Lightsail nanocrafts in deep space

by Astro Calisi

A few months ago, to be exact on April 12 this year, it was presented the *Breakthrough Starshot project*, a space program that aims to send a fleet of a thousand very small spacecraft to Alpha Centauri, the closest star to us (actually a system consisting of three stars). The spacecraft, weighing a few grams each, would be driven by the "light pressure" produced by powerful laser beams placed on Earth. This would allow to reach a 1/5 speed of light in about 10 minutes, so being able to cover the distance that separates us from Alpha Centauri - just over 4 light years (more than 40,000 billion kilometers) - in about twenty years. When arrived near the system, the ships would collect data on the stars that compose it and the planets orbiting around them (1), even taking photos at close range, then sending them all to Earth by radio signals.

One of the main supporters of the project is the scientist Stephen Hawking, according to which "within a generation" we will have sufficient knowledge and technical resources to make it happen. This certainty is based mainly on so-called "Moore's Law", extended for the occasion to the entire field of technology. According to this law, the power of microprocessors and memory chips on average doubles every 18 months, while the production costs decrease in the same proportion. So the prediction is not based on already achieved technical results, but on the ones which are presumed to achieve if progress will continue with the same current rates.

Other celebrities involved, for various reasons, in the project, with the estimated cost of around 5/10 billion dollars: Pete Worden placed in charge of the project; the Russian tycoon Yuri Milner, who has agreed to pay $ 100 million for the first phase of research and development; Mark Zuckerberg, founder of Facebook; there are also astronomers such as Saul Perlmutter, Nobel Prize for physics in 2011, and Avi Loeb, Harvard, and the mathematician Freeman Dyson.

On the project website, *Breakthrough Initiatives* (https://breakthroughinitiatives.org/Initiative/3), in addition to the dangers to which the ships will be exposed in their long journey such as the ones due to the crossing of interstellar dust clouds or bumps with microparticles, which would cause the destruction of the spacecrafts, they are described other important issues to be resolved in order to implement the project.

When we read the brief descriptions of these issues and the ways in which is intended to overcome them, we have the distinct impression that the enthusiastic supporters of the project have stopped at a rather superficial level in the examination of the difficulties to be faced, rather focusing on the most spectacular aspects of the project, the ones that most affect public's imagination. There are very important problems - in my opinion - which are not taken into account. Furthermore, it seems that no one notices how few contributions to knowledge this project will give.

All these aspects I'll try to take care on the following pages, referring as much as possible, to what is shown in the project website. I will outline the critical issues and omissions, adding here and there, observations and suggestions. For convenience of presentation, I will proceed by points:

1) How to prevent the huge energy, estimated at 1 Gw, addressed on a sail of the size of 4x4 meters, damages the spacecraft? On the website it is calculated that if the sails would absorb only 1/100,000 of the energy that strikes them, they would be heated from about 60 Kw / m^2, that is 60 times the solar lighting: a very large energy but not yet sufficient to melt the sails. On the other hand, it is observed that they are in phase of experimentation special dielectric mirrors, with a much higher reflection capacity..

It must however make sure that the reflective surface is absolutely homogeneous: even the smallest imperfection or irregularity could cause irreparable damage to the sail.

2) How to make the structure of the sails and their anchorages to the spacecraft tough enough to withstand the enormous stress to which they will be subjected during the launch phase? In fact, considering a period of 10 minutes, to achieve a speed of 1/5 than the one of light, it will be necessary an acceleration of 100 km/sec^2, ie an acceleration 10,000 times higher than Earth's gravity.

Assuming that the weight of each ship is 10 grams on Earth, in the launch phase, they would weigh on the sails and anchor with 100 Kg. All this, if it doesn't damage the spacecrafts, it is difficult that does not have repercussions in terms of deformation of the sails and consequently on the final trajectory of the spacecrafts. The website talks about the possibility to offset the deformation caused by mechanical stresses using graphene compounds, which have shown the property to change their size according to the applied voltage.

I haven't got sufficient specific knowledge to assess the effectiveness of this solution; but it seems to me quite problematic.

