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Bubbles at the Edge of Space: Merav Opher Is Changing Astrophysics

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In the yellowing photograph from the late 1970s, two twin girls, their astronomer father, and a young friend stand beneath the dish of a radio telescope outside São Paulo, smiling and waving at the camera. At a NASA press conference last year, the physicist Merav Opher, who had been one of the twin sisters in the picture, shared it to convey—with her typical exuberance—how deep her passions for space science run. Not long before the photo was taken, the two Voyager spacecraft had embarked on their long journeys past Jupiter, Saturn, and the other giant planets. Today, that little girl from Brazil has grown up and used data from those probes to revolutionize concepts about the edge of the solar system.

"The edge of the solar system" is more than a turn of phrase. A tenuous, invisible wind of ionized gas billows off the sun at a million miles per hour, carrying with it the sun's magnetic field. It does not radiate out infinitely: far beyond Pluto's orbit, this solar wind abruptly slams into the thin interstellar medium and the scattered gaseous remnants of exploded stars. That border defines what astronomers call the heliosphere.

Just a few years ago, Opher played a key role in explaining why the heliosphere is unexpectedly lopsided and off-kilter. Now an assistant professor in Boston University's astronomy department, Opher is interpeting data that suggests that part of the heliosphere's edge may be a churning magnetic froth, which could have broad implications for astrophysics.

Merav Opher. Courtesy Melody Komyerov/BU Photography

"She's had a huge impact on this outer heliosphere field," remarks James F. Drake of the University of Maryland, a physicist who collaborated with Opher on the most recent work. "When she was starting out, most people didn't really think the interstellar magnetic field itself did much. I think Merav played a lead role in convincing people."

That description might have gratified Opher's parents. "They raised us to think, 'If you're going to work in any field, just make a mark," she recalls. "'Really try to do something that matters.'"

New York-Haifa-São Paulo

Merav and her fraternal twin sister Michal were born in 1970 to a pair of expatriate New Yorkers living in Haifa, Israel. Her father, Reuven Opher, was at that time an astrophysicist at the University of Technion. Yet a sabbatical to Brazil led to her father falling in love with that country. When she was eight years old, they moved to São Paulo, where he had taken a position at the university.

She still rhapsodizes over São Paulo, which she calls a "very sophisticated, incredible place." Brazil's multicultural environment also helped the Ophers blend in, even though they continued to speak Hebrew at home. "Brazilians are super nice," she says. "It's not a place where you don't feel welcome."

In college Opher first thought she might become a film director. Then in her third year she fell in love with physics and put herself on a path to earn both a bachelors degree in physics and a Ph.D. in plasma studies.

Plasmas and the magnetic fields that animate them became the common threads running through all of Opher's work. She thinks she was drawn to the subject because she knew she could never master it. "Plasma is complex," she says. "I knew it was something I could not get my head around easily. I would have to work at it." She adds, "I felt this was something larger than me. It was scary, but I liked the fear."

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A rendering of Voyager 2. Courtesy NASA

Physics is a notoriously male-dominated discipline, which might have discouraged many women with Opher's ambitions. But her father, she says, had always impressed on his daughters that they could do whatever they liked. "My dad was always very much like, 'Why not? There's nobody stopping you from doing it.'" She suspects that the idea of sexism as a problem for women in science "didn't even occur to him."

(That confidence he inspired apparently worked for both sisters – Michal, now Lipson, is a nanophotonics engineer at Cornell University and the recipient of a MacArthur Foundation "genius" grant for her work on computer innovations.)

A rare woman in plasma physics

Opher thrived at graduate school in São Paulo. "I love the chaos. I love the creativity the Brazilians have," she says, in admiration of how they would improvise solutions to get around budgetary limitations. But driven to find opportunities she Brazil could not match, she elected to start postdoctoral work at the University of California, Los Angeles in 1999.

That move proved daunting at first, she recalls, both because of the cultural shift and because UCLA's plasma physics department had no female faculty and only one other female post-grad student. "I really felt a little bit like a fish out of water there," she says. She also felt herself moving away from her theoretical plasma interests back toward astronomy and space physics, "where I could see the plasma physics in action more than in the lab." In 2001, she found herself pondering what to do next.

Then she met Paulett C. Liewer, a project manager at NASA's Jet Propulsion Laboratory (JPL), who, Opher learned, had interests identical to hers (and was one of the few women in the field). Liewer hired Opher on the spot, and she immediately started work on data beamed back from the outer solar system by the Voyager spacecraft.

Those data are what she had continued to analyze throughout her subsequent career — first for four years at JPL, then seven at George Mason University. In 2011, Opher, her partner, and their two-year-old son moved to the Boston area, a short subway ride away from her new office at Boston University.

