


Astrobiology Perspectives on Life of the Universe

PLANET FORMATION — AND — PANSPERMIA

*New Prospects for the
Movement of Life through Space*

Edited by
Branislav Vukotić
Joseph Seckbach
Richard Gordon

 Scrivener
Publishing

WILEY

Table of Contents

[Cover](#)

[Title page](#)

[Copyright](#)

[Preface](#)

[References](#)

[Part I PHILOSOPHICAL ASPECTS OF PANSPERMIA](#)

[1 “On the Origin of Life”](#)

[2 Why We Should Take Interstellar Panspermia Seriously](#)

[2.1 Introduction](#)

[2.2 The Case for Interstellar Panspermia](#)

[2.3 Theoretical Consequences of Interstellar Panspermia](#)

[2.4 Conclusions](#)

[References](#)

[3 The Extended Continuity Thesis, Chronocentrism, and Directed Panspermia](#)

[3.1 Introduction: The Continuity as a Pre-Requisite for Scientific Grounding of Astrobiology](#)

[3.2 Versions and Resistance](#)

[3.3 Cultural Evolution and Directed Panspermia](#)

[3.4 Conclusion and Prospects](#)

[Acknowledgements](#)

[References](#)

[4 Life in the Milky Way: The Panspermia Prospects](#)

[4.1 Introduction](#)

[4.2 Three Levels of Habitability and Panspermia](#)

[4.3 Conclusions](#)

[Acknowledgements](#)

[References](#)

[Part II MICROORGANISMS AND PANSPERMIA](#)

[5 Planetary Protection: Too Late](#)

[5.1 Introduction](#)

[5.2 What is Planetary Protection](#)

[5.3 Extent of Earth Biosphere](#)

[5.4 Extension to Other Planetary Bodies](#)

[5.5 Backward Contamination](#)

[5.6 Interplanetary Exchange](#)

[5.7 Habitable Conditions for Interplanetary
Micronauts](#)

[5.8 Conclusion](#)

[Appendix A](#)

[Appendix B](#)

[Appendix C](#)

[Acknowledgments](#)

[References](#)

[6 Microbial Survival and Adaptation in Extreme Terrestrial Environments— The Case of the Dallol Geothermal Area in Ethiopia](#)

[6.1 Introduction](#)

[6.2 Planetary Field Analog: The Case of the
Dallol Geothermal Area](#)

[6.3 Life in Extreme Environments](#)

[6.4 Conclusion and Remarks on Panspermia](#)

[Acknowledgements](#)

References

7 Escape From Planet Earth: From Directed Panspermia to Terraformation

Acknowledgements

References

Part III FORMATION AND EVOLUTION OF PLANETS: MATERIAL EXCHANGE PROSPECTS

8 Catalyzed Lithopanspermia Through Disk Capture of Biologically Active Interstellar Material

8.1 Introduction

8.2 Capture of Interstellar Planetesimals

8.3 Catalyzed Lithopanspermia

8.4 Conclusion and Discussion

Acknowledgements

References

9 Lithopanspermia at the Center of Spiral Galaxies

9.1 Introduction

9.2 The *Kepler* Transit Survey and the Distribution of Living Worlds

9.3 XUV Hydrodynamic Escape and the Formation of Habitable Evaporated Cores

9.4 Frequency of Exchange in High Stellar Densities

9.5 Detecting Panspermia

9.6 Concluding Remarks

References

10 Wet Panspermia

10.1 Introduction

10.2 Earth and Its Isotopic World: Geological and Environmental Implications

[10.3 Quest for the Primordial Water Worlds](#)

[10.4 Looking for the Biotic Traces in Extraterrestrial Material](#)

[10.5 Ices of the Moon and Proposal of Earth-Induced Wet Panspermia in the Solar System](#)

[10.6 Implications for Other Planets of the Inner Solar System?](#)

[10.7 Conclusions](#)

[References](#)

[11 There Were Plenty of Day/Night Cycles That Could Have Accelerated an Origin of Life on Earth, Without Requiring Panspermia](#)

[Acknowledgement](#)

[References](#)

