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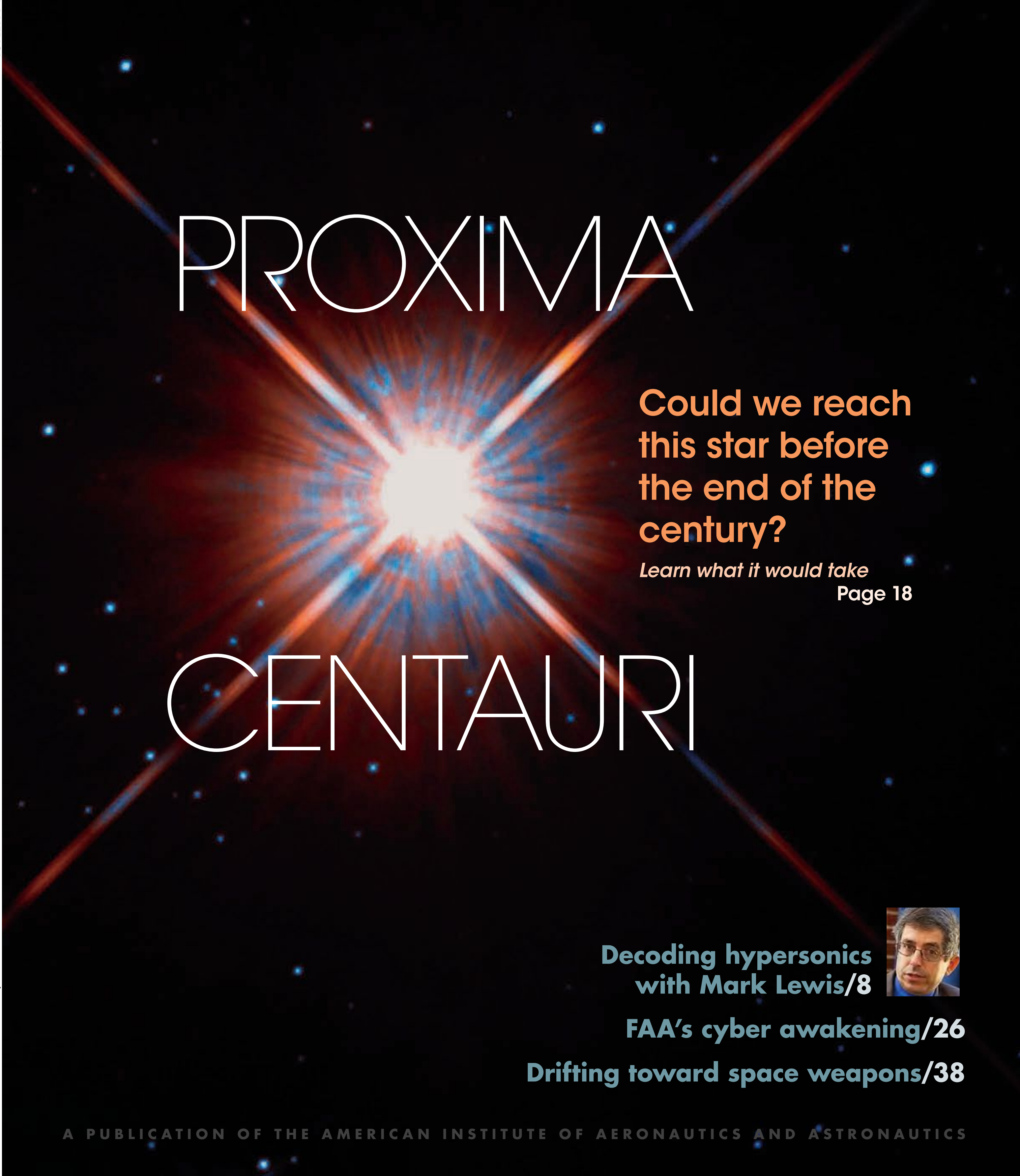

PROXIMA CENTAURI

Could we reach this star before the end of the century?