Much of her focus has been on determining the precise shape of the heliosphere. For decades, the received wisdom in astronomy was that the heliosphere's shape would be a fairly symmetrical and cometlike, with a

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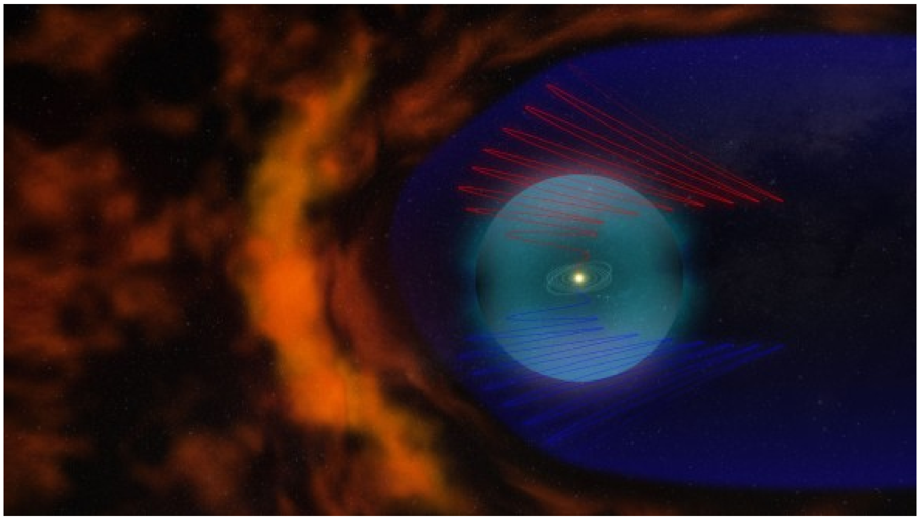
spherical head around the sun and a tail in the opposite direction of the solar system. Irregularities could be chalked up to fluctuations in the sun's activity over time.



The old view of the heliosphere: Solar wind emanating from the sun slows in the termination shock (blue) region as it collides with the interstellar medium (red), then is left behind by the sun's motion. Courtesy NASA

Opher, however, like a few other astronomers, was sure that the interstellar magnetic field might significantly distort the heliosphere's shape and orientation. In 2006 she, Liewer, and Edward C. Stone of Caltech published a model in the Astrophysical Journal that predicted an asymmetrical, bullet-shaped heliosphere, pushed in on its southern hemisphere and bulging outward to the north, and at an angle to the plane of the Milky Way's magnetic field.

The following year, Voyager 2 unexpectedly entered the termination shock region of the heliosphere (where the solar wind piles up near the edge and drastically slows down), proving that the southern expanse of the heliosphere was closer than the northern one and precisely vindicating Opher's model. That success helped to bring her a prestigious CAREER grant from the National Science Foundation and a Presidential Early Career Award from George W. Bush in 2008.

100-million-mile "bubbles"

Opher's more recent work has revealed what may be an even more complex level of structure in the outer heliosphere. The leading edge is called the heliosheath. It has usually been pictured as a relatively thin, smoothly flowing layer of energized plasma.

But an analysis of Voyager data by Opher and Maryland's Drake in 2011 suggests that the heliosheath is actually a thick cluster of plasma "bubbles" 100 million miles across. The sun's magnetic field becomes increasingly pleated and folded in the plasma of the outer heliosphere, Opher explains; in the heliosheath, pieces of the magnetic field may detach themselves and reconnect into the self-organized structures of the bubbles.

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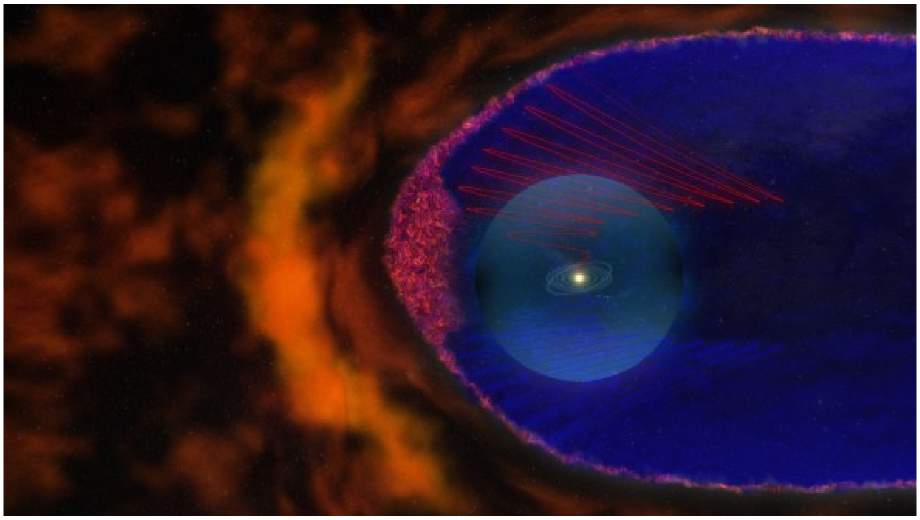

