The Search for Extraterrestrials

Intercepting Alien Signals

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Springer

Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

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USA

SPRINGER–PRAXIS BOOKS IN POPULAR ASTRONOMY
SUBJECT *ADVISORY EDITOR*: John Mason, M.B.E., B.Sc., M.Sc., Ph.D.

ISBN 978-0-387-73453-8 Springer Berlin Heidelberg New York

Springer is a part of Springer Science + Business Media (*springer.com*)

Library of Congress Control Number: 2009925768

Cover design: Jim Wilkie
Project Copy Editor: David M. Harland
Typesetting: BookEns Ltd, Royston, Herts., UK

Printed in Germany on acid-free paper

To Harriet,
our children
Ryia, Diane & Ethan,
and our grandchildren
Jake, April, Gabriella & Julia.

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Author's preface

In writing this book, I set out to educate, entertain, and stimulate public support for intelligent efforts by humankind to search for alien signals from space. As the book explains the primary facts and concepts in layman's terms, the reader will need only elementary mathematics to grasp the major issues. Whilst some oversimplification has been inevitable, the coverage is scientifically accurate. I hope the reasoning will resonate with the public. Once readers have grasped the fundamentals, I believe they will agree with me that the SETI effort to-date has been extremely limited in scope; in particular, it has not really explored the electromagnetic spectrum outside the very narrow radio-frequency region. In fact, not even 1 per cent of the spectrum has been explored!

The people involved in SETI are trying to achieve a technically challenging task in a manner consistent with the laws of physics. It has absolutely nothing to do with the "I was kidnapped by aliens" reporting of the tabloid press. Unfortunately, in the public mind UFOs and alien signals tend to get lumped together, with the result that SETI work is often portrayed as being on the fringe of science. Certainly, in the past, many engineering and scientific academics risked SETI tarnishing their careers. The low probability of success is a barrier to academics interested in furthering their careers. Some members of the public may believe a massive effort to detect alien signals is underway, but this is far from being the case. In fact, no US government funding currently exists for SETI. The limited efforts that are in progress rely on charitable funding. SETI has been mainly the work of academics well versed in a particular discipline. However, as I show in the text, the detection of extraterrestrial signals is a systems engineering problem whose solution – constrained by limited resources – both minimizes the chance of failure and maximizes the chance of success. SETI efforts to-date have been marked by basic deficiencies which make it unlikely they will succeed. Section 4 of this book offers some suggestions for how a systems engineering approach might be developed.

There has been a great deal of speculation in the literature about why we have had no success, with the inference being that this is because there is nobody to signal to us. This is known as the Fermi Paradox, but it is far too early to conclude that we are alone. Little has been done, especially at laser wavelengths. This book explains what has been done, what is being done, what can be done, and what may have to be done before we can in good conscience acknowledge the Fermi Paradox.

A related effort is that underway to identify Earth-like planets orbiting other stars. This was initially done using terrestrial telescopes, but recently satellites have joined the hunt. After years of frustration, in excess of 300 extrasolar planets have been detected in the last decade, in some cases with a single star having several planets. The early methods were best suited to finding gas giants even larger than Jupiter, but the latest systems are designed to find Earth-like planets. The latest addition to this effort is the Kepler spacecraft launched by NASA in March 2009. When it does find a planet with a mass comparable to Earth that is orbiting a solar-type star at just the right distance for the surface to be conducive to life, NASA will certainly hail it as a major discovery. And indeed it will be, but a dozen or so further requirements must be satisfied before a star system can produce an intelligence capable of attempting to communicate across interstellar distances.

This book seeks to inform the public of what has been done, what is being done, what can be done and what needs to be done, much of it at little cost and potentially great benefit to mankind. The obstacles to success are discussed in detail. There is a long way to go. SETI is limited to, at best, several million dollars per year globally. If we are serious, then we should do better than this. With public support, money can be forthcoming or the challenge may be taken up by a wealthy foundation.