[12 Micrometeoroids as Carriers of Organics: Modeling of the Atmospheric Entry and Chemical Decomposition of Sub-Millimeter Grains](#)

[12.1 Micrometeorites and the Search for Life](#)

[12.2 White Soft Minerals](#)

[12.3 Atmospheric Entry Model](#)

[12.4 Results](#)

[12.5 The Role of Primordial Atmospheres](#)

[12.6 Conclusions](#)

[References](#)

[13 Dynamical Evolution of Planetary Systems: Role of Planetesimals](#)

[13.1 Introduction](#)

[13.2 Planetesimal Formation and Evolution](#)

[13.3 Transporting Mechanism in Later Stages of Planetary System Evolution](#)

[13.4 Conclusion](#)

[Acknowledgements](#)

[References](#)

[Part IV FURTHER PROSPECTS](#)

[14 A Survey of Solar System and Galactic Objects
With Pristine Surfaces That Record History and
Perhaps Panspermia, With a Plan for Exploration](#)

[14.1 Introduction](#)

[14.2 Recording Properties](#)

[14.3 Pristine Potential of Solar System Bodies](#)

[14.4 Prospects and Conclusions](#)

[Acknowledgements](#)

[References](#)

[15 The Panspermia Publications of Sir Fred Hoyle](#)

[Acknowledgements](#)

[References](#)

[Index](#)

[Also of Interest](#)

[End User License Agreement](#)

List of Illustrations

Chapter 3

[Figure 3.1 A symbolic representation of the
feedback created by directed pansper...](#)

Chapter 4

[Figure 4.1 Sketch of the levels of influences of
matter and their inter-relation...](#)

Chapter 5

[Figure 5.1 Author \(left\) with colleagues in the class 100,000 cleanroom at the M...](#)

[Figure 5.2 Left: The very first photograph that Neil Armstrong took on the Moon:...](#)

[Figure 5.3 Left: Plotted orbits of all known inner Solar System asteroids as of ...](#)

[Figure 5.4 Left: Present-time factors for habitability of terrestrial planets. P...](#)

Chapter 6

[Figure 6.1 Location map of the Danakil Depression and the Dallol geothermal area...](#)

[Figure 6.2 Landsat 8 pan-sharpened RGB-321 color composite image \(scene ID: LC81...](#)

[Figure 6.3 \(a and b\) Photographs of the Assale salt plain showing irregular poly...](#)

[Figure 6.4 Panoramic view \(from southwest\) of the Black Mountain. Note the whiti...](#)

[Figure 6.5 \(a\) Panoramic view of a field of sulfur and halite deposits associate...](#)

[Figure 6.6 Photographs of the mounds at the Dallol Hot Springs site. \(a\) Field o...](#)

[Figure 6.7 Photographs of terrace morphologies at the Dallol Hot Springs site. \(...](#)

[Figure 6.8 \(a\) Active mushroom-like structures \(field of view ca. 4 m\). Reproduc...](#)

[Figure 6.9 \(a\) White halite salt rims \(a few mm in thickness\) forms as a result ...](#)

Chapter 7

[Figure 7.1 The TRAPPIST-1 exoplanets \(labeled b through h\), compared to Mercury,...](#)

[Figure 7.2 Breakthrough Starshot Lightsail nanocraft. \(a\). StarChip—a centimeter...](#)

[Figure 7.3 Artist's impression of 'Oumuamua \(1I/2017 U1\). Discovered on October ...](#)

Chapter 8

[Figure 8.1 Total number of captured planetesimals as a function of their size. S...](#)

Chapter 9

[Figure 9.1 Planet mean density \$\rho_p\$ as a function of galactocentric distance \$R_{gc}\$](#)

[Figure 9.2 Number of captured objects as a function of their velocities. Higher ...](#)

[Figure 9.3 Theoretical spatial density of rocky planets \(\$n_{terr}\$ \) as a function of...](#)

[Figure 9.4 Spacetime topography of life-bearing planets for a case with the incl...](#)

Chapter 11

[Figure 11.1 Estimates for the date of LUCA seem to have settled down. From Table...](#)

