks to a 30-meter telescope, something that is very likely to be around in a decade or two."

Dr. Parkin also added that within this same amount of time, improvements in filters and detectors will allow for arrays of meter-class telescopes that can work together to receive signals from the spacecraft. However, such a communications system also comes with its share of drawbacks, one of which is directly related to its tight-beam nature. Basically, the array will have to be pointed accurately at Earth in order for the data to be received.

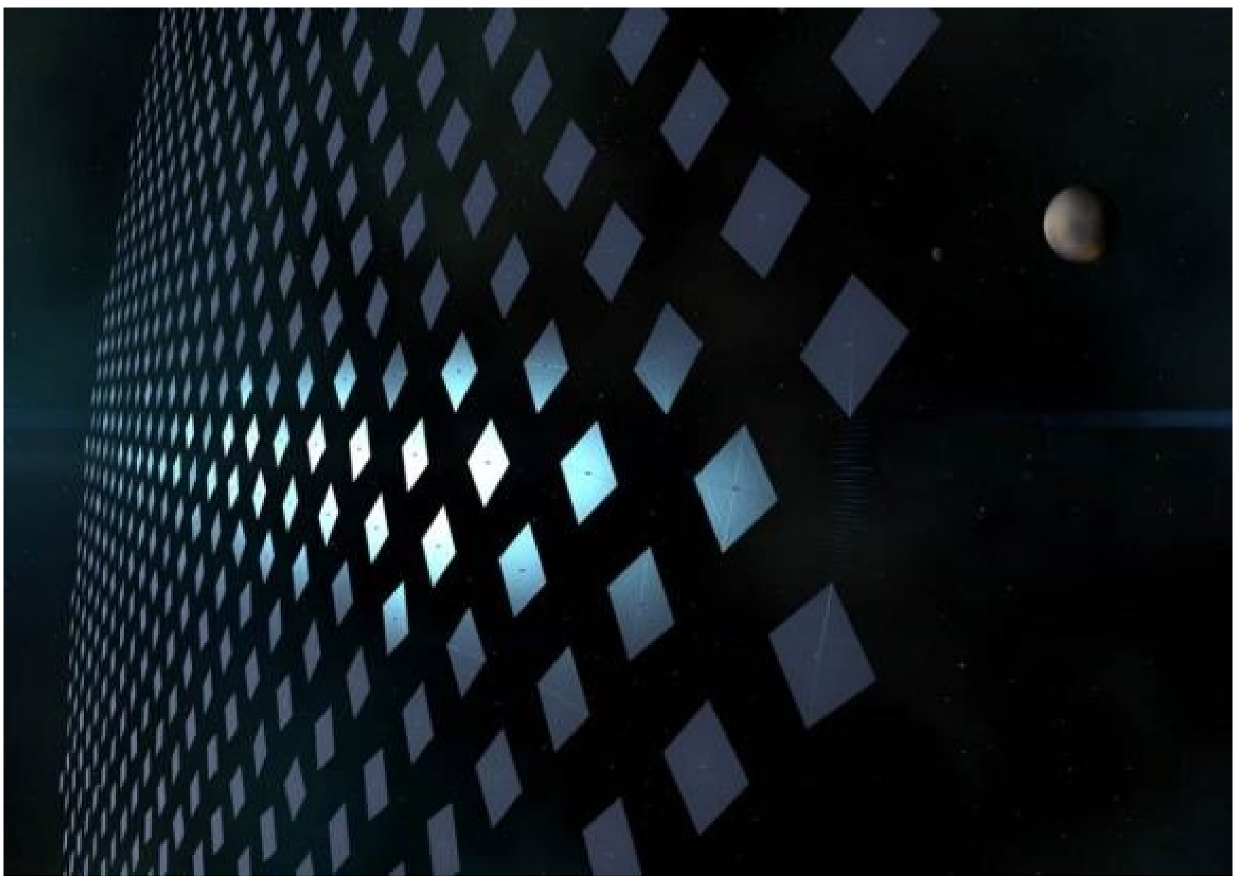


The Observable Universe on a logarithmic scale. Credit: Pablo Carlos Budassi/Wikipedia Commons

"If the sailcraft senses the relative direction of the interstellar medium, that points back to Earth (or, at least, where Earth was when the sailcraft launched)," said Dr. Parkin. "From there, it will have to find the sun. Then, because the beamwidth is only a tenth of the distance from the sun to the Earth, the sailcraft will have to calculate or find the relative position of Earth and point toward it."

