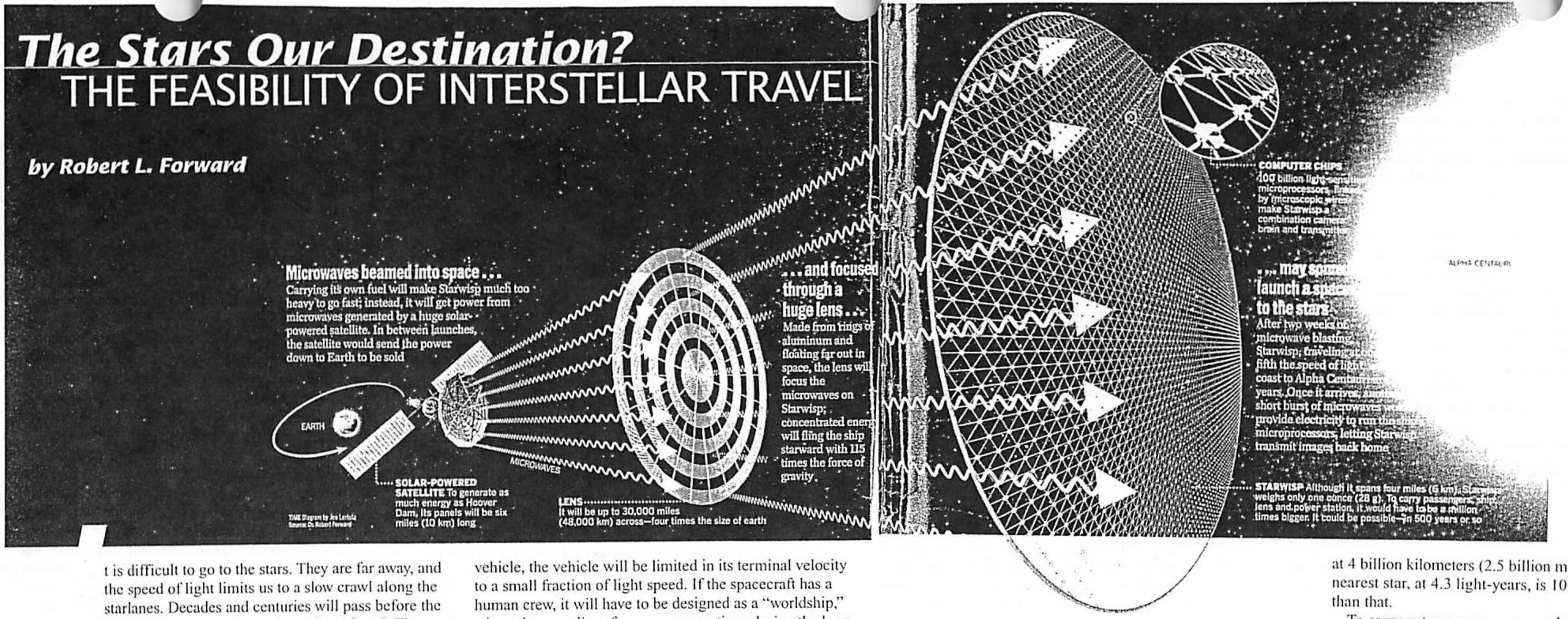
The Stars Our Destination?
THE FEASIBILITY OF INTERSTELLAR TRAVEL

by Robert L. Forward



One of Robert Forward's legacies is the Starwisp, his concept for an interstellar space probe. Three years ago, Forward shared the details of a possible Starwisp design with Time *magazine. This diagram was used to illustrate "Will We Travel to the Stars?"—a short article by Freeman Dyson that appeared in* Time*'s April 10, 2000 issue.*

Diagram: Joe Lertola,
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It is difficult to go to the stars. They are far away, and the speed of light limits us to a slow crawl along the starlanes. Decades and centuries will pass before the stay-at-homes learn what the explorers have found. The energies required to launch a manned interstellar transport are enormous, for the mass to be accelerated is large and the cruise speed must be high. Yet even these energies are not out of the question once we move our technology out into nearby space, where the constantly flowing sunlight is a never-ending source of energy—greater than a kilowatt per square meter, a gigawatt per square kilometer. There are many ideas on methods for achieving interstellar transport. In time, one or more of these dreams will be translated into a real starship.

Is It Possible?

Many people (some of them quite well-known) have "proved" by "calculation" that interstellar flight is "impossible." Actually, in each case, all they have proved is that the initial assumptions they forced on the problem made it so difficult that they were unwilling to consider it further. Some examples of these "obvious" assumptions are that a self-contained rocket has to be used; to keep the humans inside the rocket comfortable, the rocket has to accelerate at a constant one-Earth gravity; all the energy needed to run the rocket has to be extracted out of Earth's resources; and the mission has to be completed in 10 years.