Chapter 12

[Figure 12.1 Thermal curves of different entry scenarios related to a \$MgCO_3\$ micro...](#)

[Figure 12.2 Magnesium carbonate fraction occurrences at different altitudes.](#)

[Figure 12.3 Radiative and evaporative energy loss contributions during the atmos...](#)

[Figure 12.4 Grazing entry scenarios of \$\text{MgCO}_3\$ micrometeoroids.](#)

[Figure 12.5 Thermal curves of different entry scenarios related to a \$\text{CaCO}_3\$ micro...](#)

[Figure 12.6 Calcium carbonate fraction occurrences at different altitudes.](#)

[Figure 12.7 Grazing entry scenarios of \$\text{CaCO}_3\$ micrometeoroids.](#)

[Figure 12.8 Radiative and evaporative energy loss contributions during the atmos...](#)

[Figure 12.9 Thermal curves of different entry scenarios related to a \$\text{FeCO}_3\$ micro...](#)

[Figure 12.10 Iron carbonate fraction occurrences at different altitudes.](#)

[Figure 12.11 Radiative and evaporative energy loss contributions during the atmo...](#)

[Figure 12.12 Grazing entry scenarios of \$\text{FeCO}_3\$ micrometeoroids.](#)

[Figure 12.13 Thermal curves of different entry scenarios related to a \$\text{CaSO}_4\$ micr...](#)

[Figure 12.14 Anhydrous calcium sulfate fraction occurrences at different altitud...](#)

[Figure 12.15 Radiative and evaporative energy loss contributions during the atmo...](#)

[Figure 12.16 Atmospheric density effect \(Figure from \[12.80\]\).](#)

[Figure 12.17 A nitrogen molecule \(blue\) just before the impact with the crystal ...](#)

[Figure 12.18 Relative probabilities of the different events following the impact...](#)

[Figure 12.19 Thermal histories of a \$\text{MgCO}_3\$ \(top left\), \$\text{CaCO}_3\$ \(top right\), \$\text{FeCO}_3\$ \(...\)](#)

[Figure 12.20 Thermal histories of a \$\text{MgCO}_3\$ \(top left\), \$\text{CaCO}_3\$ \(top right\), \$\text{FeCO}_3\$ \(...\)](#)

[Figure 12.21 Thermal histories of a \$\text{MgCO}_3\$ \(top left\), \$\text{CaCO}_3\$ \(top right\), \$\text{FeCO}_3\$ \(...\)](#)

Chapter 13

[Figure 13.1 Illustration of how a planetesimal from the planetesimal belt reached...](#)

[Figure 13.2 Amount of delivered water on planets in TRAPPIST-1 system in percent...](#)

Chapter 14

[Figure 14.1 Diameters of objects that have their escape velocities equal in magn...](#)

List of Tables

Chapter 8

[Table 8.1 Various parameters used for the estimation of the number of captured p...](#)

Chapter 10

[Table 10.1 Comparison between the composition of the lunar \(Apollo 15\) and terre...](#)

Chapter 11

[Table 11.1 Estimates for the date of LUCA.](#)

[Table 11.2 Data from \[11.5\]. Geological names from \[11.21\] for time points desig...](#)

Chapter 12

[Table 12.1 \$\kappa'\$ values of magnesite, calcite, siderite, and anhydrite.](#)

[Table 12.2 \$\kappa'\$ values of oxides.](#)

[Table 12.3 \$\kappa'\$ values of gases.](#)

[Table 12.4 \$\kappa'\$ values of primordial atmospheres.](#)

Chapter 13

[Table 13.1 Abundance of 18 most abundant elements relative to H, taken from \[13....](#)

[Table 13.2 List of volatile materials for C, S, and M types of asteroids.](#)

Scrivener Publishing

100 Cummings Center, Suite 541J

Beverly, MA 01915-6106

Astrobiology Perspectives on Life of the Universe**Series Editors: Richard Gordon and Joseph Seckbach**

