9 Breakthrough Starshot

In 2016, the Breakthrough Foundation announced the creation of the Breakthrough Starshot program to fund basic research into a flyby mission to our nearest star system, Alpha Centauri. The plan envisages using an array of lasers to propel a spacecraft with a mass of a few grams to a velocity of one-fifth that of light. Science fact or science fiction? Let's take a look at the maths.

Firstly, how relativistic is a velocity of one-fifth the velocity of light? We can quantify this using the Lorentz factor:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}, \tag{1}$$

where v is the velocity of the craft and c is the velocity of light. The Lorentz factor can be used to determine by what factor do measurements of the world around you differ from your everyday, low-velocity expectations. If $v = 0$ then $\gamma = 1$, which indicates no difference from your common sense expectation of how the world should look. As v increases towards c, γ increases without limit to become infinite at $v = c$. In practice, no object with mass can attain this limit in Einstein's special theory of relativity.

Taking $v = 0.2\,c$ gives $\gamma = 1.02$. At these velocities, though certainly fast, most measurements of the world you would make (e.g. lengths, time) would only differ from your stationary perspective by 2 percent – small enough to ignore in order to simplify the following analysis.

A $m = 1$g mass moving at $v = 0.2\,c$ has a kinetic energy equal to

$$\text{KE} = \frac{1}{2}mv^2 = 0.5 \times 0.001\,\text{kg} \times (0.2 \times 3 \times 10^8\text{ms}^{-1})^2 = 1.8 \times 10^{12}\text{J}. \tag{2}$$

This amount of energy must be imparted to the spacecraft. The plan intends to achieve this by aiming a single laser or an array of lasers totalling approximately 1 gigawatt of power at the spacecraft's light sail.

One gigawatt equals 10^9Js^{-1}. Shining the laser on the light sail for 2000 seconds (33 minutes) will impart a total energy of approximately $2 \times 10^9\text{Js}^{-1} \times 1000\text{s} = 2 \times 10^{12}\text{J}$ to the spacecraft. You are now travelling at 0.2 times the speed of light (wave to Mars as you rush past) and you will reach Proxima Centauri (the nearest outpost of the Alpha Cen system) in 21 years.

Meanwhile, back in the real world, what other considerations have we ignored? The craft plus sail must have a combined mass of order 1g. The most powerful sustained use lasers in operation today produce around 500 kW of power. Assuming we reach 1 MW soon, this means coordinating an array of 1000 such lasers to produce the required power. Assuming the laser is aimed correctly, the challenge then becomes one of making the sail sufficiently reflective so that it does not vaporise when illuminated (as a result of the tiny fraction of energy absorbed instead of reflected). I leave discussions of miniaturisation (power, communication, science package) to another day.