I Contain Multitudes: The Microbes Within Us and a Grander View of Life. ED YONG. New York: HarperCollins, 2016. 355pp. $27.99 (hardcover).

Not every generation gets to witness the transformation of heresy into dogma. We didn't get to read the Copernican revolution in the literature as it happened. Nor the Darwinian one. But we are in the midst of one right now.

So fresh and on-the-cusp-of is this revolution, that it has no eponymous name associated with it. Candidates for that honor might include Anton de Bary who coined the term symbiosis; Ivan Wallin who recognized that mitochondria are symbiotic bacteria living in the cellular cytoplasm; Konstantin Mereschkowski who coined the term symbiogenesis; or Lynn Margulis who advanced and substantiated a theory of a symbiotic Earth.

There will, however, be no disputing the name of a science writer who described this revolution in a rigorous and delightfully readable book. Ed Yong is a science writer for *The Atlantic* and *National Geographic* hosts his blog, Not Exactly Rocket Science. He lives in London and Washington, D.C.

When he gives a talk about his new book, Yong walks from one side of the stage to other, pointing out milestones in the epoch of life on Earth much like a big historian. He starts with the formation of the Earth at one end of the stage, points out the emergence of prokaryotic life about a quarter of the way across, the emergence of eukaryotic life before halfway mark, the emergence of multicellular life an inch before the end of the stage, and the emergence of humans, of course, at the *actual edge* of the stage. Seeing this timeline on stage, it's easy to think of the prokaryote as distant relatives, separated from us by millions years. But the central thesis of Yong's book is that we are not distant nor separate from those ancient life forms at all. They are, in fact, us.

Yong synthesized 10 years of articles about the microbes within us so that readers can experience a grander view of life. Debunked is the notion that any eukaryotic organism is a single individual. He describes an early Earth teeming with prokaryotes. Every inch of land and sea, ice and atmosphere is covered or saturated with bacteria and archaea. "For roughly the first 2.5 billion years, bacteria and archaea charted largely separate evolutionary courses. Then, on one fateful occasion, a bacterium merged with an archaeon," prototyping the first eukaryote (p.9). Swept into the dustbin is also the notion that inherited genes alone are responsible for the great diversity on Earth. At every level—bodies, organs, cells, even nuclei—and in every function—metabolism, reproduction, development, homeostasis, and most surprisingly speciation—prokaryotic life is enriching the genetic potential of all eukaryotic life.

Wait, what? What's wrong with rugged individualism? "Bacteria," Yong answers, "are infinitely more versatile than we are. They are expert pharmacologists…[and they] reproduce rapidly and swap genes readily. In the great evolutionary race, they sprint, while we crawl" (p. 207). Evolution does its slow work through heredity, but it can move at a blinding pace through symbiosis since complex plants and animal bodies "are hubs of genetic innovation, because they allow DNA to flow more freely between the huddles masses of microbiome" (ibid.).

One of the most compelling examples of this symbiotic view of life is the Hawaiian Bob-tail Squid and its relationship with bioluminescent bacteria called *Vibrio fisheri*. Yong takes us on a field trip to the lab where tanks of these squid at all ages are being studied. Upon seeing a thumb-sized squid up close, changing before his eyes from white to "an autumnal scene painted by Seurat" Yong confesses, "I'm rather taken. The squid oozes personality" (p.49).

The squid hides in the sand by day but it feeds at night. It swims on the surface of shallow water and is preyed upon from below by fish good at detecting shadows. So it's a good thing the squid is equipped with a specialized light organ that acts like an invisibility cloak. This ability to hide is a superpower masterminded by a symbiosis. The researchers attach a florescent marker to a group

of bioluminescent V. fisheri microbes and watch as they make the squid a new invisibility cloak every day.

During the day, the surface of the light organ is covered in mucus and beating hairs called cilia. The hairs create a current that draws in particles of bacterial size. Microbes amass in the mucus, V. fisheri among them. When at least five of V. fisheri, enough to make a quorum, detect the presence of a squid, they start spewing out a cocktail which repels or kills any other microbe and attracts even more V. fisheri. The column of pure V. fisheri marches into the light organ. Once inside, the microbes release enzymes that remodel the light organ to make room for themselves and close the door behind them. When night falls, sensors on the top of the squid detect the precise amount of moonlight. That information gets communicated to the light organ community so that when they simultaneously decide to turn on their light, the light shining down from the squid matches the light shining down on the water (p. 51).

This single instance of symbiosis reveals a stunning amount of agency for a group of blind, gutless, and brainless prokaryotes—they sense physical parameters, talk to each other, make group decisions, synthesize innovative enzymatic actions, encourage tissue growth, and modify host social behavior. Even harder to believe is that the microbiome is not a constant entity. The bacteria in the squid are pumped out of the light organ every morning and re-recruited every afternoon.

This is an astonishingly complex procedure, one that certainly caused this reader's jaw to drop. Like the collective shock and awe emitted from the globe when the image of Earth from the moon was beamed from space in 1969, we are likely to be changed after reading Yong's book. Although we have no crisp image to stare at, Yong's compilation of vignette after vignette paints a picture in our mind's eye that life on Earth is a collection of nested ecosystems, from the climate to the nucleus of a gut cell in a fruit fly.

This revelation has implications for managing the well-being of the ecosystems that surround us and live within us. It might move us away from waging war with disease, infection, allergy, and autoimmunity and toward tending the invisible gardens of microbes instead. It might encourage us to forgo biocides—pesticides, herbicides, fungicides—and focus on learning how to use diversity to grow the ecosystem services we crave. We do have to be careful, Yong warns. "Symbiotic microbes are still their own entities, with their own interests to further and their own evolutionary battles to wage. They can be our partners, but they are not our friends. Even in the most harmonious of symbioses, there is always room for conflict, selfishness, and betrayal" (p.76).

At the very least, reading this book would make big historians recognize that we need to update the grand narrative with a fuller discussion of prokaryotic symbiosis. Without symbiotic relations; there would be no eukaryotes, no multicellularity, no adaptive immune system. There would be much slower adaptations to new habitats and food sources, slower co-evolution between plants and animals, and perhaps considerably less speciation.

At its core, the book adds another dimension to our understanding of increasing complexity. Recapitulating the narrative of big history, Yong writes "cities are hubs of innovation because they concentrate people in the same place, allowing ideas and information to flow more freely." Likewise, our bodies concentrate bacteria. "Close your eyes" he continues, "and picture skeins of genes threading their way around your body, passed from one microbe to another. We are bustling marketplaces, where bacterial traders exchange their genetic wares" (p.196).

Perhaps understanding the role of prokaryotic

symbiosis in the life sector of the big history narrative will give us a useful metaphor for understanding the cosmic, Earth and humanity sectors of Big History. Are molecules the first example of symbiosis? Is the gravitational asteroid-sweeping that Jupiter provides for Earth reciprocated? What is the influence of Earth's gravity on the potential for life on Europa? What is the best way to promote human dignity across the globe—keeping cultures distinct and separated, or connected and homogenized? The metaphor is a certainly a generative one.

The application of this new idea is generative as well. The final chapter is an uplifting one. Yong describes just of a smattering of the research and development that is exploding in the literature on health, agriculture, aquaculture, pest management, personalized medicine, and ecosystem management on land and sea. It is a great gift to humanity when the scientific endeavor generates a grander view of the grand narrative. *I Contain Multitudes* provides us with a panoramic look at this grandeur.

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