Harvard University's Professor Avi Loeb, Chair of the Breakthrough Starshot project, tells *SciTech Europa Quarterly* about how the initiative plans to launch ultra-fast light-driven nanocrafts to Alpha Centauri within the next generation

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Breakthrough Starshot: reaching for the stars

The Breakthrough Initiatives were founded in 2015 by Yuri and Julia Milner to explore the Universe, seek scientific evidence of life beyond Earth, and encourage public debate from a planetary perspective. The Breakthrough Starshot project aims to demonstrate proof of concept for ultra-fast light-driven nanocrafts, and lay the foundations for a first launch to Alpha Centauri within the next generation. Along the way, the project could generate important supplementary benefits to astronomy, including solar system exploration and the exploration of near-Earth asteroids.

SciTech Europa Quarterly spoke with the Chair of the project's Advisory Committee, Professor Avi Loeb at Harvard University, USA, about the project's concept, design, technology, target, and future.

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Public announcement of Breakthrough Starshot (April 12, 2016). With Yuri Milner, Stephen Hawking, and Freeman Dyson

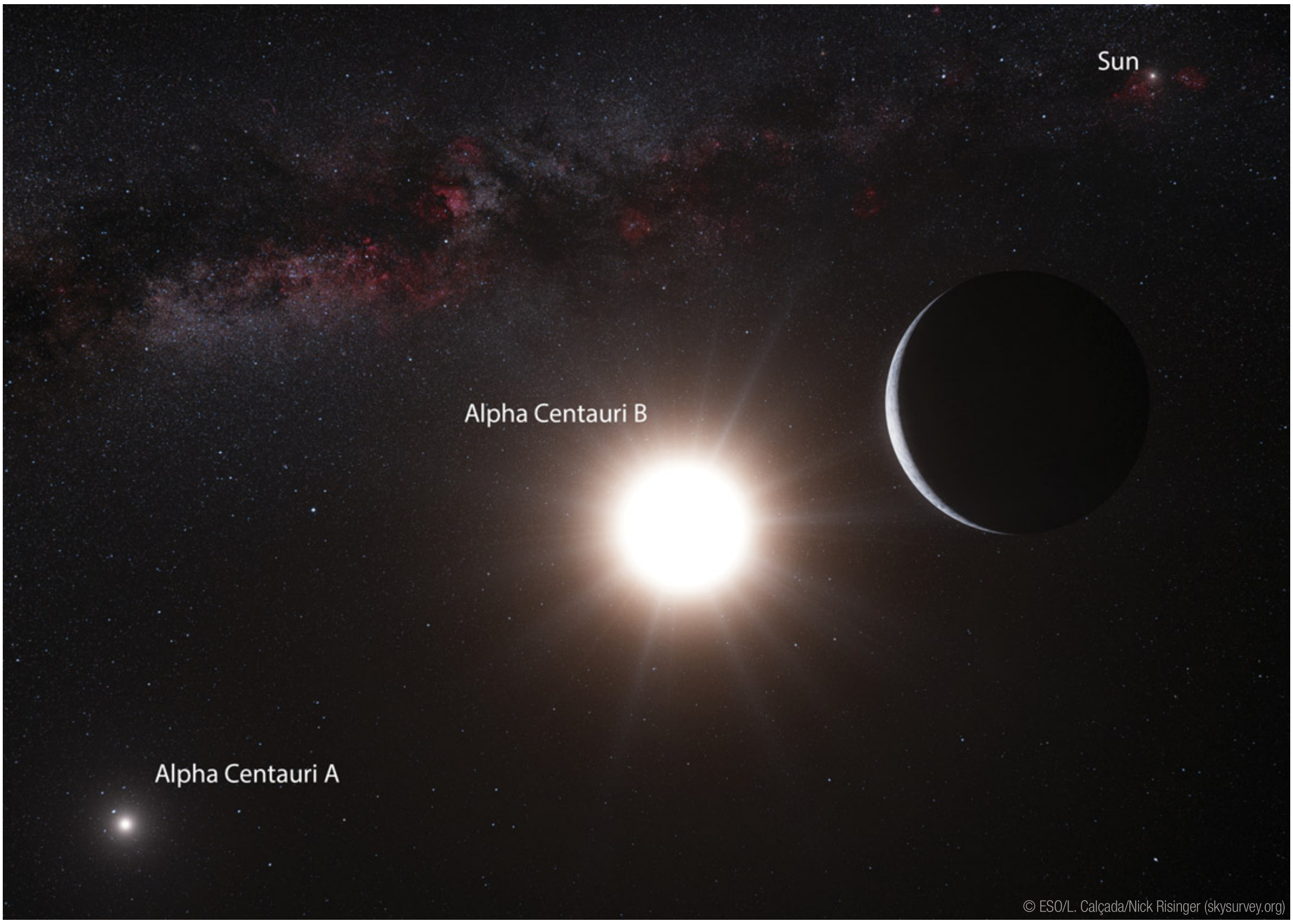
What is the rationale behind Breakthrough Starshot? Why was Proxima b chosen as the target?