In his 1687 book *Principia*, Isaac Newton showed how a body launched atop a tall mountain parallel to the ground would circle the Earth. Many of us are old enough to have witnessed the realization of this dream in the launch of Sputnik in 1957. Since then our ability to enter, view and understand the Universe has increased dramatically. A great race is on to discover real extraterrestrial life, and to understand our origins, whether on Earth or elsewhere. We take part of the title for this new series of books from the pioneering thoughts of Svante Arrhenius, who reviewed this quest in his 1909 book *The Life of the Universe as Conceived by Man from the Earliest Ages to the Present Time*. The volumes in ***Astrobiology Perspectives on Life of the Universe*** will each delve into an aspect of this adventure, with chapters by those who are involved in it, as well as careful observers and assessors of our progress. Guest editors are invited from time to time, and all chapters are peer-reviewed.

Publishers at Scrivener

Martin Scrivener (martin@scrivenerpublishing.com)

Phillip Carmical (pcarmical@scrivenerpublishing.com)

Planet Formation and Panspermia

New Prospects for the Movement of Life through Space

Edited by

Branislav Vukotić

Astronomical Observatory, Belgrade, Serbia

Richard Gordon

Gulf Specimen Marine Laboratory & Aquarium, Panacea, FL, USA and Wayne University, Detroit, MI, USA

and

Joseph Seckbach

The Hebrew University of Jerusalem, Israel



WILEY

This edition first published 2021 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

© 2021 Scrivener Publishing LLC

For more information about Scrivener publications please visit

www.scrivenerpublishing.com.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

Wiley Global Headquarters

111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Limit of Liability/Disclaimer of Warranty

While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read.

Library of Congress Cataloging-in-Publication Data

ISBN 978-1-119-64039-4

Cover image: Courtesy of NASA

Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Preface

The panspermia hypothesis dates back to the works of ancient philosophers. In the 1800s, organics in meteorites were considered by the Swedish chemist Jacob Berzelius [1.3] [1.4] and later German physician Hermann E. Richter [1.15] speculated on the possibility of life transport by meteors. Lord Kelvin [1.9], discussed the possibility of panspermia in his Presidential Address to the British Association for the Advancement of Science. At the beginning of the next century, Swedish physicist/chemist Svante August Arrhenius (1908) presented his book on the panspermia theory [1.2]. There is a long history from before this time through the last century of claims of finding life in meteorites [1.6]. Astronomical sciences also developed significantly during this period to the point where we can observe gravitational waves from merging black holes, which was hardly imaginable just a few decades ago, and visualize black holes. With the discovery of many exoplanets astrobiology has matured as a scientific discipline. A tentative discovery of the intergalactic meteor particle in 2007 [1.1] and recent discoveries of an anomalous object “Oumuamua [1.11] and comet 2I/Borisov [1.8], that appear to have visited us from outside the Solar system, point out that our planet and its host star may not be an isolated island, in an otherwise lifeless universe. They are likely to exchange matter with the other stars from their vicinity as probably is the case with other stellar systems too, perhaps containing life. There is currently a bias that any such panspermia, if they exist, are prokaryotes [1.13] [1.16] or rugged, microscopic Eukaryotes [1.14].

In addition to transporting the physical bodies of microorganisms, another important aspect is the transport of biological information about these living systems. After all, the evolution of life on Earth is about altering the genetic code, either by natural or artificial means. Given that the organic matter, the building blocks for living organisms, is omnipresent in the universe, the aforementioned information might in some way be considered as the essence of life, at least in our current geocentric view of life [1.5]. The aspect of sending just the information signal in order to spread life is investigated in the visionary sci-fi novel "His Master's Voice" by Polish writer Stanislaw Lem, first published in 1968 [1.10]. Contemporary with the beginning radio SETI searches [1.18], this offered a convergence point between sending and receiving SETI signals and the panspermia hypothesis. Information panspermia was later born in 2005 with the work of Vahe Gurzadyan [1.7].

