LAURA KATZ

Evolution Revolution

Four decades after being rejected by the scientific community, Lynn Margulis's insights into evolution have become standard textbook fare and established her as one of the most creative scientific thinkers of our day.

By Eric Goldscheider

Lynn Margulis MS'60 is one of those rare scientists whose research fundamentally altered the way we view the world — in this case, the way we view evolution. With blunt language, she batters humanity out of its self-image as the pinnacle of life.

"Man is the consummate egotist," Margulis has written. "It may come as a blow to our collective ego, but we are not masters of life perched on the top rung of an evolutionary ladder." Instead, she likes to say that "beneath our superficial differences, we are all of us walking communities of bacteria."

Margulis is a leading proponent of an evolutionary concept called symbiogenesis — a hypothesis that states that new adaptations do not arise primarily from random mutations, but from the merging of two separate organisms to form a single new organism.

Margulis, photographed while attending the World Summit on Evolution in Ecuador's Galapagos Islands in 2005, asserts that we have neglected the earliest stages of evolution that preceded animals — a period that represents seven-eighths of the history of life on Earth.

Symbiogenesis theory flies in the face of an accepted scientific dogma called neo-Darwinism, which holds that adaptations occur exclusively through random mutation, and that as genes mutate in unpredictable ways, their gradual accumulation sometimes results in useful attributes that give the organisms an advantage that eventually translates into evolutionary change.

What tipped Margulis off that new traits could arise in another way was the fact that DNA, thought to reside only in the nucleus, was found in other bodies of the same cell. This realization led to research showing not only how crucial symbiotic relationships can be to the immediate survival of organisms, but also that one of the most significant sources of innovation — indeed, even the origins of new species — occurs when, over time, symbiotic partners fuse to create new organisms.

In other words, complexity at the cell level is not the result of lethal competition from lucky mutants, but rather interactive chemistry that begins as symbiotic relationships between gene sets that together accomplish things that would otherwise have been impossible.

Margaret McFall-Ngai, who teaches medical microbiology and immunology in the UW-Madison School of Medicine and Public Health, counts Margulis as a personal and professional mentor and friend. She explains Margulis's concept of symbiogenesis as "a whole bunch of simple cells getting together to make one cell that's more complex." It was "an event in geological history that happened several billion years ago," setting a course toward the complexity that imbues the biosphere, says McFall-Ngai, "so this was a huge discovery about the nature of the cells of all animals and plants."

Margulis's observation that constituent parts of the same cell had different genetic histories was largely written off as crank science in 1964 when she started submitting her paper on the topic to academic journals. No one wanted it. After more than a dozen rejections, the *Journal of Theoretical Biology* published "On the Origin of Mitosing Cells" in 1967, and then something very interesting happened. Requests for reprints started pouring in, more than eight hundred in all. "Nothing like that had ever happened in the Boston University biology department," Margulis says. Although she was a part-time adjunct professor there at the time, she won a prize for faculty publication of the year. Eventually, a full-time position that lasted twenty-two years followed.

But in spite of, or maybe because of, this modicum of recognition, the scientific establishment viewed her skeptically, if not with outright hostility. Her grant proposals weren't funded. Margulis tells of being recruited for a distinguished professorship at Duke University, only to have it subverted at the last minute by a whispering campaign. Since 1988, she has taught at the University of Massachusetts in Amherst, where she holds the title of Distinguished University Professor in the Department of Geosciences.

Margulis is known for being outspoken — both in praise of controversial ideas she thinks have merit, and in criticizing what others view as accepted truth. Her sharpest barbs are reserved for those fellow scientists who she believes have sold out to the power structure of academia to the point where they persist in teaching discredited theories. Margulis has a reputation for being something of a misanthrope. But it's not that she's asocial or hostile; she simply believes we humans have an exalted view of our place in the world that is not only unjustified, but is also destructive.

She expresses obvious disdain for neo-Darwinists who, to her way of thinking, hijacked the field of evolutionary biology. She regards the acceptance of random mutation theory as one of the great wrong turns in the history of science. In her view, its advocates promoted themselves, and by extension bad science, by appealing to the spirit of the time in which they operated. Their thinking is "restricted, parochial — ignorant, basically," Margulis says in one of her characteristically acerbic, yet quiet rants. "It's just zoological and anthropocentric, taking human relations and pushing them on biology." She has written that "the neo-Darwinist population-genetics tradition is reminiscent of phrenology. ... It will look ridiculous in retrospect, because it is ridiculous."

