New photonic devices are said to be poised to enable the next leap in deep space exploration

November 1 2018

New directed energy propulsion systems may enable the first interstellar missions, with small, robotic spacecraft exploring neighboring solar systems, according to experimental cosmologist Philip Lubin. He will present these and other advances at The Optical Society's (OSA) Laser Congress, Light the Future Speaker Series, 4-8 Nov. in Boston.

Imagine a wafer-thin spacecraft powered by laser light capable of speeds greater than one quarter the speed of light—fast enough to reach the closest neighboring star to our solar system within 20 years, or something closer to home, like getting people to Mars in a month. By tapping into photonics-driven propulsion, researchers are well on their way to making this seemingly impossible science-fiction achievement a reality, said Lubin, who is a professor of physics at the University of California, Santa Barbara.

The research results Lubin will describe stem from NASA's Starlight and Breakthrough Starshot programs, both of which support advanced research in photonics. Lubin is director of the Starlight program.

"Photonics, the production and manipulation of light, is already a part of our daily lives—from cellphones to computers to light-emitting-diode (LED) light bulbs to fiber optics that carry your data all over the place—even though you may not see it," said Lubin. "You can point to practical examples of photonics in everyday life and it appears to have nothing to do with interstellar flight, but in fact it does, because it's synergistic with the technology you need to achieve interstellar flight."

One of the greatest challenges in validating this photonics concept as it relates to propulsion is the demonstration of the laser power required to accelerate the proposed/hypothetical spacecraft, according to Lubin.

Synthesized optics for directed energy propulsion systems

Large directed energy systems are not built using a single gigantic laser, but instead rely on beam combining, which involves the use of many very modest power laser amplifiers.

"Our system leverages an established typology called 'Master Oscillator Power Amplifier' design," said Lubin. "It's a distributed system so each laser amplifier "building block" is between 10 and 1000 Watts. You can hold it in your hand. Instead of building a gigantic laser, you combine a lot of small little laser amplifiers that, when combined, form an extremely powerful and revolutionary system."

Lubin suggests an analogy with supercomputers, which are built using a large number of central processing units (CPUs). "By coherently combining billions of low poser laser power amplifiers—similar to the same power of a typical modern household LED—you suddenly have this amazingly capable directed energy system," he said.

Interstellar probes powered via laser light

Directed energy systems may enable interstellar probes as part of human exploration in the not-too-distant future, and they are at the heart of the NASA Starlight program and the Breakthrough Starshot Initiative to enable humanity's first interstellar missions. The same core technology has many other applications, such as rapid interplanetary travel for high mass missions, including those carrying people; planetary defense; and the search for extraterrestrial intelligence (SETI).

"Our primary focus currently is on very small robotic spacecraft. They won't carry humans onboard—it's not the goal for the interstellar portion of our program," said Lubin. "If humanity wants to explore other worlds outside our solar system, there are no other physically obtainable propulsion options for doing this—with two exceptions.

"One way would be if we could master a technological approach known as antimatter annihilation engines, which are theoretical propulsion systems that generate thrust based on energy liberated by interactions at the level of subatomic particles. But we don't currently have a way to do that," Lubin said, "and it involves a number of complexities we do not have a current path to solving.

"The other option is directed energy or photonic propulsion, which is the one we're focusing on because it appears to be feasible," Lubin said. In one variant, directed energy propulsion is similar to using the force of water from a garden hose to push a ball forward. Miniscule interstellar spacecraft (typically less than a kilogram and some that are spacecraft on a wafer) can be propelled and steered via laser light, he said.

"Miniaturizing spacecraft isn't required for all of the mission scenarios we're considering, but the lower the mass of the spacecraft the faster you can go," Lubin said. "This system scales in different ways than ordinary mass ejection propulsion."

So far, all of the rockets that have blasted off from Earth are based on chemical propulsion systems whose basic designs date back to World War II. They are just barely able to make it off the surface of the Earth and into orbit. Making a bigger rocket doesn't make it go faster, it just allows the rocket to carry more mass. Photonic propulsion works differently, because the less dense the payload the faster you go. So you want to lower the mass to go faster.