3) Problem of correct positioning of the spacecrafts at launch. There are several aspects to be considered.

a) A first aspect is constituted by the need to assume the spacecrafts the correct orientation with respect to the laser battery positioned on Earth's surface. According to the project, the ships should be brought into an orbit 60,000 km from Earth by an appropriate vector, and then be released. At that point, each spacecraft will open its wing, waiting to be projected towards Alpha Centauri. But, moving freely in space, nothing prevents them from turning in on themselves, taking on the most various positions relative to Earth. It may even happen that at the time of receiving the laser drive, any of them is upside down, that is, with the sail towards Earth's surface. However, any different orientation with respect to the optimal position, represented by the spacecraft with the sail pointing directly to space, in the direction of Alpha Centauri, could cause oscillations that affect the final trajectory of the spacecraft.

b) So that the spacecraft trajectory is correct, it is necessary that at launch, each spacecraft is on to intersect the route that ideally connects the laser cannon to Alpha Centauri. The slightest deviation from that point, in fact, would cause a deviation from the expected position at the end of the journey of more than 600,000 km (nearly twice Earth-Moon distance) for each initial meter.

One of the conditions required is that the orbit imprinted to vessels by the vector steps to the point determined with absolute precision, as well as, of course, that the laser beam is activated exactly in correspondence of that point (or, better, 0.2 seconds before, for giving time to the beam to cover the distance that separates the cannons from the ships).

c) In the project the launch is described as if it occurs from a well-defined and stable position. To use a sporty image, it is like if they were considering a property golfer in front of a ball to be sent directly into a hole, placed at a great distance.

In the case of ships we are faced with a very different situation. In fact, we have that Earth, where the laser cannons are placed, moves due to the rotation around its own axis, giving it to every point of its surface, in 10 minutes, an arc that subtends an angle of 2.5 °.

To return to our sports metaphor, we must think to a golfer, running perpendicular to the road which leads into the hole, who have to hit a ball, in motion too, with the aggravating circumstance that the strike lasts 10 minutes, during which the player continues his run.

Although it can be assumed that the momentum of every ship as a result of its orbital motion is completely neutralized by the enormous pulling power of the laser beam, the movement of Earth's surface, with attached laser cannons, continues during the 10 minute launch, leading to a remarkable change in the angle at which the laser beam strikes the spacecraft.

Someone might suggest to overcome this problem by placing the laser batteries exactly at the south pole, in order to compensate Earth movement by a slight rotation of the laser pointers. But, in that case, we should build the huge structure used to launch the spacecraft in an extremely inhospitable and hard to reach place. In addition, it would pose the problem to supply the equipment: being out of the question to build in the vicinity new electric plants capable of providing the needed energy (which is estimated to equal to one of mid-sized 100 nuclear power plants), we should build tens of thousands kilometers of power lines for the transport of electricity produced by existing plants.

It is a very serious problem, which is completely ignored in the project website, being scarcely credible the hypothesis mentioned on the same site, to correct the spaceships route after their launch. In fact, having the spaceships weight to be very low (in the order of 10 grams), the amount of fuel delivered to feed any micro-thrusters could not reasonably exceed 2/3 grams.

When we have to deal with very large quantities, or very small ones, far away with situations from our ordinary experience, sometimes we don’t realize all the implications. In the case of ships, we have that each of them would weigh - as seen - around 10 grams, about how much a common gun bullet, which travels on average between 250 and 400 m/sec. If it's hard to imagine of being able to deviate by an appreciable extent the trajectory of a projectile during its run by microscopic lateral thrusters, much more difficult it will be with respect to ships travelling about 200,000 times faster, with a kinetic energy of 40 billion of times higher.

Numbers fail to make good the magnitude of this difference. Well, then we must think that this energy is equivalent to the one of a gun bullet travelling at 300 m/sec, but with a weight of 400 thousand tons!

4) Problem of the *angular divergence* of the laser beam, that is, the angle with which a laser beam deviates from perfect parallelism. The laser beams, being constituted by monochromatic light, are much less subject to dispersion, with respect to ordinary light: they can, therefore, be concentrated in a very fine brush. Usually, depending on the materials and techniques used to produce the beam, the angular divergence is between 0.2 and 0.8 milliradians, corresponding to a deviation of 0.2-0.8 mm per meter path by the beam. Suppose we can reduce, with the right devices, the angle of divergence at 0.001 milliradians. In this case, at the distance of 100 Km, the beam diameter would be of only 10 cm. It seems a very small divergence, but already at a distance of 384,000 Km (equal to that which separates the Moon from Earth) the diameter would have reached a size of 384 meters.

At the maximum distance reached by the laser beam during the boost phase of the spacecraft (about 18 million km), the beam diameter would become 18 Km, corresponding to a radiating surface of about 250 km^2. A sail of the dimensions of 4x4 meters (16 m^2) would receive accordingly an extremely small fraction of the total energy radiated by the laser.