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Her direct way of stating her case has won Margulis her share of detractors as well as admirers. Not everything about Margulis's theories is generally accepted,

but her basic insight has earned wide, if sometimes begrudging, respect for having fundamentally altered the lens through which we view a seminal event that happened more than two billion years ago.

The story of how Margulis changed a scientific paradigm runs squarely through the University of Wisconsin-Madison.

She grew up on Chicago's south side. A precocious student and voracious reader, Margulis was fourteen when she entered the University of Chicago, where, she says with both pride and gratitude, she was part of the last graduating class of Robert M. Hutchins's Great Books curriculum, which mandated a classical education. Thinking for oneself was valued far more than memorizing facts.

It was there that she met her first husband, the late astronomer Carl Sagan, whom she describes as a "big shot" upperclassman who glommed onto her when she was sixteen and he was twenty. They married three years later in what she describes as an ill-considered decision made in response to cultural pressures of the times. Margulis is as critical of the private Sagan as she is admiring of his public persona as a celebrity astronomer. "Have you ever lived with someone you can't stand?" she asks, calling him "unbelievably self-centered" to the point of abdicating his role as father to their two sons.

In 1957, she and Sagan moved to Madison, where she enrolled in graduate school in biology while also embarking on motherhood with the birth of their first son, Dorion, two years later. The couple chose Madison because it is only seventy miles from the Yerkes Observatory in Williams Bay, Wisconsin, where Sagan was getting his doctorate.

The move would prove momentous. "Madison was great. I learned my basic biology, including genetics, there," says Margulis. She enthusiastically recalls professors who helped set the course of her lifelong passions. "Hans Ris was a fine teacher — the best of my whole career," she says of the cytologist who taught her microscopy. "He was a scientist's scientist; he made no concessions at all." James F. Crow, who at ninety-three is still a presence on campus, is another UW-Madison professor she singles out as an inspiring mentor. "I adored Crow's general genetics course; it changed my life," Margulis wrote in her 1986 book *Symbiotic Planet: A New View of Evolution.*

"I learned to do and teach science at the University of Wisconsin," she says. Margulis earned a master's degree in zoology and genetics in 1960, the year her second son, Jeremy (now an inventor of the musical software program Metro), was born. The family then moved to Berkeley, following Sagan's career path.

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In her characteristic directness, Margulis insists that the thoroughness of her education in Wisconsin meant that by the time she got to California, she knew more real biology than many narrow-disciplined faculty members. "I found I was often teaching my fellow students and instructors," she says. Comments like these, typical of her brash manner, can be offputting, and she readily admits that she utterly lacks the diplomatic skills to be an academic administrator. Her frank rudeness perhaps is indicative of the self-confidence that has enabled her to press on with maligned theories, some of which have gained acceptance. By now, she has authored or co-authored more than one hundred and fifty research articles and more than fifty books.

Crow says he formed a friendship with Margulis and Sagan in the late 1950s, and he has followed her career since then. "She's a maverick, and she made one very great contribution by really calling attention to the fact that many of the cellular organelles like mitochondria have an extra-cellular origin," says Crow. Not only did she see something new, he adds, but "maybe more important than just seeing, she was quite willing to say so and to report on it. ... Other people had taken a look at the idea and then tossed it off. She took it seriously and then brought a lot of evidence for it." Crow, who saw Margulis on his last visit to Amherst, says he admires what he calls her "freewheeling," "unrestricted," and even "somewhat undisciplined" imagination.

McFall-Ngai says Margulis is "somebody who can *look* — she has phenomenal powers of synthesis; she can put things together and see things that other people can't see." While scientific advancement has always relied on risk-taking visionaries, Margulis has been fortunate in that advances in microscopy and imaging have borne out some of her insights within her lifetime. "The fact of the matter is that everybody is waking up to [the importance of symbiogenesis], and it's only been going on for about the last ten years, so basically Lynn was way, way ahead of her time," says McFall-Ngai. "If you

pick up a biology textbook and you go to the index, she'll always be in there as the endosymbiosis theory person."

Margulis, seventy-one, is also a driven teacher, researcher, and writer whose daily routine includes bicycling the mile from her home to her lab. Sleep is one of those things that gets short shrift in her life, and by her own accounting, not a single day in decades has gone by that hasn't included work.