In times when a number of exciting new discoveries are made and the new ones seem to be just around the corner, the millennia old panspermia hypothesis has not yet matured into a full fledged theory and some of its aspects might still not have been envisioned. Along the lines of scientific falsificationism, we can consider that no evidence against panspermia are found to date and that much of the controversy still remains [1.12]. The search is even more active in the opposite direction but still there is an evident lack of convincingly non-terrestrial microorganisms on Solar system bodies other than Earth. The recent experiments with micro-organisms exposed to space conditions at the International Space Station offer accumulating evidence that these organisms can withstand the harsh conditions of open space for long periods of time while preserving their biological potential. Even more, there are mounting concerns that human made space

vehicles can spread life from our biosphere to other bodies of the Solar system, the most recent one being that the Israeli space mission that transported tardigrades to the Moon [1.17].

While panspermia is related to microorganisms and small scale processes on one end, on the other end, the transport of material depends on environmental conditions in galaxies. The evolution of galaxies depends on the interaction of galaxies within galaxy clusters and the overall evolution of matter in the universe. The galaxies are the main building blocks of our universe, analogous to cells in a human body. The stars and their planets are condensed from the clouds of galactic gas and dust that are rich in organics. The process of planetary formation is at the middle among the above stated scales that are relevant for panspermia. Starting from planetary formation, studies can go in either direction, to larger or smaller scales, to investigate phenomena that could spread life.

This collection of chapters incorporates studies from biology, astronomy and geology that investigate the possibility of panspermia, with most of them directly investigating phenomena related to the process of planetary formation. The processes described in these chapters permit the panspermia hypothesis, but empirical confirmation is still lacking at the level of our current knowledge. The basic aim of this book is to provoke readers to contemplate their respective research fields that are related to panspermia. For that matter it presents the basics of panspermia but also the advanced studies in the research fields presented. The chapters are comprehensible on a student level but at the same time they might be very interesting to experienced researchers. Possibly, some of them are already working on current and future space missions that may offer an empirical

vindication of extra-terrestrial life transfer through the vastness of space.

Branislav Vukotić
Richard Gordon
Joseph Seckbach
September 1, 2021

References

- [1.1] Afanasiev, V.L., Kalenichenko, V.V., Karachentsev, I.D., Detection of an intergalactic meteor particle with the 6-m telescope. *Astrophys. Bull.*, 62, 4, 301-310, 2007.
- [1.2] Arrhenius, S., *Worlds in the Making; the Evolution of the Universe*, Harper, New York, 1908.
- [1.3] Berzelius, J.J., Analysis of the Alais meteorite and implications about life in other worlds. *Ann. Chem. Pharm.*, 10, 134-135, 1834.
- [1.4] Chyba, C.F., Extraterrestrial amino acids and terrestrial life. *Nature*, 348, 6297, 113-114, 1990.
- [1.5] Gordon, R., Are we on the cusp of a new paradigm for biology? The illogic of molecular developmental biology versus Janus-faced control of embryogenesis via differentiation waves. *BioSystems* (Waves Fertilization, Cell Division Embryogenesis, Guest Editors: Jack Tuszynski, Luigia Santella & Richard Gordon), 203, 104367, 2021.
- [1.6] Gordon, R. and McNichol, J., Recurrent dreams of life in meteorites, in: *Genesis - In the Beginning: Precursors of Life, Chemical Models and Early Biological Evolution*, J. Seckbach (Ed.), pp. 549-590, Springer, Dordrecht, 2012.
- [1.7] Gurzadyan, V.G., Kolmogorov complexity, string information, panspermia, and the Fermi paradox. *Observatory*, 125, 1189, 352-355, 2005.

[1.8] Guzik, P., Drahus, M., Rusek, K., Waniak, W., Cannizzaro, G. and Pastor-Marazuela, I., Initial characterization of interstellar comet 2I/Borisov. *Nat. Astron.*, 4, 53–57.

[1.9] Kelvin, L., On the Origin of Life. *Excerpt. From the Presidential Address to the British Association for the Advancement of Science*, held at Edinburgh, 1871, https://zapatopi.net/kelvin/papers/on_the_origin_of_life.html

.

[1.10] Lem, S., *His Master's Voice*, Northwestern University Press, Evanston, Illinois, USA, 1999.

[1.11] Loeb, A., *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth*, Houghton Mifflin Harcourt, Boston. Massachusetts, USA, 2021.

