# Riding a laser to Mars

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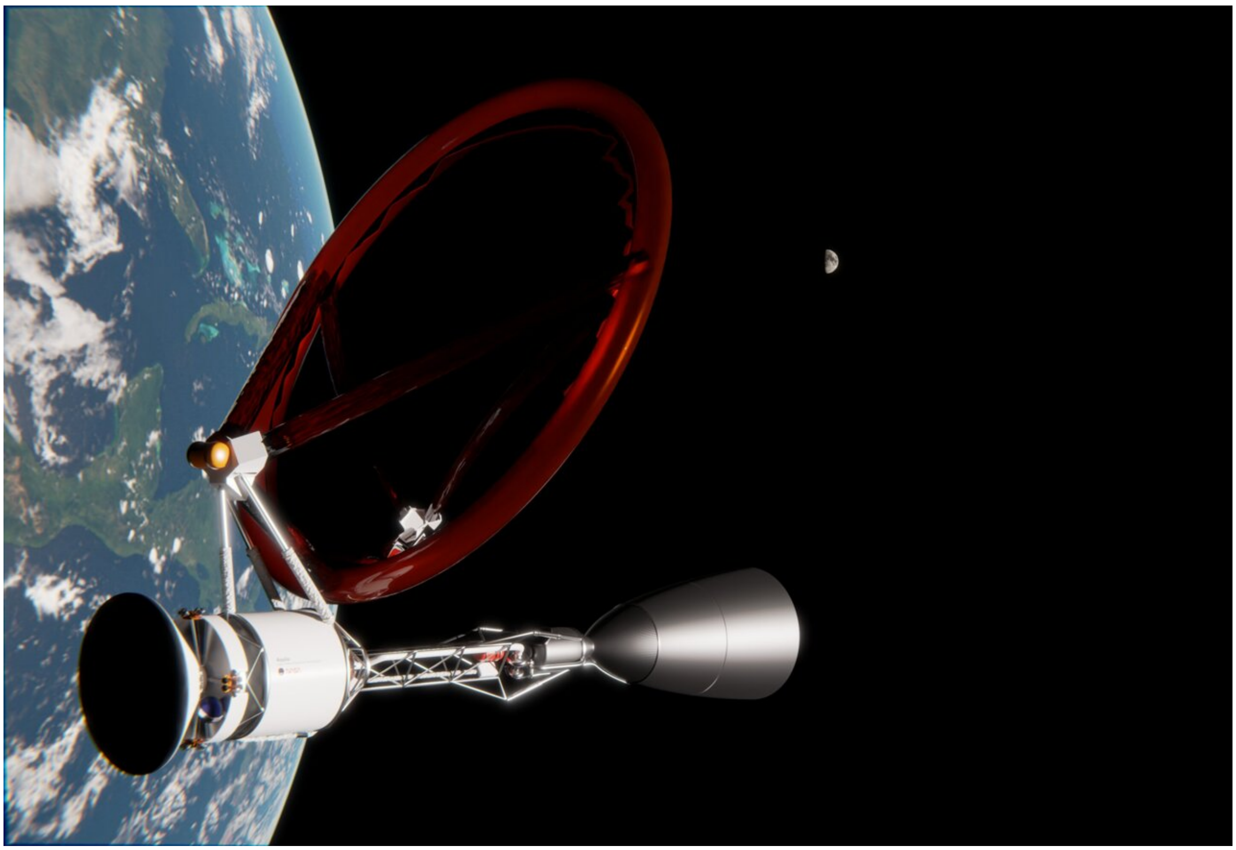

Laser-thermal propelled spacecraft in Earth orbit awaiting its departure. Credit: Creative Commons Attribution 4.0 International License

Could a laser send a spacecraft to Mars? That's a proposed mission from a group at McGill University, designed to meet a solicitation from NASA. The laser, a 10-meter wide array on Earth, would heat hydrogen plasma in a chamber behind the spacecraft, producing thrust from hydrogen gas and sending it to Mars in only 45 days. There, it would aerobrake in Mars' atmosphere, shuttling supplies to human colonists or, someday perhaps, even humans themselves.

In 2018, NASA challenged engineers to design a mission to Mars that would deliver a payload of at least 1,000 kilograms in no more than 45 days, as well as longer trips deep into, and out of, the solar system. The short delivery time is motivated by a desire to ferry shipments and, someday, astronauts to Mars while minimizing their exposure to the damaging effects of galactic cosmic rays and solar storms. Elon Musk's SpaceX envisions a human trip to Mars would take six months with its chemical-based rockets.

