THE DRAKE EQUATION

Estimating the Prevalence of Extraterrestrial Life through the Ages

In this compelling book, leading scientists and historians explore the Drake Equation, which guides modern astrobiology's search for life beyond Earth. First used in 1961 as the organizing framework for a conference in Green Bank, West Virginia, it uses seven factors to estimate the number of extraterrestrial civilizations in our galaxy. Using the equation primarily as a heuristic device, this engaging text examines the astronomical, biological, and cultural factors that determine the abundance or rarity of life beyond Earth and provides a thematic history of the search for extraterrestrial life.

Logically structured to analyze each of the factors in turn, and offering commentary and critique of the equation as a whole, contemporary astrobiological research is placed in a historical context. Each factor is explored over two chapters, discussing the pre-conference thinking and a modern analysis, to enable postgraduates and researchers to better assess the assumptions that guide their research.

DOUGLAS A. VAKOCH is Director of Interstellar Message Composition at the SETI Institute and Professor of Clinical Psychology at the California Institute of Integral Studies. He also serves as Chair of the International Academy of Astronautics Study Group on Interstellar Message Construction and has edited numerous books in the field of astrobiology and space exploration.

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To Amy Dowd, for her patience and support
To Joe Castrovinci, for his hard work and dedication

Contents

Contributors

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Foreword

Humble and simple though it may be, the equation attempts to quantify a phenomenon of prime interest to both the scientific world and the general public: the abundance of observable technical civilizations in space. It is obvious that learning of those civilizations, many of them much older than our own, will enrich us greatly in facts of biology, sociology, philosophy, and science in general. We will learn how other civilizations have conducted their affairs over times much longer than we have existed. We will perhaps learn of the problems they faced and how the problems were dealt with. We will learn the limitations, opportunities, and possible dangers of technologies much more advanced than our own. We will learn the ways of life of creatures and places much different from those on Earth. It will be the ultimate exciting journey to exotic foreign countries.

To achieve these results, we must detect and study those distant worlds. No doubt the search will be lengthy, expensive, and resource-intense, including the time of talented people and sophisticated search instruments of great power and cost. Already, for more than fifty years, we have embarked on such searches without success. This is not surprising, however, since even the most optimistic analysis of the amount of searching required for success is far beyond what we have done to date.

To formulate future searches, optimize them, and make a case for the resources needed for success, we need to create, as best we can, an estimate of how much searching will be required to have a good chance of success. To do this, we need to estimate the number of places, which we call N, from which evidence of intelligent life might be coming, and compare that to the totality of galactic stars, which number approximately 200 billion.

The equation was invented to provide an estimate of N. It is a simple arithmetical product of seven variables. It works to quantify the production of galactic planets, their habitability, the possible origin of life on a planet, the evolution of intelligence, the evolution of technology we might detect, and the length of time the technology is detectable. The equation is described in detail elsewhere in this book.

The equation works as a recipe to make detectable civilizations. Take seven ingredients in the proper amounts, mix them together, let simmer for about three billion years, and you get N advanced civilizations! Indeed, the equation is basically very simple: just seven variables, all to the first power. No exponents, no exponentials, no trig functions. This is all to the delight of students with math anxiety when they are presented with the equation in elementary astronomy courses, as is common these days. It is even simpler than Kepler's laws. There is also a sigh of relief from many others, as well as students, when they see it for the first time. So simple, yet it is dealing with something of the most profound importance. It gives the answer, when solved, to one of the oldest and most important questions, scientific or philosophical, which exists for humanity: What is the abundance of intelligent life in the universe?

Of course, it is not all that simple. What are the values of the variables? When the equation was first formulated in 1961, we had crude knowledge of only one variable: the rate of star formation. This hardly justified a book. But much has happened in the fifty-three years since, particularly the blossoming of astrobiology, which is, after all, the study of everything involved in the equation. Fifty-three years ago very few people worked on the variables; today, the number of workers is not really known but is surely in the many thousands. Now it is time to stand back and look at where we are. That is what this book is about.

In those fifty-three years, we have seen the discovery of thousands of other planetary systems – none were known in 1961. Some of these planetary systems belong to red-dwarf stars, stars that we didn't think, back then, could harbor habitable planets. Planets in the habitable zone of the red dwarfs have been found, increasing the number of habitable objects in the galaxy by about ten times. We have achieved a growing understanding of the habitability of those planets. We have even found more than four other objects in the solar system itself with large liquid lakes, possibly suitable for life, on them. This has expanded our deduced limits on the "habitable zone," where life as we know it may survive. That qualifies many more objects as potential abodes of life than we thought fifty-three years ago.

There have been numerous experiments simulating the chemical situations on young planets; these have identified a variety of chemical pathways that can produce the basic molecules of life. It almost has gone unnoticed, but in none of these experiments has a "showstopper" surprised us. No complex or rare catalyst or unnatural molecule like a freon is required to produce life's basic building blocks, just molecules using very common elements are required. Studies of the brains of mammals have shown, again, that there seem to be no showstoppers when it comes to evolving intelligence. All of this makes us optimistic that the development of living things and high intelligence elsewhere in space should occur, and possibly very prolifically.

You will see that some of the writers of the chapters here are limited in their ability to quantify the factor in the equation they are writing about. This is as it should be. The last four variables in the equation, in particular, are ones where our only information, right now, is from Earth history. The writers are reluctant, as ethical scientists, to draw any firm conclusions from a sample of one. So there is still much to be learned before we will be able to arrive at any firm quantitative results from the equation. We wish, in particular, to make a discovery of at least a second, independently produced, system of life. For now, we can only speculate and use our intuition to arrive at possibly plausible answers.