The general goal of the project is to send a probe, including a camera, to the Alpha Centauri system, our nearest star system, in order to better understand what it is like there. When we first considered the project, we didn't know that there is a habitual planet (Proxima b) next to the nearest star, Proxima Centauri; we just imagined that this was a possibility and so the question was whether we could send a camera that would fly by that planet and take photographs so that we can tell if there is vegetation there, or whether there is an ocean; we wanted to see it from up close, rather than from a distance.

Of course, it is possible to gain some limited information from remote observations using telescopes, but that is very different from flying by and actually seeing the details. The main challenge that Proxima Centauri – or the Alpha Centauri system more generally – poses is the fact that it is four light years away, and if we want to get there within our life time, say in 20 years, then the spacecraft needs to move at a fifth of the speed of light.

The only method that seemed potentially feasible when we first started to consider this challenge was light sail technology, where, rather than carrying fuel, you use a powerful laser to push against a lightweight sail. We established the perimeters for this about six months later, finding that we would need to use a very powerful laser (some 100 gigawatts in power) which will be delivered to the sail for a few minutes. If the sail weighs roughly a gram, and the payload (including the camera, navigation device, and communication device) weighs roughly a gram, then it is possible to reach a fifth of the speed of light by pushing on the sail, which is a few metres in size, with the laser.

The sail needs to be in place outside of the Earth's atmosphere, otherwise the friction would prevent it from working. As such, the concept sees the craft being released from a 'mother ship' above the atmosphere, with the laser being fired from the ground through the atmosphere to the sail. We have investigated the parameters of the system and have not come across anything which should prevent us from realising this ambition. The amount of power required from the laser is roughly the same as that which is required deliver to the space shuttle into orbit. But, of course, because our craft weighs so little it is able to reach exceptional speeds.



The Alpha Centaury system

Even at a fifth of the speed of light, it would take about 20 years to reach the Alpha Centauri system, and then another four years for the signal to be communicated back to us on Earth. Nevertheless, this will be the very first time that humans have been able to bridge the gap between stars, which will be a major milestone.

The first phase of the project will take place over the next decade or so, and we will be focusing on the technology development and investment in the most critical technologies that are essential for this concept to work, such as the laser beams. We will also be working to develop the materials for the sail. In terms of material selection, we have already done some preliminary work and have also made some progress towards optimising the shape of the sail, although there is still work to be done. The sail needs to ride on the laser beam in a stable fashion. These are the two critical technologies we are starting with. After that, we will progress into the communication technology and other issues.

We have already selected about a dozen proposals from experimental teams that are able to work on the laser technology, and a similar number will work on the sail technology. Funding for this work has now begun to be allocated.

How will the sail differ from existing solar sails?

A solar sail follows a similar concept, in that it is lightweight and is pushed by light. Although, of course, in the case of a solar sail this light comes from the Sun. Sunlight, however, has a limited amount of power, perhaps a kilowatt per metre, while with our laser it is possible to reach a much stronger power per unit area, not least because the material has been tuned to fit the frequency of the laser. A second advantage of using a laser is also the fact that the amount of power you can put on a given area is under your control. You can also tailor the shape and time evolution of the laser beam, such that it will optimise the launch. The power for the laser will ultimately come from the Sun because we envisage it being powered by energy generated from solar cells.

Given that this is a long-term initiative, how do you hope to be able to build on the future discoveries set to be made, for example, by the JWST?

Of course, any scientific information about the Alpha Centauri system, especially Alpha Centauri a and b and Proxima Centauri, will be very helpful. Proxima Centauri is a dwarf star that is just 12% of the mass of our Sun, and Proxima b is a planet located 20 times closer to its star than the Earth is to the Sun. Despite this relative proximity, the planet is potentially habitable because the Proxima Centauri is much fainter than the Sun, meaning that it needs to be 20 times closer in order to reach a similar surface temperature to Earth. However, we only know that this planet exists; we don't know if it has an atmosphere, which is necessary to support life because otherwise water ice will instantly become a gas and evaporate into space – which is why Mars doesn't have liquid water on its surface. As such, it is important for us to find out whether Proxima b has an atmosphere. One way to do that will be with the James Webb Space Telescope.