Learn what it would take

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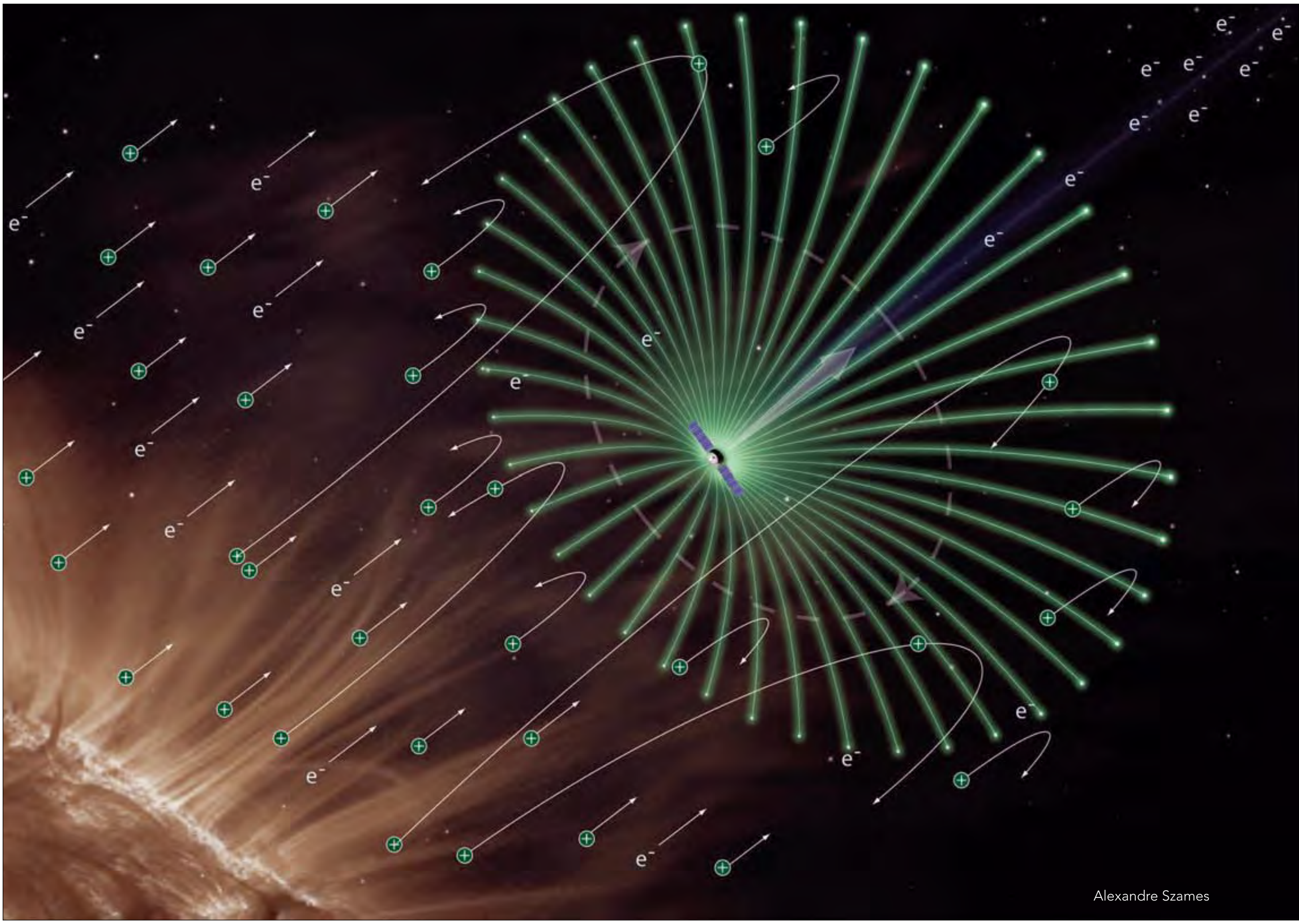
Sailing on electricity

If U.S. scientists want to explore the far fringes of the solar system, they'll need new propulsion options. Michael Peck spoke to NASA researchers who say the answer might lie in tapping the interactions between the solar wind and electric fields.

NASA's Voyager 1 took 35 years to reach the heliopause, the unexplored region where the solar wind stops and the interstellar plasma eventually takes over. There has to be a faster way to explore the outer planets and the heliopause than Voyager 1's chemical-rocket propulsion.

Two researchers at NASA's Marshall Space Flight Center in Huntsville, Alabama, think they've found one. Bruce Wiegmann, an aerospace flight engineer, and Les Johnson, a physicist as well as the technical assistant at NASA's Advanced Concepts Office, have devised a concept they call the Heliopause Electrostatic Rapid Transit System, or HERTS.

Their project, the physics of which is undergoing analysis and testing in a plasma chamber, calls for extending 10 to 20 wires, each 20 kilometers long, from a spacecraft that would slowly rotate as it heads off into deep space. As the wires slice through the solar wind, protons in the wind would strike the electric field surrounding the wires, and the



NASA is researching an electric-sail spacecraft that would trail many long conducting wires to draw propulsive energy from solar wind. Such a craft could reach the heliosphere, or the beginning of the outer solar system, in 10 years, compared to 20 years for solar-sail craft.

momentum of those protons would be converted into propulsive force.