The "limitation of the sample of one" applies particularly strongly to the variable L. Not only do we have only ourselves as a source of knowledge about L, but we have seen in ourselves the perceived limits on L to be changing rapidly, even on the time scale of human lives. The variable L represents the length of time a civilization uses a technology we can detect. We have only our technological history to rely on for this information. What do we see? In just fifty years, our ability to detect various technologies has greatly improved, and there is reasonable room for improvement. This can increase the operative value of L if we are typical. At the same time, improvements in technology have decreased the strength of some of the strongest signs of our existence, such as television broadcasts and military radar systems. This acts to reduce L if we are typical. Overall, we just don't know what "typical" is for civilizations; it is a great unknown, and has a huge impact on any calculation of N. We are in a catch-22 situation: We won't know how much effort it will take to succeed in our searches until we have succeeded.

History is repeating itself as we explore the cosmos for other creatures. We have become like Columbus, setting sail to discover a rich new world without knowing how far we must sail before we will reach that land. Nevertheless, we are confident that there are glorious new worlds to be discovered out there among the stars.

Frank Drake

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Edited by Douglas A. Vakoch and Matthew F. Dowd
Frontmatter
More information

Preface

The Drake Equation: Estimating the Prevalence of Extraterrestrial Life through the Ages provides a thematic history of the search for extraterrestrial life to the present day, using the terms of the Drake Equation as organizing categories. This equation was originally proposed by the astronomer Frank Drake, who conducted the first modern experiment in the search for extraterrestrial intelligence (SETI). He used the equation as the organizing theme for a conference on interstellar communication held in 1961 at the National Radio Astronomy Observatory in Green Bank, West Virginia. By multiplying the following seven terms, Drake provided an estimate of the number of extraterrestrial civilizations currently transmitting in our galaxy:

- R^* Rate of formation of stars suitable for the development of intelligent life
- f_p Fraction of stars with planetary systems
- n_e Number of planets, per solar system, with an environment suitable for life
- f_l Fraction of suitable planets on which life actually appears
- f_i Fraction of life-bearing planets on which intelligent life emerges
- f_c Fraction of civilizations that develop a technology that releases detectable signs of their existence into space
- L Length of time such civilizations release detectable signals into space

From the outset, the Drake Equation has served as a means for quantitatively estimating the number of extraterrestrial civilizations in our galaxy that are capable of making contact at interstellar distances. Some continue to use the equation in that manner, and an examination of efforts to estimate the specific values for various terms will be discussed in this book. More people, however, use the equation as a heuristic device to consider the factors relevant to the search for evidence of life beyond Earth without a strong emphasis on quantifying these terms, and this book will similarly explore the equation in this manner.

Fifty years after it was first introduced, the Drake Equation continues to influence scientists involved in astrobiology – the study of the origin, evolution, distribution, and future of life in the universe. While scholarly works, textbooks, and popular writings in astrobiology often include sections on the Drake Equation, until now there has been no stand-alone volume on the topic.

We have two reasons for writing this book. First, we wish to provide a comprehensive review and analysis of each term of the equation. This will provide a resource for scientists and graduate students actively conducting research in the many disciplines related to astrobiology. Second, the book places contemporary astrobiological research in historical context by including two chapters for each term of the Drake Equation: one covering the concept before the 1961 Green Bank conference, and the other ranging from 1961 to the present. To promote dialogue between practicing scientists and historians, authors cross-reference one another's chapters liberally, highlighting the complex interplay between the terms. By understanding the historical context of contemporary science, we hope that scientists will better recognize and appreciate the suppositions that guide their own research, often in unspoken ways.

Acknowledgments

To the authors of *The Drake Equation*, we express our appreciation of the innovation, depth, and sensitivity of the work they share here. They deserve special thanks for thoughtfully engaging one another's ideas, as reflected in the numerous cross-references between chapters throughout the volume, highlighting the links between the terms of the equation. It is especially meaningful for us to include a chapter by Mike Crowe, who first introduced both editors, separately, to the history of discussions about the prevalence of extraterrestrial life.

We are grateful to Joe Castrovinci for so capably copyediting each chapter in their early stages, enhancing the consistency across chapters while still encouraging authors to keep their own voices. His organizational ability combined with his expertise in technical writing allowed us to move ahead smoothly and on schedule.

Doug Vakoch would especially like to thank his many colleagues from the SETI Institute, who have shared with him their insights into the Drake Equation over the past fifteen years. He especially thanks Molly Bentley, David Black, James Brewster, Steve Brockbank, Edna DeVore, Frank Drake, Andrew Fraknoi, Dane Glasgow, Gerry Harp, Ly Ly, David Morrison, Michelle Murray, Chris Munson, Chris Neller, Karen Randall, Jon Richards, Pierre Schwob, Seth Shostak, and Jill Tarter. More recently, Doug warmly acknowledges the administration, faculty, staff, and students of the California Institute of Integral Studies (CIIS), especially for support from Joseph Subbiondo, Judie Wexler, and Mera Atlis. In addition, he thanks Harry Letaw and Joyce Letaw for their ongoing support of this work.

For encouraging us to develop this project and then shepherding the book through the editorial process at Cambridge University Press, we are indebted to Vince Higgs. Also at Cambridge University Press, Sara Werden has our gratitude for helping to move the book swiftly and efficiently into production.

We wish to thank our families, including our parents, Alvin Vakoch and Stella Vakoch, and Jim Dowd and Betty Dowd, for their never-ending love and support. Doug is especially grateful to his wife, Julie Bayless, in more ways than he can or will share here. Matt is similarly grateful to his wife, Amy, and apologizes to his sons, Ben and Mike, for a missed cross-country season.

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