It is possible to tell, without visiting the planet, that Proxima b is tidally locked to its star and thus that there is a permanent day side and a permanent night side, with a temperature contrast between them because the same side of the planet always faces the star. The permanent day side is much hotter than the night side, and that temperature contrast can inform us about whether there is an atmosphere because an atmosphere would moderate the temperature difference. For instance, there would be rain, and if there was an ocean, that would moderate the temperature even further.

We would also like to know just how much hotter the day side is relative to the night side, and that can be determined by observations with the James Webb Space Telescope because it will be able to look at the light of that planet as it moves around the star and, by analysing the light curve, we should be able to discern the level of temperature contrast.

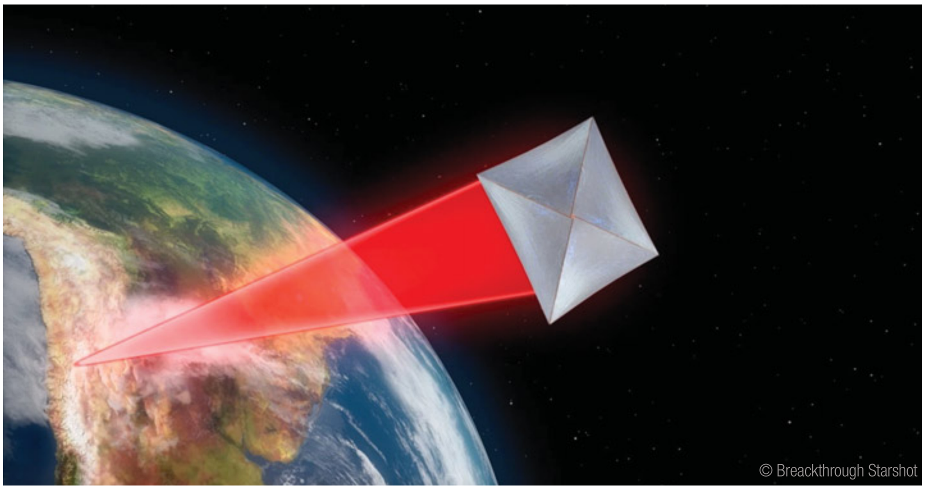
By modelling that light curve, moreover, it will be possible to compare that to an environment, for example, of bare rock, and so gain some potential insights as to what the surface of the planet is like. The James Webb Space Telescope thus has the potential to provide us with evidence supporting the idea that there is an atmosphere on the planet and, of course, if this proves to be the case then it will become a much more attractive place for us to visit with Starshot.

There is also the potential of finding other planets in the habitable zone around Alpha Centauri a and b and, with future telescopes such as JWST there will be teams working to identify such planets, both in this system and elsewhere, which is another exciting thing to look forward to in the next decade.

Our plan for Starshot also involves building a dedicated space station to look for habitable planets around Alpha Centauri a and b. As such, moving forwards we stand to learn a lot more about Proxima b in terms of its habitability, whether it has an atmosphere, and whether there are more planets in the vicinity which we would like to visit.

Does that mean that the target is relatively flexible, in that should the JWST etc. provide information to suggest that there is no life on Proxima b, but that another planet elsewhere may have, then you can switch targets?

Absolutely. In principle, the spacecraft are relatively cheap, with most of the investment being spent on the infrastructure (the laser and launch systems). Once that is in place, that spacecraft would only cost in the region of $100 (~€88) each, and so the idea would be to launch a number of them (perhaps one per day or one every few days) and we could potentially aim them at different targets, with some visiting other planets and systems as they travel to their final destination. And, given the speed at which these spacecraft – which will be the size of a typical mobile telephone – will be travelling, they would be able to reach a number of interesting targets within the Solar System in relatively short timeframes. For instance, it would take just a few days to reach Pluto, rather than the nine and half years that it took NASA's New Horizons mission. We could also investigate the existence of so-called 'planet nine', which is believed to exist at the edge of the Solar System, or we could fly by other objects of interest and take photographs of them. For example, the first interstellar asteroid was recently discovered travelling through the Solar System. However, even if chemical rockets had been used it would have been impossible to chase 'Oumuamua' down and take photographs of it. However, had Starshot been operational, we could have reached it quite easily. The Breakthrough Starshot laser beam could also be used to ablate and hence deflect a dangerous asteroid.



The research and development phase of Breakthrough Starshot, which will take place over the next decade, will work towards demonstrating that it is indeed possible to combine numerous small lasers into a coherent laser beam that is powerful enough to power the spacecraft up to a fifth of the speed of light

In your last article you argued that there is a need for more investment in building better observatories and searching for a wide variety of artificial signals in the sky. How would you like to see this being approached?

The search for extra-terrestrial life is becoming a very prominent theme in space-based plans for the future, particularly in the context astrobiology, which is the combination of biology and astrophysics, but also in the mainstream, with projects and missions searching for signatures of primitive and microbial life, for example, in the composition of a planet's atmosphere. If we can infer the composition to contain oxygen, for instance, or methane, then that could be indicative of microbial life.