SETI has been of interest to me personally since 1965, soon after the birth of the laser. In 1961 Robert Schwartz and Charles Townes wrote a scientific paper which explained the potential for lasers in extraterrestrial communications. However, little was done while attempts to detect signals concentrated on radio frequencies. Interest in optical SETI was kept alive by a few people, notably myself, Stuart Kingsley and Ragbir Bhathal, until the lack of success at radio frequencies forced reconsideration. I pointed out in 1965 that laser signals would be best sent by short pulses, since this would allow a modest transmitter to readily overcome the brightness of the host star. Today, there is a serious effort at Harvard devoted to pulsed laser signals, but all the efforts at all wavelengths are still quite limited in relation to what can be done. Thus, this book is in four sections. The first section discusses the likelihood of intelligent life, taking into account the many constraints which could conceivably mean that we are the only intelligence in the galaxy. The second section discusses the basics of space communication and the technical approaches and issues. The third section describes the SETI efforts that have been attempted and are currently underway. The final section explains how we might proceed further. The bibliography should assist anyone seeking a guide to the literature on the subject.

In my career, lasers have gone from being a new subject of interest, to finding use in a wide range of applications. I addressed laser communication in my 1965 book *Laser Receivers*, and spent my career helping to develop laser communication. It is gratifying that the advances in power and efficiency of lasers have facilitated such varied applications, and in my role as technical editor of a *Laser Applications* series by the Academic Press I kept up to date with the myriad uses of lasers in industry, defense, medicine and entertainment. I participated in these advances, being the first to patent a semiconductor diode pumped crystal laser that is ubiquitous today from a green laser pointer for public speakers, to a satellite-to-satellite communication link. As Director of Laser Space Systems for McDonnell Douglas for many years, and in working with both NASA and the United States Air Force, I was intimately involved with the development of space communication. In 1975 the IEEE gave me a Fellow Award, as did McDonnell Douglas in 1985, both for "Leadership and Contributions to laser communications". I believe there are excellent reasons for lasers being the best choice for SETI. I leave it to the reader to form a judgement on which part of the spectrum we are more likely to intercept a signal from space: radio-frequency, optical, infrared, ultraviolet, or something else. I discuss a variety of considerations, including information that makes it clear how difficult it is for interception to occur. The material on communication is based explicitly on my background and expertise. That on the likelihood of a planet giving rise to intelligence derives from the rapidly increasing body of knowledge of planetary science. Overall, I hope that this book provides a firm base for those who might wish to further the search for alien signals.

Finally, it should be borne in mind that signals may be being sent to us right now, but we will not know it unless we are looking in the right part of the spectrum at the right time, with the right equipment pointing in the right direction. Success may be tomorrow, or a millennium away.

Monte Ross
July 2009

Acknowledgments

I must thank Clive Horwood of Praxis for accepting this book for publication, John Mason for suggesting how it should be structured, and David M. Harland for editing the manuscript. I am also grateful to Miriam Pierro-Ross and Mark Peterson, who helped me to navigate the computer world. It would be difficult to thank each and every person whose work I have used in compiling the facts essential to this book, but I have mentioned in the text those individuals whose work had most impact and I have included an extensive bibliography. I must also thank Robert Olshan and Stephen Webb for their helpful suggestions. The illustrations are from varied sources. Some are off the Internet, but others were created specifically for this book. If I have not assigned a credit, and the owner notifies me via the publisher, I will be glad to rectify that omission in a future edition.

Part 1: The likelihood of extraterrestrial intelligence

1 Vast distances and long travel times

It has been said that the discovery of an extraterrestrial intelligence will be the most important event in mankind's history. For millennia, humans have been looking at the stars at night and wondering whether we are alone in the universe. Only with the advent of large-dish radio-frequency antennas and ultra-sensitive receivers in the late-twentieth century did it become possible to attempt a search for extraterrestrial intelligence (SETI).

The search at radio frequencies continues and has even involved the public (see SETI@home) by allowing home PCs to analyze some of the received noise. With so much data collected, it becomes easier to examine if pieces of the data are divided up and dispersed to many individual computers. A home PC can analyze the data at a time it is otherwise idle (see Chapter 8). The fact that tens of thousands of people signed up to participate illustrates the strong public interest in SETI. Whilst a very successful promotion, it has had no success in finding an extraterrestrial signal.