The HERTS team says their craft could travel at 100 to 150 kilometers per second, compared to Voyager 1's 17 kilometers per second, putting it at the heliopause in 10 or 12 years. Though much swifter than the Voyager, the HERTS craft would follow a different, and longer, trajectory. If researchers are right, a heliophysicist could propose a mission to the heliopause and receive the science in the span of a normal career, opening the door to the first detailed study of the heliopause and perhaps the region beyond. Few scientists would stake a career on a mission or element of a mission that won't deliver results for 35 years.

"This is the kind of technology we need to have for propulsion systems [for] the first steps into the interstellar medium," says Johnson, a technical advisor for HERTS.

The team calls the concept an electric or E-sail to distinguish it from solar sail concepts that are also in consideration for other exploration applications. Because there would be fewer photons to propel it farther out from the sun, a solar sail would stop accelerating at a distance of five astronomical units, or five times the distance from Earth to the sun, Wiegmann says. The protons that propel an E-sail taper off at a much more gradual rate, enabling the spacecraft to continue accelerating out to 15 AU. An E-sail would enjoy the additional acceleration compared to a solar sail because the spacecraft's electrical field expands as it moves farther from the sun.

Bruce Wiegmann, principal investigator for NASA's Heliopause Electrostatic Rapid Transit System, holds a sample of Amberstrand composite string, one of the tether materials under investigation for use in a spacecraft propelled by electric sails. Behind him is an artist's concept for the electric sail.

Debye sheath

The HERTS team says the technology road will be a long one, but that with the right investments, a scientific spacecraft with this kind of propulsion system could be ready in 10 years and return the first science data sometime between 2025 and 2030, assuming a technical demonstration mission were launched between 2020 to 2022. The team is studying whether to conduct experiments via a high-altitude balloon or a flight on a suborbital rocket as the next steps.

More immediately, the researchers are conducting experiments in a small plasma chamber at Marshall. The chamber is equipped with an ion generator that is capable of very low pressures, like those HERTS would experience.

The chamber experiments can't do it all, but they are a start toward accurately modeling the interactions with its surroundings.

"All of our modeling to date has been built upon some plasma physics models that may have shortcomings when applied to this topic," Wiegmann says.

Specifically, each wire generates an electric field known as a Debye sheath (named after physicist Peter DeBye). The team wants to know how many electrons pass through the Debye sheath and accelerate toward a positively charged wire, as well as how many protons are reflected off the sheath, which will indicate the propulsive force a HERTS spacecraft will experience.

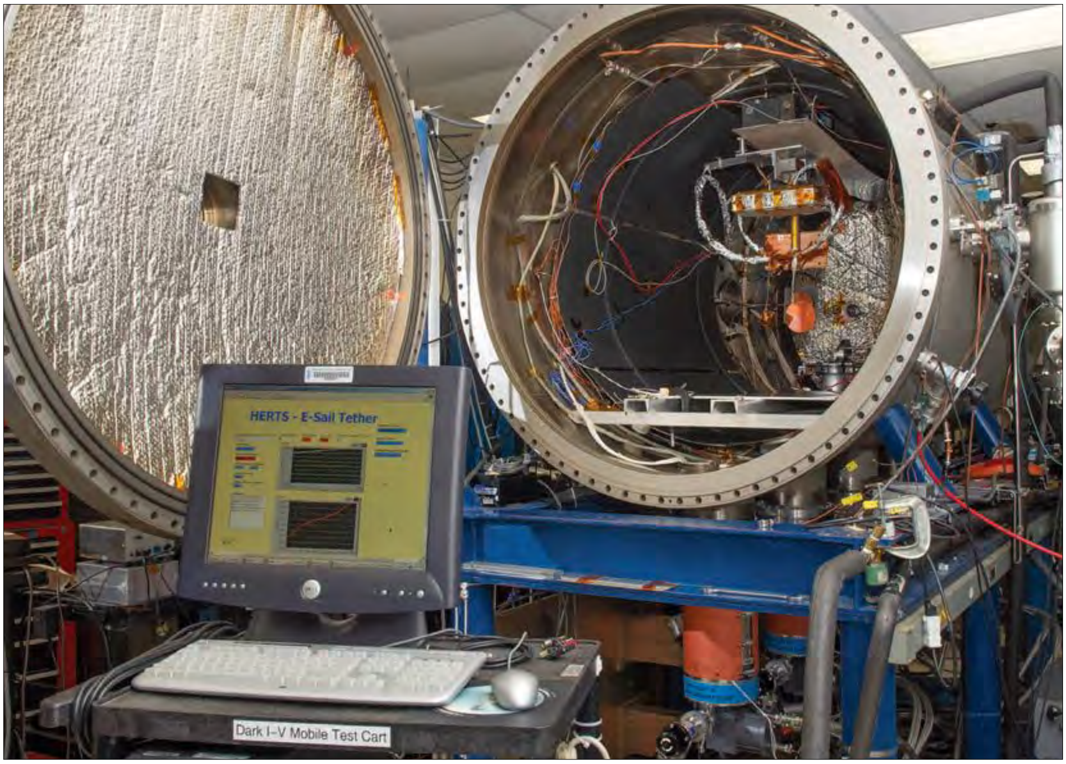
The Debye sheath will extend eight to 10 meters from the wires at a distance of one AU. The spacecraft will also rotate at one revolution per hour, which will ensure that the wires are extended 90 degrees from the axial center.