[1.12] McNichol, J. and Gordon, R., Are we from outer space? A critical review of the panspermia hypothesis, in: *Genesis - In the Beginning: Precursors of Life, Chemical Models and Early Biological Evolution*, J. Seckbach (Ed.), pp. 591–619, Springer, Dordrecht, 2012.

[1.13] Ott, E., Kawaguchi, Y., Kölbl, D., Rabbow, E., Rettberg, P., Mora, M., Moissl-Eichinger, C., Weckwerth, W., Yamagishi, A., Milojevic, T., Molecular repertoire of *Deinococcus radiodurans* after 1 year of exposure outside the International Space Station within the Tanpopo mission. *Microbiome*, 8, 1, 150, 2020.

[1.14] Persson, D., Halberg, K.A., Jørgensen, A., Ricci, C., Møbjerg, N., Kristensen, R.M., Extreme stress tolerance in tardigrades: surviving space conditions in low earth orbit. *J. Zool. Syst. Evol. Res.*, 49, 90–97, 2011.

[1.15] Raulin-Cerceau, F., Maurel, M.C., Schneider, J., From Panspermia to bioastronomy, the evolution of the hypothesis of universal life. *Origins Life Evol. Biosphere*, 28, 4-6, 597–612, 1998.

[1.16] Stan-Lotter, H., Survival of subsurface microbial communities over geological times and its implication for astrobiology, in: *Model Ecosystems in Extreme Environments [MEET, Volume 2 in series: Astrobiology: Exploring Life on Earth and Beyond, series editors: Pabulo Henrique Rampelotto, Richard Gordon & Joseph Seckbach]*, J. Seckbach and P.H. Rampelott (Eds.), pp. 169–188, Elsevier B.V., Amsterdam, 2019.

[1.17] T., N., Israeli Beresheet Spacecraft Allegedly Brought Microscopic Organisms to the Moon, Possibly Taking Over, Tech Times, New York, USA, 2020,
<https://www.techtimes.com/articles/255393/20201227/israeli-beresheet-spacecraft-allegedly-brought-microscopic-organisms-moonpossibly-taking.htm>.

[1.18] Wikipedia, Search for extraterrestrial intelligence, https://en.wikipedia.org/wiki/Search_for_extraterrestrial_intelligence,2020.

Part I

PHILOSOPHICAL ASPECTS

OF PANSPERMIA

1

“On the Origin of Life”

By Lord Kelvin (William Thomson)

Excerpt. From the Presidential Address to the British Association for the Advancement of Science; held at Edinburgh in August, 1871 Reprinted in Kelvin’s *Popular Lectures and Addresses*, p. 132-205. (Bracketed additions are from reprint.)

[p. 197.]

Think now of the admirable simplicity with which Tait’s beautiful “sea-bird analogy,” as it has been called, can explain all [?] these phenomena.

The essence of science, as is well illustrated by astronomy and cosmical physics, consists in inferring antecedent conditions, and anticipating future evolutions, from phenomena which have actually come under observation. In biology the difficulties of successfully acting up to this ideal are prodigious. The earnest naturalists of the present day are, however, not appalled or paralysed by them, and are struggling boldly and laboriously to pass out of the mere “Natural History stage” of their study, and bring zoology within the range of Natural Philosophy. A very ancient speculation, still clung to by many naturalists (so much so that I have a choice of modern terms to quote in expressing it) supposes that, under meteorological conditions very different from the present, dead matter may have run together or crystallised or fermented into “germs of life,” or “organic cells,” or “protoplasm.” But science brings a vast mass of inductive evidence against this hypothesis of spontaneous generation, as you have heard from my predecessor in the Presidential chair.