On the other hand, look at what we have accomplished in less than 200 years: we have progressed from essentially being limited to communicating within earshot or by messengers traveling on foot or riding horses, to communicating at the speed of light with space probes millions of kilometers away. This fantastic accomplishment illustrates the exponential growth of our technology. In this context, several decades spent on SETI is a mere drop in the bucket of time. The disappointment of SETI to-date is, I believe, due to the overoptimistic expectation of there being an advanced intelligence in our immediate neighborhood. Less than 100 years ago it was widely believed that there might be beings on Mars or Venus, the nearest planets to us. We now know this is not so. Indeed, we have come to realise that whilst intelligent life on planets orbiting other stars is feasible, its development is dependent on a number of conditions that may not occur in combination very often.

In spite of there being several hundred billion stars in our Milky Way galaxy, the likelihood of an intelligent society sending signals our way is thought to be low. The recent discovery of over 300 planets orbiting relatively nearby stars lends hope that there are many planets that can sustain life, some of which will develop intelligence that is willing to communicate. But the equation developed by Frank Drake in 1960 (Chapter 6), the hypothesis advocated by Peter Ward and Donald E. Brownlee in their book *Rare Earth: Why Complex Life is Uncommon in the Universe*, published in 2000 (Chapter 3), and the study by Stephen Webb using the Sieve of Eratosthenes in his book *If the Universe is Teeming with Aliens... Where is Everybody*, published in 2002 (Chapter 6), all highlight the many probabilities in play. Depending on how optimistic one is in assigning probabilities to each factor, one can reach either very low probabilities or much better odds. A probability of one in a million would still mean 400,000 stars in our galaxy have intelligent life - and there are hundreds of billions of galaxies. So where are they? Either intelligence is scarcer, or we have not been looking in the right places using the right instruments at the right time.

The failure of SETI to-date raises the intriguing question of whether our search at radio frequencies was naive, since no intelligent society would use radio frequencies to transmit over distances of hundreds of light-years if other wavelengths were more useful. Is a technology which we ourselves have only recently acquired likely to be favored by a far more advanced society? In fact, a good argument can be made that radio frequencies are an unlikely choice for an advanced society, and that if we must select just one part of the electromagnetic spectrum to monitor then visible, infrared or ultraviolet offer better prospects for SETI. In essence, the case against radio is that it is a high-powered transmission whose wide beam washes over many stars. In contrast, lasers in the visible, infrared or ultraviolet require less power and the energy is aimed towards a particular star system. A civilization seeking to establish contact with any intelligences around stars in its neighborhood might aim such a laser at a star which shows characteristics likely to support life. As so few star systems have such characteristics, we would probably be included in a targeted search by a nearby civilization. If we were fortunate, we might spot such a laser probing for a response from any life in our system. Although many papers have been written showing why and how laser signals could be present, early studies by radio-frequency engineers compared continuous-wave laser signals with continuous-wave radio frequencies and drew conclusions that may not actually be correct. It was clear from the physics and from the noise and background light that the most efficient modulation method at optical wavelengths was high-peak-power short-pulse low-duty-cycle pulses. The term short-pulse low-duty-cycle refers to the fact that the signal is not continuous, but is active only for a small fraction of the time. For example, the transmitted pulse may be on for one nanosecond, and the pulse rate may be once per millisecond. As the duty cycle is the pulse width multiplied by the pulse rate, we have 1 nanosecond multiplied by 1,000 pulses per second for a duty cycle of one part in a million. This means that the system is transmitting one-millionth of the time. Thus the peak power can be 1,000,000 times the average power, or the continuous power in this example. Other issues in determining the best choice for such communication are discussed in later chapters.

In retrospect, it is evident that SETI began searching at radio frequencies because extraterrestrial intelligence was initially believed to be plentiful and we had systems for receiving weak radio signals from probes operating in deep space, whereas laser technology was not at the same level of development.

