Ground-based lasers could accelerate spacecraft to other stars

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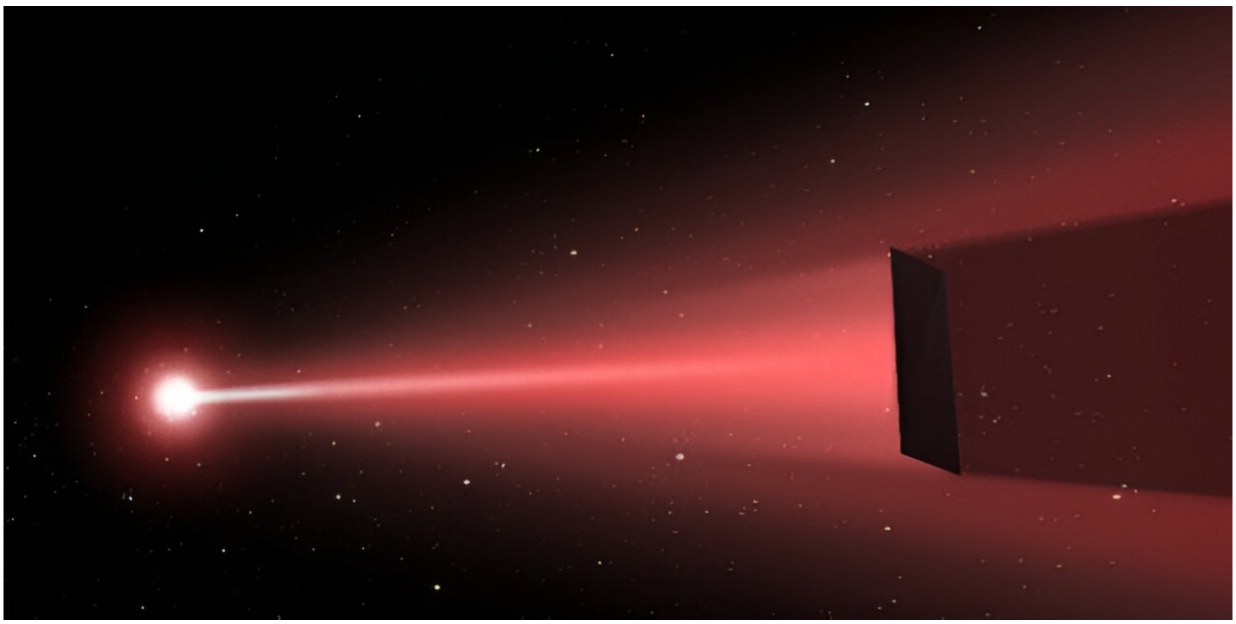

Artist’s impression of a directed-energy propulsion laser sail in action. Credit: Q. Zhang/deepspace.ucsb.edu

The future of space exploration includes some rather ambitious plans to send missions farther from Earth than ever before. Beyond the current proposals for building infrastructure in cis-lunar space and sending regular crewed missions to the moon and Mars, there are also plans to send robotic missions to the outer solar system, to the focal length of our sun's gravitational lens, and even to the nearest stars to explore exoplanets. Accomplishing these goals requires next-generation propulsion that can enable high thrust and consistent acceleration.

Focused arrays of lasers—or directed energy (DE)—and lightsails are a means that is being investigated extensively—such as Breakthrough Starshot and Swarming Proxima Centauri. Beyond these proposals, a team from McGill University in Montreal has proposed a new type of directed energy propulsion system for exploring the solar system. In a recent paper, the team shared the early results of their Laser-Thermal Propulsion (LTP) thruster facility, which suggests that the technology has the potential to provide both high thrust and specific impulse for interstellar missions.