Rapid interstellar travel with simple rocket technology is not feasible. If standard rockets are used to propel a space vehicle, the vehicle will be limited in its terminal velocity to a small fraction of light speed. If the spacecraft has a human crew, it will have to be designed as a "worldship," where the crew lives for many generations during the long journey between the stars. To get to the stars in less than a human lifetime, interstellar vehicles must use some form of "rocketless rocketry," where the vehicle does not carry its energy source, reaction mass, or other parts of a conventional rocket. (In a chemical rocket, the propellant is the reaction mass; it contains the energy to expel itself through the nozzle.)

Interstellar travel at a constant one-Earth-gravity acceleration is not feasible. After the first year of acceleration, the vehicle is moving at 0.7 c (70 percent the speed of light). From then on, the energy used for propulsion doesn't make the vehicle go significantly faster (to the people at home paying for the mission). Instead, all that energy just adds to making the vehicle heavier and harder to push. A properly optimized interstellar mission accelerates up to some cruise velocity that depends on the mission and then coasts, cutting energy and fuel requirements by orders of magnitude.

Interstellar travel using only the resources of Earth is not feasible. The vehicles can be easily built with Earth resources (proposed interstellar unmanned probes might have masses from 20 grams to 100 tons, while manned exploration vehicles can go up to 100,000 tons). However, the reaction mass and especially the energy to drive the interstellar vehicles should be extracted from space.

Interstellar travel with round-trip times of 10 years is not feasible. Even light requires 8.6 years to get to the nearest star system and back. By admitting that interstellar missions will require trip times of 30 to 50 years, the coast velocities needed to carry out a mission to the nearer stars drop from more than 0.9 c (90 percent the speed of light) to less than half the speed of light. This eliminates many problems, such as the erosional effects of the interstellar medium.

If one uses "obvious" but improper assumptions like those mentioned above, one can show that interstellar travel is not feasible. Yet, as we shall see, interstellar travel is feasible if instead the proper assumptions are made and the proven techniques are used.

The first travelers to the stars will be our robotic probes. They will be small and won't require amenities such as the food, air, and water that humans find necessary. The power levels to send the first flyby probes are within the present reach of the human species. If we started today, the first flyby interstellar probe could be on its way before the present millennium is out.

Interstellar Distances

It is not easy to comprehend the distances involved in interstellar travel. Of the billions of people living today on this globe, many have never traveled more than 40 kilometers (about 25 miles) from their place of birth. Of these billions, a dozen have traveled to the Moon, which at almost 400,000 kilometers (248,560 miles) distance is 10,000 times 40 kilometers away. Soon, one of our interplanetary probes will be passing Neptune, 10,000 times farther out at 4 billion kilometers (2.5 billion miles). However, the nearest star, at 4.3 light-years, is 10,000 times farther than that.

To carry out even a one-way probe mission to the nearest star, in the lifetime of the humans that launched it, will require a minimum velocity of 0.1 c (10 percent the speed of light). At that speed, it will take the probe 43 years to get there and 4.3 years for the information to get back to us. The nearest star is Proxima Centauri, part of a three-star system called Alpha Centauri. One of the stars is similar to our Sun.

Farther away are two other single stars similar to our Sun that are our best candidates for finding an Earth-like planet: Epsilon Eridani at 10.8 light-years and Tau Ceti at 11.8 light-years. To reach these stars in a reasonable time will require probe velocities of 0.3 c (30 percent the speed of light). At this speed, it will take nearly 40 years to get there, plus another 11 to 12 years for the information to return to Earth.

Yet, although we need to exceed 0.1 c to reach any star in a reasonable time, if we can attain a cruise velocity of 0.3 c, there are 17 star systems with 25 visible stars and probably hundreds of planets within 12 light-years. This many stars and planets within reach at 0.3 c should keep us busy exploring while our engineers work on faster starship designs.

Rocketless Rocketry

We need not use the rocket principle to build a starship. If we examine a generic rocket, we find that it consists of payload, structure, reaction mass, energy source, an engine to put the energy into the reaction mass, and a thruster that

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expels the reaction mass to provide thrust. In most rockets, the reaction mass and energy source are combined into the chemical fuel. The fuel is then burned in the engine and expelled through the thruster. Because a standard rocket has to carry its fuel along with it, its performance is significantly limited.

There is a whole class of spacecraft that does not have to carry along any energy source or reaction mass or even an engine and consists only of payload, structure, and a thruster. These spacecraft work by means of beamed power propulsion. In a beamed power propulsion system, the heavy parts of a rocket (reaction mass, energy source, and the engine) are all kept in the solar system.