The likelihood of radio frequencies being used in lieu of lasers is diminished if nearby star systems are not transmitting. This is due to the much larger antennas that would be required at the receiver site to receive signals from much greater

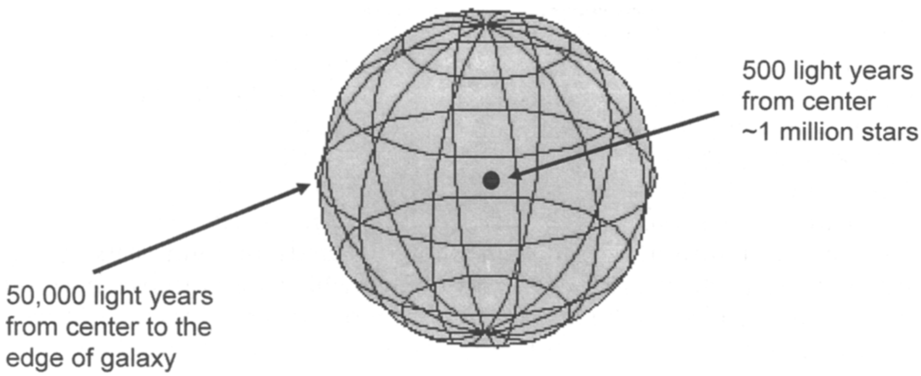

Figure 1.1. The vastness of our galaxy.

distances. The received power is proportional to the area of the antenna. A light-year is 9.46×10^{12} kilometers, and stars are many light-years apart. Owing to the inverse square law in which the area irradiated increases by the square of the distance, there is a factor of 400 difference in the signal power lost in space between a source that lies 10 light-years away and one 200 light-years away. If the same transmitter is used, the area of the receiving antenna must be increased by a factor of 400 in order to detect a source 200 light-years away compared to 10 light-years away (i.e. 20×20). This may well be impracticable. And this is only one argument against using radio frequencies for interstellar communication. It is more likely that the stars will be far away because of geometry. That is, imagine the Sun to be located at the center of a sphere in which the other stars are assumed to be more or less equally distributed (Figure 1.1), then the fact that volume is a function of the cube of distance means that there will be 8 times more star systems within a radius of 100 light-years from the Sun than a radius of 50 light-years, and 64 times more within 200 light-years. It is therefore 512 times more likely that an intelligent society may be sending us signals if we look to a distance of 400 light-years rather than a distance of 50 light-years. Figure 1.2 shows that there are approximately 1 million stars similar to the Sun within a radius of 1,000 light-years. However, as constraints are applied and more is learned about potential star systems, the probability of there being anyone signaling to us continues to decline.

How far are the stars and how do we know?

One question that is often asked is how we know stellar distances. One of the major ways is to use the parallax effect. As shown in Figure 1.3, parallax measures the angle to a point from two vantage points. The distance to that point can be calculated by applying simple trigonometry to the angular measurements. The distance between the vantage points is the baseline, and the longer the baseline