Her unrelenting dedication has paid off. The cinderblock walls of her UMass lab are bedecked with more than a dozen honorary degrees. The collection includes a certificate marking her election to the National Academy of Sciences in 1983, and the National Medal of Science that President Bill Clinton presented to her in a White House ceremony in 2000. That one is probably the sweetest, she says. "What's interesting is the NSF [National Science Foundation] — after rejecting all my proposals for years — it was NSF that put me forward." This year, she was among a handful of recipients of the Darwin-Wallace Medal, which was given out for the first time in fifty years by the Linnean Society of London. It is the highest honor for any naturalist.

By the time Margulis moved to Amherst — where her small yard abuts the Emily Dickinson homestead and museum — in 1988, she and chemistry professor T.N. Margulis had already divorced ("I quit my job as wife twice," she says), and she had given birth to two more children (Zachary Margulis-Ohnuma, now a New York criminal lawyer, and Jennifer Margulis di Properzio, a writer). The split, an amicable one, occurred when she was offered a stint as a distinguished scholar at Scripps Institute of Oceanography, and her husband didn't want her to go and didn't want to follow her to southern California.

Her offspring, she says, quip that after the divorces, she kept the children and her exes kept the money. For the last quarter century, she has had a personal and research partnership with microbiologist Ricardo Guerrero, a professor at the University of Barcelona, to whom she refers as her "compañero."

But it is her collaboration with her son Dorion Sagan that has contributed the most to her public reputation. They have functioned as a writing team for more than two decades, with Dorion bringing philosophy and poetry to the prose they produce together. *Microcosmos*, the title of their first collaboration, mirrors *Cosmos*, the title of the wildly popular book and public television series, which was hosted by Dorion's late father and made Carl Sagan perhaps the most recognizable scientist of his day.

Dorion Sagan is himself the author of many books, mostly on science. Their collaboration has, in large measure, taken Margulis beyond the realm of turgid peer-reviewed scientific journals, where she still publishes prodigiously. Yet she chafes at the suggestion that she and Dorion write "popular science," retorting, "What we do is make real science accessible to readers."

One aspect of science that she'd like to make more accessible is the much-neglected primordial phase of evolution. In the early part of the last century, theories of evolution focused on how human beings, regarded uncritically as the summit of evolutionary achievement, came to be the way they are over a period of hundreds of millions of years since

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Margulis sees beauty in the object of many hours of study — a cylinder of laboratory mud teeming with microbial life. She is so passionate about her research that not a single day has gone by in decades that hasn't included work.

animals crawled out of the sea. What went on before that, especially in the vast and ancient arena of microscopic life forms, received scant attention.

"Life on Earth is such a good story you can't afford to miss the beginning," Margulis says. "Do historians begin their study of civilization with the founding of Los Angeles? This is what studying natural history is like if we ignore the microcosm."

Among myriad tangible examples of symbiosis is our dependence on specific bacteria within our intestines and colons that produce the vitamins that allow us to live. The mutual dependence that has evolved between us and these bacteria means that as a matter of survival, we have acquired some of each other's genomes and in a way fused into a single individual. More than a thousand such healthy organisms reside permanently in all our bodies. Many of them have already passed some genes into our chromosomes, Margulis explains.

"Molecular biology has shown that this process is going on, and we've received many genes from bacteria and viruses. We are expected to receive more and lose more," she says. Margulis has done prodigious research on termites, which have bacteria and other wood-digesting beings known as protoctists in their hindguts. Without these microbes, the insects' survival on a diet composed of wood and water, which they convert into usable sugars and proteins, would be impossible.

The extent to which symbiogenesis can explain the emergence of new species is debated, but Margulis's indefatigable fieldwork, lab research, dogged teaching, and writing have put the "random-mutation-is-enough" theorists on the defensive. Still, she experiences her share of rejection. She is now advancing evidence that ancient symbiogenesis led to the origin of cilia (short, hairlike, waving structures on cells that produce locomotion). She thinks that cilia, involved in taste and smell, originated as bacteria. And again, she is meeting with resistance.

"I just laugh," she says when asked how she responds to criticism. "I don't take it personally — I just collect more and more and more evidence." Quizzed on where she summoned the confidence to persist in the face of financial rejection, public ridicule, and sustained attempts by the scientific establishment to dismiss her ideas, her response is as spontaneously direct as it is paradoxical. "It wasn't confidence; I just know I'm right — I mean, I really *do* know I'm right." ■

Eric Goldscheider, a freelance writer based in Massachusetts, is working on a book about a criminal case involving a botched DNA test.