The new view: Because of interactions with the interstellar magnetic field, the heliosphere is pushed in along its southern hemisphere and bulges out along its northern one. Distortions in the solar magnetic field become so extreme at the edge of the heliosphere that it breaks down into magnetic bubbles of plasma 100 million miles wide. Courtesy NASA

If Opher's suggestion holds up to further observations, it could force astronomers to rethink some of their ideas about cosmic rays. "The heliosheath is a shield," she explains: its plasma stops some highly energetic particles called cosmic rays from entering the solar system. If the heliosheath's structure is inconsistent, then the shield has holes in it. It might be stopping fewer cosmic rays than has been assumed—or it might be stopping more, if the bubbles absorb the particles more efficiently. A change in either direction could affect astrophysical models about phenomena that produce cosmic rays and the levels of radiation bathing planets around other stars, for example.

Frustratingly, the magnetic signatures for the bubbles are so weak that they hover near the detection threshold of the Voyager magnetometers. The best way to verify the bubbles' existence would be to launch a new probe to the outer heliosphere—one that might have the benefit of a faster propulsion system and instrumentation that isn't 35 years out of date.

For that reason, Opher has tried as much as possible to rally support for just such a mission. To her, she says, it's like the Voyagers are "screaming urgently, 'Send a better instrument! There's so much to learn!'"

Top image: Reuven Opher with his daughters, Merav and Michal (now Lipson) and a friend. Courtesy Merav Opher

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John Rennie is an editor at large for Txchnologist. He served as editor in chief of Scientific American between 1994 and 2009 and is an adjunct instructor in New York University's Science, Health and Environmental Reporting Program. His last story for Txchnologist was about deep sea mining. John can be found on Twitter @tvjrennie.

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Excellent article, John. Thank you for helping me discover this wonderful scientist. Also, Penn Jillette has a new podcast and it would be great to have you on.

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Chris Reeve *1 month ago*

Message to John Rennie and readers …

Please be aware that there is a longstanding debate over how to model cosmic plasmas that dates back to the origin of magnetohydrodynamics (MHD) by Hannes Alfven. Alfven originated this notion that magnetic fields can be frozen into the plasma — which is the theory which permits you to analogize the behavior of plasmas to fluids ("bubbles", etc.). But, he came to consider this concept which he created to be "pseudo-pedagogical", meaning a concept which appears to help, but in fact drastically misleads. In the laboratory, plasmas are an electromagnetic phenomenon. When astrophysicists model the cosmic plasmas, these models deviate from their observations of laboratory plasmas insofar as they generally assume that the plasmas exhibit no electrical resistance, basically crippling their ability to sustain any electric field.

There is a paper which very clearly explains why this is a problem: "Why Space Physics Needs to Go Beyond the MHD Box" by Parks. I strongly urge you to read this article. The implications for our understanding of the universe are enormous, for it is by now recognized that plasma is the universe's fundamental state for matter. 99.999% of what we see with our telescopes is matter in the plasma state. Thus, any allegation that the plasma models might be in error should be taken with absolute seriousness.

It also worth noting that the only theorist who can offer a cosmological model which *naturally* predicts the IBEX results is in fact Wallace Thornhill, of the Electric Universe. For more information, see:

http://www.holoscience.com/news.php?article=74fgmwne (Electric Sun Verified)

Astrophysicists have a very long history of trying to prove that cosmic plasmas behave fundamentally like fluids and gases. But, the critical thinker should ask why this is, when the laboratory plasmas are fundamentally electromagnetic. Why are our cosmic plasma models different from the behaviors of plasmas which we observe within the laboratory? This is a very important question, and the behavior of the universe's preferred state for matter turns on the answer to this question.

It's also worth noting that magnetic reconnection experiments require electrical currents to work. The second you shut the power off, they stop working. Thus, we are all within our right to ask the astrophysicists who perform their experiments: Why is it that their magnetic reconnection theory does not account for the electrical current which the experiments demand in order to work? The Electric Universe theorists point out that magnetic lines are not physical entities; they cannot actually "reconnect" since they don't actually exist. We should all be wary of adopting such theories which treat mathematical concepts as though they are real, physical objects. Also, it is very much worth noting that magnetic reconnection is explained by many plasma physicists as merely a cross-section of a Birkeland Current.

The world continues to wait for the serious treatment that this debate demands. If the plasma models are wrong, then HUGE CHUNKS of conventional theory are wrong. These models rest at the very base of our entire scientific endeavor, and the astrophysicists continue to pretend as though no debate even exists.

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