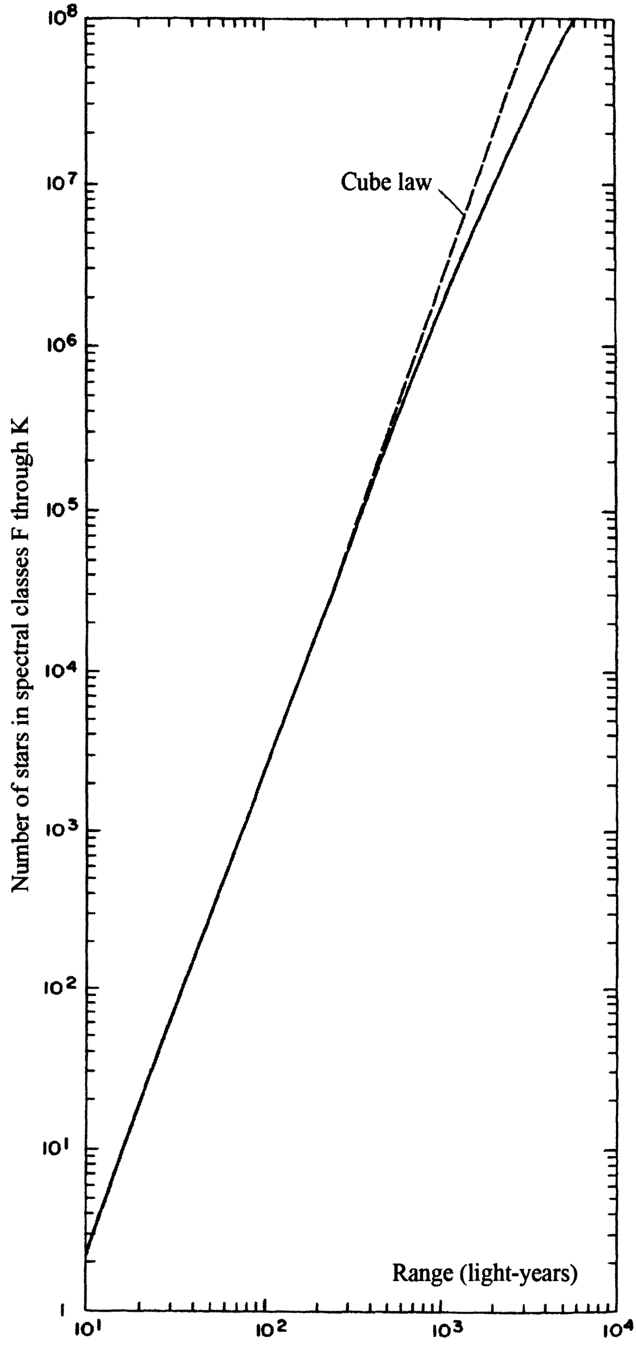

Figure 1.2. The number of stars in spectral classes F through K.

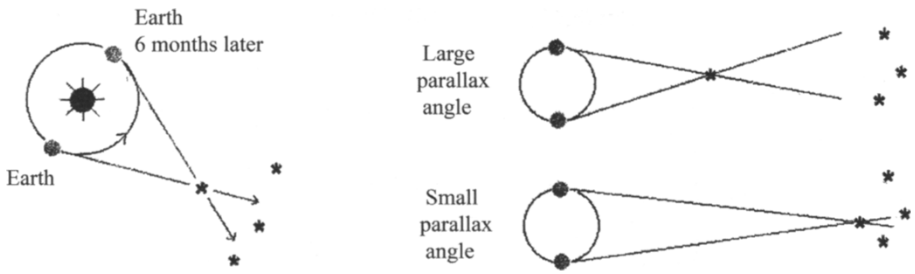

Figure 1.3. The parallax effect (left) and parallax change with distance (right).

the more accurate the distance measurement. The longest baseline available to a terrestrial observer is the diameter of Earth's orbit around the Sun. A star observed at suitable times 6 months apart will appear in a different position on the sky as the angle of viewing changes slightly. The closer the star, the greater its parallax and the more it will be displaced relative to the background of more distant stars. However, even for nearby stars the effect is small, and highly accurate measurements are required to obtain results with high confidence. The annual parallax is defined as the angle subtended at a star by the mean radius of Earth's orbit of the Sun. A 'parsec' is 3.26 light-years, and is based on the distance from Earth at which the annular parallax is one second of arc. The angles are very small because the distance across Earth's orbit of the Sun is extremely small in comparison to the distances of the stars. Indeed, the nearest star, Proxima Centauri, lies 4.3 light-years away and has a parallax of only 0.76 seconds of arc.

The accuracy of angular measurements made from Earth's surface is limited by distortions in the atmosphere. Telescopes in space therefore have an advantage. In 1989 the European Space Agency put a satellite named Hipparcos into orbit around Earth to employ the baseline of Earth's orbit around the Sun to accurately measure parallaxes for stars as far away as 1,600 light-years. There are methods which do not use geometric parallax and facilitate measurements at greater distances. These are more difficult to implement, but can yield reasonably accurate results. In 1997 NASA began a study of a Space Interferometry Mission (SIM). Progress was slow due to budget constraints. As currently envisaged, the renamed SIM Lite will be launched at some time between 2015 and 2020 and be put into solar orbit trailing Earth. It will have a number of goals, including searching for terrestrial planets in nearby star systems. Optical interferometry will enable the positions of stars on the sky to be measured to within 4 millionths of a second of arc. This will facilitate measuring distances as far away as 25 parsecs to an accuracy of 10 per cent, which is many times better than is possible from Earth's surface.

By a variety of techniques the parallax effect can provide acceptable results out to about 1,000 light-years, with the distances to the nearer stars being more accurate than those farther away. Such a volume of space includes a large