Here, around the Sun, unlimited amounts of reaction mass are readily available, and an energy source (usually the abundant sunlight) and an engine can be maintained and even upgraded as a mission proceeds.

Starwisp: A Maser-Pushed Probe

Starwisp is a lightweight, high-speed interstellar flyby probe pushed by beamed microwaves. The basic structure is a wire-mesh sail with microcircuits at each intersection. The mesh sail is pushed at high acceleration using microwave power formed into a beam by a large segmented transmitter lens made of alternating sparse metal mesh rings and blank rings. The high acceleration allows Starwisp to reach a coast velocity near that of light while still close to the transmitting lens.

Upon arrival at the target star, the transmitter floods the star system with microwave energy. Using the wires as microwave antennae, the microcircuits on Starwisp collect energy to power their optical detectors and logic circuits to form images of the planets in the system. The direction of the incoming microwave beam is sensed at each point of the mesh, and that information is used to electronically transform the mesh into a microwave antenna that beams a signal back to Earth.

A minimal Starwisp would be a 1-kilometer (0.6-mile) mesh sail weighing 16 grams (0.6 ounces) and carrying 4 grams (0.1 ounce) of microcircuits. Starwisp would be accelerated at 115 gravities by a 10-gigawatt microwave beam, reaching one-fifth the speed of light in a few days. Upon arrival at Alpha Centauri 21 years later, Starwisp would collect enough microwave power to return a high-resolution color television picture during its fly-through of the system.

Because of the probe's very small mass, the beamed power level needed to drive a minimal Starwisp is about that planned for the microwave power output of a solar power satellite. Thus, if power satellites are constructed in the next few decades, they could be used during their checkout phase to launch one or more Starwisp probes to the nearer stars.

Once the Starwisp probes have found interesting planets, we can use another form of beamed power propulsion to visit these bodies. Although microwave beams can be used only to "push" a spacecraft away from the solar system, if we go to laser wavelengths, then it is possible to design a beamed power propulsion system that can use laser power sent from the solar system to make a return journey.

Laser-Pushed Lightsails

One of the best methods for traveling to the stars would use large sails of light-reflecting material pushed by the photon pressure from a large laser array in orbit around the Sun. With this technique, we can build a manned spacecraft that not only can travel at reasonable speeds to the nearest stars, but also can stop, then return its crew back to Earth within their lifetimes. It will be some time before our engineering capabilities in space will be up to building the laser system needed, but no new physics is involved, just a large-scale engineering extrapolation of known technologies.

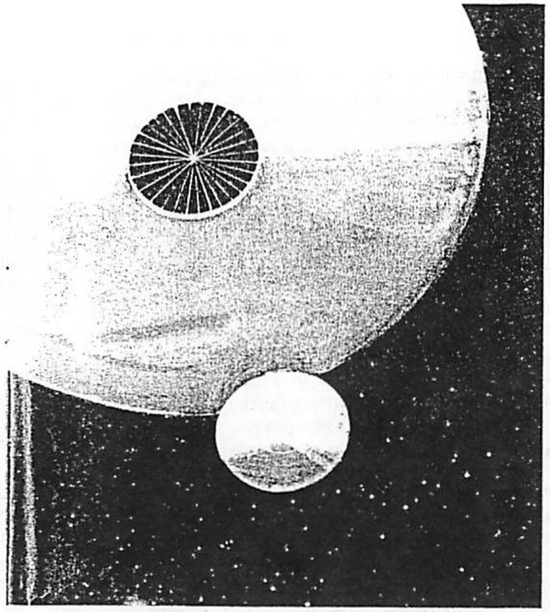
The lasers would orbit Mercury to keep them from being blown away by the reaction from their light beams. They would use the abundant sunlight at Mercury's orbit to produce coherent laser light, which would be collected into a single coherent beam and sent out to a segmented transmitter lens floating between Saturn and Uranus. The transmitter lens consists of rings of 1-micron-thick plastic film alternating with empty rings. Because it is crude in construction, it only works well at one wavelength of light. We chose the laser wavelength to match the design wavelength of the lens. The lens would be 1,000 kilometers (about 620 miles) in diameter with a mass of 560,000 tons, about the mass of a solar power satellite. A lens this size can send a beam of laser light over 40 light-years before the beam starts to spread.

The lightsail carrying the payload would be 1,000 kilometers in diameter and made of thin aluminum film stretched over a supporting structure. The total mass would be 80,000 tons, including 3,000 tons for the crew, their habitat, their supplies, and their exploration vehicles. The lightsail would be accelerated at 0.3 gravities by 43,000 terawatts of laser power. (For comparison, Earth now produces only 1 terawatt of electrical power. We would certainly want to power the lasers by collecting sunlight from space with large reflectors rather than attempting to use Earth-based power sources.) At this acceleration, the lightsail will reach a velocity of half the speed of light in 1.6 years. The expedition will reach Epsilon Eridani in 20 years Earth time and 17 years crew time, and it will then be time to stop.