The research team was led by Gabriel R. Dube, an Undergraduate Research Trainee with the McGill Interstellar Flight Experimental Research Group (IFERG), and Associate Professor Andrew Higgins, the Principal Investigator of the IFERG. They were joined by Emmanuel Duplay, a graduate researcher from the Technische Universiteit Delft (TU Delft); Siera Riel, a Summer Research Assistant with the IFERG; and Jason Loiseau, an Associate Professor with the Royal Military College Of Canada.

The team presented their results at the 2024 AIAA Science and Technology Forum and Exposition and in a paper that appeared in the *AIAA SCITECH 2024 Forum*.

Higgins and his colleagues originally proposed this concept in a 2022 paper that appeared in *Acta Astronautica* titled "Design of a rapid transit to Mars mission using laser-thermal propulsion."

As Universe Today reported at the time, the LTP was inspired by interstellar concepts like Starshot and Project Dragonfly. However, Higgins and his associates from McGill were interested in how the same technology could enable rapid transit missions to Mars in just 45 days and throughout the solar system. This method, they argued, could also validate the technologies involved and act as a stepping stone toward interstellar missions.

As Higgins told Universe Today via email, the concept came to them during the pandemic when they were unable to get into their lab:

"[M]y students did a detailed conceptual study of how we could use the kind of large laser arrays envisioned for the Breakthrough Starshot for a more near-term mission in the solar system. Rather than at 10-km-diameter, 100-GW laser envisioned for Breakthrough Starshot, we limited ourselves to a 10-m-diameter, 100-MW laser and showed it would be able to deliver power to a spacecraft out to nearly the distance of the moon. By heating hydrogen propellant to 10,000s of K, the laser enables the 'holy grail' of high thrust and high specific impulse."

The concept is similar to nuclear-thermal propulsion (NTP), which NASA and DARPA are currently developing for rapid transit missions to Mars. In an NTP system, a nuclear reactor generates heat that causes hydrogen or deuterium propellant to expand, which is then focused through nozzles to generate thrust.

In this case, phased-array lasers are focused into a hydrogen heating chamber, which is then exhausted through a nozzle to realize specific impulses of 3,000 seconds. Since Higgins and his students returned to the lab, he said, they have been attempting to experimentally verify their idea:

"Obviously, we don't have a 100 MW laser at McGill, but we now have a 3-kilowatt laser set-up in the lab (which is scary enough) and are studying how the laser would couple its energy to a propellant (eventually hydrogen, but for now argon just because it is easier to ionize). The AIAA paper reports on the design, construction, and 'shake-down' of our 3-kW laser facility."

Higgins and his team constructed an apparatus containing 5 to 20 bars of static argon gas from their tests. While the final concept will utilize hydrogen gas as a propellant, they used argon gas for the test because it is easier to ionize. They then fired the 3-kW laser in pulses at a frequency of 1,070 nanometers (corresponding to the near-infrared wavelength) to determine the threshold power necessary for Laser-Sustained Plasma (LSP). Their results indicated that around 80% of the laser energy was deposited into the plasma, which is consistent with previous studies.

The pressure and spectral data they acquired also revealed the peak LSP temperature with the working gas, though they stress that further research is needed for conclusive results. They also stressed that a dedicated apparatus is needed to conduct forced flow and other LSP tests. Lastly, the team plans to conduct thrust measurements later this year to gauge how much acceleration (delta-v) and specific impulse (Isp) a laser-thermal propulsion system can deliver for future missions to Mars and other planets in the solar system.

If the technology is up to the task, we could be looking at a system capable of delivering astronauts to Mars in weeks rather than months. Other concepts selected for the NIAC this year include tests to evaluate hibernation systems for long-duration missions in microgravity. Alone or in combination, these technologies could enable fast-transit missions that require less cargo and supplies and minimize astronaut exposure to microgravity and radiation.

More information: Gabriel R. Dubé et al, Laser-Sustained Plasma for Deep Space Propulsion: Initial LTP Thruster Results, *AIAA SCITECH 2024 Forum* (2024). DOI: 10.2514/6.2024-2029

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