Like driving in a rain storm—in space

One significant challenge for relativistic spacecraft is radiation hardening, because "when we begin to achieve speeds close to the speed of light, the particles in interstellar space, protons in particular, that you plow into—ignore the dust grains for the moment—are the primary radiation source," said Lubin. "Space isn't empty; it has roughly one proton and one electron per cubic centimeter, as well as a smattering of helium and other atoms."

Smashing into those particles can be significant at high speeds because while they may be traveling slowly within their own frame of reference, for a fast-moving spacecraft they make for high-speed impacts.

"When you hit them it's like driving in a rainstorm. Even if the rain is coming down straight from the sky your windshield gets plastered because you're going fast—and it's quite a serious effect for us," Lubin said. "We get enormous radiation loads on the leading edge as the front gets just absolutely clobbered, whereas the rest of the spacecraft that is not the forward edge and facing in different directions doesn't get hit much at all. It's an interesting and unique problem, and we're working on what happens when you plow through them."

In terms of a timeframe for putting directed energy propulsion technology to work, "We're producing laboratory demos of each part of the system," said Lubin. "Full capability is more than 20 years away, although demonstration missions are feasible within a decade."

Getting to Mars quickly

The same core photonics technology in the NASA Starlight program also allows for extremely rapid interplanetary missions, including missions to Mars that could transport people in trips as short as one month. This would dramatically reduce the dangers to humans on the long journey to the red planet and is currently being studied as one option.

Trillion Planet Survey

Photonics advances also mean that we can now leave a light on for extraterrestrial intelligence within the universe if we want to be found—in case there is other intelligent life that also wants to know the answer to the question, "are we alone"?

Lubin's students explore this concept in their "Trillion Planet Survey" experiment. This experiment is now actively searching the nearby galaxy Andromeda, which has about a trillion planets, and other galaxies as well as ours for signals of light.

Combining Lubin's research with his students' experiment, there are opportunities for signaling life. When technological advances allow for the demonstration of lasers powerful enough to propel the tiny spacecraft, these lasers could also be used to shine a beacon towards the Andromeda Galaxy in hopes that any life form there could discover and detect that source of the light in their sky.

The reverse case is more interesting. Perhaps another civilization exists with similar capability to what we are now developing in photonics. They may realize, as we do, that photonics is an extremely efficient means of being detected across vast distances far outside our galaxy. If there is an extraterrestrial civilization that is broadcasting their presence via optical beams, like those proposed for photonic propulsion, they are candidates to be detected by a large scale optical survey such as the Lubin team's Trillion Planet Survey.

"If the transmission wavelength of an extraterrestrial beam is detectable, and has been on long enough, we should be able to detect the signal from a source anywhere within our galaxy or from nearby galaxies with relatively small telescopes on Earth even if neither 'party' knows the other exists and doesn't know 'where to point,'" Lubin said. This "blind-blind" scenario is key to the "Search for Directed Intelligence" as Lubin calls this strategy.

Planetary defense

Perhaps one of the most intriguing uses for photonics—closer to home—is to tap it to help defend Earth from external threats such as hits from asteroids and comets.

The same system the researchers are starting to develop for propulsion can be used for planetary defense by focusing the beam onto the asteroid or comet. This causes damage to the surface, and as portions of the surface are ejected during the reaction with the laser light, momentum would push the debris one way and the asteroid or comet in the opposite direction. Thus, little by little, it will deflect the threat, Lubin said.

"The long-term implications for humanity are quite important," he added. "While most asteroid threats are not existential threats, they can be quite dangerous as we saw in Chelyabinsk, Russia in 2013 and in Tunguska, Russia in 1908. Sadly, the dinosaurs lacked photonics to prevent their demise. Perhaps we will be wiser."

Provided by Optical Society of America