At 0.4 light-years from the target star, the 320-kilometer (about 200-mile) rendezvous portion of the sail is detached from the center of the lightsail and turned to face the large ring sail that remains. The laser light from the solar system reflects from the ring sail, which acts as a retro-directive mirror. The reflected light decelerates the smaller rendezvous sail and brings it to a halt in the Epsilon Eridani system.

Returning Home

After the crew explores the system for a few years (using their lightsail as a solar sail), it will be time to bring them back. To do this, a 100-kilometer-diameter (62-mile-diameter) return sail is separated from the center of the 320-kilometer rendezvous sail. The laser light from our solar system hits the ring-shaped remainder of the rendezvous sail and is reflected back on the return sail, sending it on its way back to the solar system. As the return sail approaches the solar system 20 Earth-years later, it is brought to a halt by a final burst of laser power. The members of the crew have been away 51 years (including 5 years of exploring), have aged 46 years, and are ready to retire and write their memoirs.



In the future, this light sail could be used for an interstellar rendezvous. Laser light transmitted from our solar system would bounce off a ring sail 1,000 kilometers (about 620 miles) in diameter onto a rendezvous stage 320 kilometers (200 miles) wide, decelerating the sail to a stop in its target star system. Painting: Seichi Kiyohara

It is important to recognize that although interstellar unmanned probes and manned starships are possible, they will be difficult to build as well as expensive. The masses needed to produce any kind of interstellar transportation system and the power levels to operate it will require that we first have a large industrial base in space. A space station with 20 to 100 people in residence at one time is not enough. We will need many space stations, bases on the Moon, prospectors in the asteroid belt, and solar power stations for processing materials and powering factories. This is at least 20 to 50 years away.

A simple example is the amount of power needed to carry out an interstellar mission. No matter what propulsion method you can dream of, to accelerate a 1-ton interstellar probe up to one-third the speed of light even over a three-year period requires a power input of 50 gigawatts. Even at 50 percent efficiency, this requires a power input of 0.1 terawatt. (One gigawatt equals 1 billion watts; one terawatt equals 1 trillion watts.) This is one-tenth Earth's present output of electrical power. For a crewed vehicle weighing 10,000 tons, the power required is 1,000 terawatts. To obtain this power, we must be out in space where sunlight supplies more than 1 kilowatt per square meter and must have the manufacturing capability to build solar collectors 1,000 kilometers in diameter.

The masses required for such large structures are not trivial either. These solar collectors, thin aluminum and microwave lenses made of fine wire, will weigh between 50,000 and 100,000 tons, while laser lenses with 1-micrometer-thick plastic will reach 600,000 tons. For the microwave lens, this mass can be obtained from a nickel-iron asteroid 25 meters in diameter, while the aluminum can be obtained from a stony asteroid 100 meters across. The plastic will have to be made from carbonaceous chondrites perhaps 1 kilometer in diameter. These are modest-size asteroids, but all that mass has to be processed in a reasonable time, and that will take a very big factory.

New Industrial Revolution

But in 20 to 50 years, it is likely that there will be a new industrial revolution where robots take over all labor, leaving management to humans. Suddenly, labor costs may disappear; only capital, energy, and material costs would remain. Especially for such simple structures as solar collectors and segmented ring lenses, robots would be more than adequate construction workers.

Once we have constructed the space industrial base and once we have found the right asteroids, we can invest a little capital in a small crew of smelter and spinner robots and a solar collector to provide energy. We then go away, and return in a few years to find the asteroid gone and a wire-mesh microwave ring lens in its place. During the fabrication phase, the waste products from the smelting operation have been heated and expelled to provide thrust to move the entire system to the position and velocity desired (typically far from the Sun and not orbiting a planet).

What will this cost? A lot—but not as much as you might think if you attempted to do it with material hauled up on the expensive space shuttle and assembled by expensive human beings.

It is difficult to go to the stars, but it is not impossible. Many different technologies, all under intensive development for other purposes, if suitably modified and redirected can give the human species a flight system that will reach the nearest stars. All it really takes is the desire and the commitment to a few decades of hard space-engineering work. Our first interstellar probe could be heading to the stars within our lifetimes.

The late Robert L. Forward is remembered as one of the world's leading experts in exotic physics and future space travel. At the time of his passing in September 2002, Forward was owner and chief scientist for Forward Unlimited and chairman and chief scientist for its spin-off company, Tethers Unlimited Inc. In addition to more than 200 papers and articles, Forward published 11 "hard" science fiction novels.