However, this can be overcome by sending multiple spacecraft, which is in keeping with the overall vision of Starshot. For years, Breakthrough Initiatives has been contemplating how a fleet of lightsail-towed "nanocraft" that weigh just a few grams could enable interstellar travel and exploration. As Dr. Parkin explained: "Economics favors launching light and often, such as one 4-gram sailcraft per week (the energy cost is only $6M). This means that there will not just be one downlink, but many downlinks. As seen from Earth, the various sailcraft will be lined up across the sky, forming a sort of pipeline of sailcraft at various stages of rendezvous with Alpha Centauri."

An added benefit of sending multiple spacecraft with direct downlinks, adds Dr. Parkin, is the possibility of crosslinks between them. In this scenario, the connection to Earth would become a data pipeline of its own—a pipeline within a pipeline. This would reduce the risk of losing essential data and allow sailcraft that have already passed through the Alpha Centauri system to relay information to the ones that are still en route.



Swarm of laser-sail spacecraft leaving the solar system. Credit: Adrian Mann

A final recommendation Dr. Parkin made in the paper was the inclusion of a distributed algorithm that would allow the spacecraft to function in tandem and with a degree of autonomy, each one responsible for mapping a different part of the Alpha Centauri system. Dr. Parkin indicates that this would cut down on the "decision-act cycle," which is incredibly slow over interstellar distances:

"The advantages to doing that are enormous—the entire system could be scouted and mapped before the first data ever reaches Earth. Notionally, the first sailcraft might spot a distant planet as a point of light that moves between images, and on that basis, constrain its orbit so that the next sailcraft can maneuver to pass at closer range, resolving surface details. Subsequent sailcraft can build up maps, track surface features, and discover most of the planets and moons in the system over time."

To break it all down, Dr. Parkin envisions a fleet of sailcraft conducting automated explorations of distant star systems. The first to enter the system would be responsible for mapping out the planets and moons, the next wave would characterize their orbits, and those that follow will observe them at close range and map and monitor their surfaces.

In this respect, the concept presented here addresses one of the greatest challenges of interstellar exploration, which is the difficulty of communicating with probes over such great distances. Prof. Abraham Loeb—the Frank B. Baird Jr. Professor of Science at Harvard University and the chair of the Breakthrough Starshot Advisory Committee—told Universe Today via email:

"The communication link that Kevin's paper addresses is one of the biggest challenges for the Starshot program. The vast distance to the nearest star, 4.24 light-years, and the low power of the transmission, implies a faint signal and hence a large receiver on Earth. There is no opportunity for sending commands to the spacecraft in real time because the shortest two-way trip of light signals would take 8.48 years."

Finally, Dr. Parkin addressed the burning question of what needs to happen before a project of this nature can be realized. While the paper presents several creative solutions to the challenge of communications, one of the most pervasive issues dogging Starshot is the fact that future advancements and innovations are necessary in order to bring it into the realm of cost effectiveness.

"To realize the full capabilities of a sailcraft as described here may take 100 years, or it may be a byproduct of commercially driven research over the coming few decades," he said. "Microwave phased arrays have been in use for 50 years, but optical phased arrays are not here yet, and will take a lot of work to integrate into a ceramic sail. Power generation from the interstellar medium is arguably unique to Starshot and needs research, but the payoff is that the power available for the downlink is orders of magnitude greater than otherwise possible."

Then again, any and all concepts for interstellar or deep space exploration present their share of challenges, some of them particularly daunting. And like so many other technical hurdles facing the Starshot team, these challenges have a way of inspiring creative and innovative solutions. In the meantime, all we can do is wait and hope that progress will happen and create new opportunities.

Previous studies by Dr. Parkin includes the 2018 study, "The Breakthrough Starshot System Model," which appeared in *Acta Astronautica*. This paper describes the Starshot mission and concept in detail and how it would benefit human exploration, not just in the interstellar domain but also within the solar system.

More information: A Starshot Communication Downlink: arxiv.org/ftp/arxiv/papers/2005/2005.08940.pdf

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