The NASA chamber test can accommodate just one wire with a Debye sheath length of 0.2 centimeters to one centimeter. So the HERTS team plans to extrapolate the results from this chamber to develop a Particle in Cell engineering model that can predict the thrust on an electric sail spacecraft. The PIC model will also predict the effects of solar winds and coronal mass ejections.

Once the PIC model is developed, the HERTS team will know the rate at which electrons from the solar wind will jump on the E-sail's charged wires, which must maintain a positive electric charge for the propulsion system to work.

"This is a major concern as we must be able to remove these electrons through an electron gun to enable a positive bias on the wires," Weigmann says. The chamber experiment will quantify the rate at which electrons jump on the wires.

Since the Debye sheath of a charged wire would be tens of meters in diameter, there is no vacuum plasma chamber with an ion generation source that could simulate the natural solar wind environment, Wiegmann says.



NASA/Emmett Given

NASA is conducting tests inside a controlled plasma chamber, called the High Intensity Solar Environment Test system, to examine the rate of proton and electron collisions with a positively charged tether from a spacecraft's electric sail.

Space experiments

For maximum confidence, the design would need to be tested outside of Earth's magnetosphere, which deflects the solar wind needed to propel the spacecraft. Wiegmann envisions testing a HERTS spacecraft in the vicinity of the moon and beyond Earth's magnetosphere. On the dayside of Earth, the solar wind compresses the magnetosphere to about 65,000 kilometers. On the nightside, the magnetotail extends to 6.3 million kilometers, far beyond the orbit of the moon. The experiment would need to be timed to coincide when the moon is outside the magnetosphere.

"When the moon is at the 3 o'clock or 9 o'clock position, where 12 o'clock is toward the sun and 6 o'clock is away from the sun, in Earth¹s shadow, the moon is outside the Earth's magnetic field," Wiegmann says. "This may be the closest location where we can perform a technology demonstration mission for the E-sail."

Two space shuttle missions, in 1992 and 1996, attempted to test a space concept for generating electricity by extending 20-kilometer-long tethers consisting of a wire bundle wrapped in a covering of clear insulation, and then covered by Kevlar and then Nomex. A jammed deployment mechanism on the first shuttle mission ended the experiment after the tether extended just 256 meters, while the second mission managed to extend the wire 19.7 kilometers before it broke.

However, the shuttle tests provided limited data for HERTS because they were conducted within the magnetosphere. Also, the shuttle missions were conducted with an eye toward assessing the ability to gather ions in low earth orbit and use them to generate electricity to power a spacecraft's electronics.

"Nobody was looking at them as propulsion systems, and there was no instrumentation deployed to validate this," Johnson says.

Design considerations

Without much data to go on, the engineers are still weighing key design decisions, such as the best material for their all-important wires.

"Our design is based upon 35-gauge aluminum wire, primarily for mass savings as it is about one-third the mass of copper wire," Weigmann says. "But we have not made a clear down-select yet to the best material to use for the wire."

No matter the material, perhaps the biggest question is how to deploy multiple thin, bare wires 10 to 20 kilometers long from a spacecraft.

Wiegmann says his team is investigating this through modeling and simulation, and then perhaps a small test where wires are laid out on the floor at Marshall. One solution for a HERTS space mission is to unravel the wires by spinning the spacecraft, though the deployment system would need to slowly stop extending the wires without breaking them. A second option would be to have cubesats that are attached to the main spacecraft pull the wires out. Two cubesats might pull five wires each, and once the wires are extended, radial thrusters on the cubesats and the HERTS craft would spin the spacecraft to one revolution per hour, bringing the wires to their deployed position. The team plans to assess these solutions with computer simulation from space technology company Tether Sim.

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