McGill's concept, called laser-thermal propulsion, relies on an array of infrared lasers based on Earth, 10 meters in diameter, combining many invisible infrared beams, each with a wavelength of about one micron, for a powerful total of 100 megawatts—the electric power required for about 80,000 U.S. households. The payload, orbiting in an elliptical medium Earth orbit, would have a reflector that directs the laser beam coming from Earth into a heating chamber containing a hydrogen plasma. With its core then heated as high as 40,000 Kelvin (72,000 degrees Fahrenheit), hydrogen gas flowing around the core would reach 10,000 K (18,000 degrees Fahrenheit) and be expelled out a nozzle, creating thrust to propel the ship away from Earth over an interval of 58 minutes. (Side thrusters would keep the craft aligned with the laser's beam as Earth rotates.)

When the beaming stops, the payload zips away at a velocity of almost 17 kilometers per second relative to Earth—fast enough to go past the moon's orbital distance in a mere eight hours. When it reaches the Martian atmosphere in a month and a half, it will still be traveling at 16 km/s; however, once there, placing the payload in a 150-km orbit around

Mars is a difficult problem for the engineering team to solve.

It's difficult because the payload can't carry a chemical propellant to fire a rocket to slow itself down—the fuel needed would reduce the payload mass to less than 6 percent of the original 1,000 kilograms. And until humans on the red planet can construct an equivalent laser array for the incoming craft to use its reflector and plasma chamber to provide reverse thrust, aerocapture is the only way to decelerate the payload at Mars.

Even then, the aerocapture, or aerobraking, in Mars' atmosphere could be a dicey maneuver, with the spacecraft experiencing decelerations of up to 8 g (where g is the acceleration due to gravity at Earth's surface, 9.8 m/s2), about the human limit, for only a few minutes, as it is captured within a single pass around Mars. The large heat fluxes on the craft due to atmospheric friction would be above traditional thermal protection system materials, but not those under active development.

Laser-thermal propulsion of spacecraft into deep space—Mars and further—contrast with other previously proposed methods of conveyance, such as laser-electric propulsion, in which a laser beam would impinge on photovoltaic (PV) cells behind the payload; solar-electric propulsion, in which sunlight on the PV cells creates the propulsive thrust; nuclear-electric propulsion, in which a nuclear reactor creates electricity that produces ions propelled out a thruster; and nuclear-thermal propulsion, in which a nuclear reactor's heat converts liquid to a gas that's propelled out a nozzle to create thrust.

"Laser-thermal propulsion enables rapid transport missions of 1 ton with laser arrays the size of a volleyball court—something laser-electric propulsion can only do with kilometer-class arrays," says Emmanuel Duplay, lead author on the study, who worked on the project over two years while part of McGill University's Summer Undergraduate

Research in Engineering Program. Duplay is now in Delft University of Technology's Master of Science Program in Aerospace Engineering with a specialization in Spaceflight.

A great advantage of laser-thermal propulsion mission concept presented by Duplay et al. is its extremely low mass-to-power ratio, in the range 0.001–0.010 kg/kW—"unparalleled," they write, "far below even those cited for advanced nuclear propulsion technologies, due to the fact that the power source remains on Earth and the delivered flux can be processed by a low-mass inflatable reflector."

Laser-thermal propulsion had first been studied in the 1970s using 10.6 micron $CO_2$ lasers, the most powerful at the time. Today's present-day fiber-optic lasers, at one micron, which can be combined in massively parallel, phased arrays with a large, effective diameter, means a focal length of power delivery over two orders of magnitude higher—50,000 km in Duplay's laser-thermal propulsion concept.

Duplay explains that an architecture for phased-array lasers is being developed by a group led by physicist Philip Lubin at the University of California at Santa Barbara. Lubin's group's array uses individual laser amplifiers of about 100 watts each—each amplifier is a simple loop of fiber optics and an LED light as a pump, and can be mass produced inexpensively—so the Mars mission envisioned here would require on order of 1 million individual amplifiers.

The first humans to Mars likely won't get there using laser-thermal propulsion technology. "However, as more humans make the trip to sustain a long-term colony, we will need propulsion systems that get us there faster—if only to avoid radiation hazards," Duplay says. A laser-thermal mission to Mars might launch 10 years after the first human missions, he speculates, so perhaps around 2040.

**More information:** Emmanuel Duplay et al, Design of a rapid transit to Mars mission using laser-thermal propulsion, *Acta Astronautica* (2021). DOI: 10.1016/j.actaastro.2021.11.032