At the same time, one can imagine searching for intelligent, technological civilisations by looking for 'techno-signatures'. We already have the technology to search for such signals in space, including the industrial pollution of atmospheres, artificial lights, the redistribution of heat, mega-structures, and so on. It could also be possible to discover the burned surfaces of planets which have seen devastating changes in their climate as a result of the activities of a past or current civilisation, or perhaps the remains of other civilisations which no longer exist. This could be form the basis of 'space archaeology', where people search for the signatures of civilisations that are now extinct.

The search for both primitive and technologically advanced extra-terrestrial life should be pursued because we know that humans exist on Earth, and we know that about a quarter of all the stars in the Milky Way galaxy have a planet the size of the Earth orbiting them which has a surface temperature similar to Earth's, meaning that liquid water may exist of their surface, just like Proxima b, and so the chemistry of life as we know it may be there. The realisation that Earth-like planets are so common should push us to search for either microbial or technological life, and I think the next decade will be very exciting as people start to do so. If we are successful, then this would answer one of humanity's most fundamental questions: 'are we alone?'

What are your short-term goals for Starshot?

In the first instance, we want to demonstrate the technologies, and this will constitute the research and development phase over the next decade as we work to demonstrate that we are able to combine numerous small lasers into a coherent laser beam that is powerful enough for our task. We will also be working to demonstrate that we can build a lightweight sail made of a material that is strong enough to sustain the forces acted upon it by the laser and, indeed, that is designed in a shape that can ride, in a stable fashion, on the laser beam. Then, we want to be able to demonstrate that we

While the surface composition of Proxima b remains unknown, it is evident that this planet is tidally locked to its star and thus that there is a permanent day side and a permanent night side, with a temperature contrast between them

can communicate back to Earth across the vast distances that the project will involve.

These are significant challenges, but they are not insurmountable, and people are very excited about what we hope to achieve, especially the general public, because since the Apollo missions there have been very few others to demonstrate such a level of ambition. Going to another star for the first time is much more challenging than many of the other missions we have seen in recent years, and it is exciting because it could potentially help us understand our place in the Universe. If we find a technologically advanced civilisation, of course, then that would change everything; we could learn from them, we could see advanced technologies that we haven't even dreamed of.

Developing these technologies will also have a lot of benefits for other applications. Where do you think those are going to lie moving forwards?

The impact on astronomy will be tremendous because, at the moment, the field is focused on the physical Universe in the sense that we imagine a Universe populated with stars and planets that are totally devoid of life. If we do find any evidence of life, either microbial or technological, then this will entirely change our perception of the sky.

When I look up at the stars in the sky at night, it is easy to think of them as just the lights from distant planets and stars. But if I imagine that there could be another being out there looking back at me, then that changes everything; not least my own perception of my place in the Universe.

Finding life on another planet would have a profound impact on human psychology, too, as well on philosophy and religion, and not just on the science of astronomy. In a general sense, it is not too much to presume that this discovery would also have an impact on the way people behave and how they interact with each other here on Earth, because we might come to feel as though we are a part of a single, unified team, humanity, and stop focusing so much on mundane issues like geographical boarders.

The other thing to keep in mind is that, one way or another, humans will have to leave Earth at some point. The latest we can imagine staying here is for another billion years or so, when the Sun will heat the Earth up to the point that the oceans will boil. But before that, there could be an asteroid impact of the type that killed the dinosaurs, while climate change or a nuclear war could leave the Earth uninhabitable. Currently, should any of those things happen, then we risk extinction as we are unable to leave the Earth for other planets in any real meaningful way. As such, we need to start exploring how we are going to stretch out into space and, in order to do that, we must start at the beginning with small spacecraft so that we can demonstrate that it is indeed possible to reach very great distances. That is just the first step; beyond that, we will start exploring how to move larger objects at faster speeds.

You cannot start the journey without the first steps. Even the critics who argue that the necessary technologies don't exist yet will admit that you have to start somewhere; you have to have a dream. Otherwise, we will never leave the Earth and we will be left to our fate.

Professor Avi Loeb holds the following positions:
Frank B. Baird, Jr., Professor of Science, Harvard University
Chair, Harvard Astronomy Department
Director, Institute for Theory and Computation (ITC)
Founding Director, Black Hole Initiative (BHI)
Chair, *Breakthrough Starshot* Advisory Committee
Chair, Board on Physics and Astronomy, National Academies

Professor Abraham Loeb
Harvard University
Chair, Breakthrough Starshot Advisory Committee

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aloeb@cfa.harvard.edu