In the project website it is assumed to further reduce the divergence angle. At this point, however, other problems arise. Suppose for simplicity of being able to determine at will the divergence angle: if we take as a reference the instant of departure (at 60,000 km from Earth) and we did so that the beam corresponds exactly to the surface of the sail, in the final phase of the thrust (about 18 million kilometers away) it would have taken a diameter of 1.2 km, with a considerable reduction of boost power.

If we did the opposite, assuming as a reference the maximum distance to be achieved, it would happen that, at start, the sail would be hit by a laser beam diameter of just 1 cm. This means that the entire radiated power (and mechanical stress) would focus on a very small area: the sail probably would melt or otherwise deform seriously as a result of the stress, compromising the correct addressing of the spacecraft toward its goal.

5) When the ships arrive near Alpha Centauri, the pressure of the light coming from the star system, moreover, made more powerful by the displacement of the light towards the violet due to the high approach speed, push the sails to position itself in the direction of Earth, forming a sort of screen for communications departing from the spacecraft.

This disadvantage could be avoided by releasing the sails once the launch phase, although this will not be without problems: the release mechanism must be built to withstand the heavy weight of the spacecraft (100 kg) during the launch.

6) Issue of the radio transmitters power.

40 million billion Km correspond to 7,000 times the maximum distance ever achieved by a terrestrial spaceship. For a radio signal, it means reducing by about 50 million times its power received on Earth. The sensitivity of any radio receiver can't be increased indefinitely. It reaches its limit when the signal is so weak as to be confused with the background noise produced by the equipment. There are reasonable grounds to think that a radio signal from a similar distance, taking into account the reduced size of the batteries that power the transmitter, is situated well below this limit.

This problem must be appropriately detailed, since it would not make sense to launch spaceships that succeed with great difficulty, in reaching their destination, making findings, and then not be able to receive their messages because of the low power of their transmitters.

7) The ships survived the long trip, which continue to follow the planned route - after some of them were damaged at launch, others clashed with stray objects in space or have still suffered failures of their equipment, others went dispersed in space areas of no use for the project - should collect data and take pictures once they arrive near Alpha Centauri. However, at a speed of 60,000 km/sec, the time available for the close-range observation would be very low.

Just think that the probe *New Horizons*, which in 2015 collected data on Pluto and took very detailed pictures of its surface, was traveling at just 16 km / sec, and it came close up to 12,000 km from the planet. The ships of *Breakthrough Starshot project*, because the very high speed imprinted them, instead would cover a distance equal to the Earth-Moon in just 6 seconds. If you also consider the difficulties to focus on objects that are constantly changing size and angle, and, as for their small size, the camera lenses will have a poor ability to zoom, you can easily understand that the photos taken will be very few and very quality poor.

Moreover, at a speed of 1/5 of light it is not remotely thinkable to place the spacecraft into orbit in one of the stars of the system, or even around its planets.

These considerations give us the real measure of results that even in the best case, one can reasonably expect from the project.

The very truth is that such an enterprise, despite its novelty, does not promise a significant increase of our knowledge. From this point of view, certainly other projects already implemented, such as the aforementioned *New Horizon*, for close observation of Pluto, or the one that sent to Mars rover *Opportunity* to observe and analyze Mars surface, or the *Rosetta* mission, which involved a close encounter with a comet - to name a few - have contributed much more to increase our spatial knowledge than what will make *Breakthrough Starshot*. This, taking into account the huge costs involved and the many uncertainties that weigh on its success, makes legitimate to raise doubts on whether to pursue the course of its realization.

My opinion is that the resources which one wants to engage in this project could be used much more profitably for other less unrealistic projects, which have more positive impact on men’s lives. I’m thinking about projects now almost within our reach, such as the construction of stable human settlements on the Moon and Mars, which would be followed closely by detailed exploration, by robotic probes, of the larger asteroids between Mars and Jupiter’s orbits and the satellites of Jupiter itself.

The exploitation of probable deposits of precious minerals and the management of services related to the space colonization, in addition to requiring a scientific and technological effort of considerable magnitude, and therefore constitute a factor of progress, could greatly contribute to ease the conflicts that still affect large masses of people. In fact, gradually shifting the focus "predatory" by big economic groups and governments from Earth's surface to the surrounding space, it would have the effect of reducing one of the main reasons behind the tensions and wars that plague our planet.

NOTE

(1) Since 2012, we know that one of the two stars of the main system has got a planet, *α Centauri Bb*; while few days ago it has officially been given the news of the existence of another planet orbiting Proxima Centauri, the third star of the system, which is almost 2,000 billion kilometers from the main couple.

[Translation into English by the autor]