Careful enough scrutiny has, in every case up to the present day, discovered life as antecedent to life. Dead matter cannot become living without coming under the influence of matter previously alive. This seems to me as sure a teaching of science as the law of gravitation. I utterly repudiate, as opposed to all philosophical uniformitarianism, the assumption of “different meteorological conditions”—that is to say, somewhat different vicissitudes of temperature, pressure, moisture, gaseous atmosphere—to produce or to permit that to take place by force or motion of dead matter alone, which is a direct contravention of what seems to us biological law. I am prepared for the answer, “Our code of biological law is an expression of our ignorance as well as of our knowledge.” And I say yes: search for spontaneous generation out of inorganic materials; let any one not satisfied with the purely negative testimony of which we have now so much against it, throw himself into the inquiry. Such investigations as those of Pasteur, Pouchet, and Bastian are among the most interesting and momentous in the whole range of Natural History, and their results, whether positive or negative, must richly reward the most careful and laborious experimenting. I confess to being deeply impressed by the evidence put before us by Professor Huxley, and I am ready to adopt, as an article of scientific faith, true through all space and through all time, that life proceeds from life, and from nothing but life.

How, then, did life originate on the Earth? Tracing the physical history of the Earth backwards, on strict dynamical principles, we are brought to a red-hot melted globe on which no life could exist. Hence when the Earth was first fit for life, there was no living thing on it. There were rocks solid and disintegrated, water, air all round, warmed and illuminated by a brilliant Sun, ready to become a garden. Did grass and trees and flowers spring

into existence, in all the fulness of ripe beauty, by a fiat of Creative Power? or did vegetation, growing up from seed sown, spread and multiply over the whole Earth? Science is bound by the everlasting law of honour, to face fearlessly every problem which can fairly be presented to it. If a probable solution, consistent with the ordinary course of nature, can be found, we must not invoke an abnormal act of Creative Power. When a lava stream flows down the sides of Vesuvius or Etna it quickly cools and becomes solid; and after a few weeks or years it teems with vegetable and animal life; which, for it, originated by the transport of seed and ova and by the migration of individual living creatures. When a volcanic island springs up from the sea, and after a few years is found clothed with vegetation, we do not hesitate to assume that seed has been wafted to it through the air, or floated to it on rafts. Is it not possible, and if possible, is it not probable, that the beginning of vegetable life on the Earth is to be similarly explained? Every year thousands, probably millions, of fragments of solid matter fall upon the Earth—whence came these fragments? What is the previous history of any one of them? Was it created in the beginning of time an amorphous mass? This idea is so unacceptable that, tacitly or explicitly, all men discard it. It is often assumed that all, and it is certain that some, meteoric stones are fragments which had been broken off from greater masses and launched free into space. It is as sure that collisions must occur between great masses moving through space as it is that ships, steered without intelligence directed to prevent collision, could not cross and recross the Atlantic for thousands of years with immunity from collisions. When two great masses come into collision in space it is certain that a large part of each is melted; but it seems also quite certain that in many cases a large quantity of debris must be shot forth in all directions, much of which may have experienced no greater violence than individual pieces of rock experience in a land-

slip or in blasting by gunpowder. Should the time when this Earth comes into collision with another body, comparable in dimensions to itself, be when it is still clothed as at present with vegetation, many great and small fragments carrying seed and living plants and animals would undoubtedly be scattered through space. Hence and because we all confidently believe that there are at present, and have been from time immemorial, many worlds of life besides our own, we must regard it as probable in the highest degree that there are countless seed-bearing meteoric stones moving about through space. If at the present instant no life existed upon this Earth, one such stone falling upon it might, by what we blindly call *natural* causes, lead to its becoming covered with vegetation. I am fully conscious of the many scientific objections which may be urged against this hypothesis, but I believe them to be all answerable. I have already taxed your patience too severely to allow me to think of discussing any of them on the present occasion. The hypothesis that [some] life [has actually] originated on this Earth through moss-grown fragments from the ruins of another world may seem wild and visionary; all I maintain is that it is not unscientific, [and cannot rightly be said to be improbable.]

2

Why We Should Take Interstellar Panspermia Seriously

Amedeo Balbi

*Dipartimento di Fisica, Università degli Studi di Roma
"Tor Vergata" Via della Ricerca Scientifica, Roma, Italy*

Abstract

After a long period of neglect, the hypothesis of interstellar panspermia has gained new consideration in recent years, due to a series of theoretical and observational developments. In this chapter, I briefly outline why this possibility should not be dismissed, especially in regions of the Galaxy with higher stellar density than average. Furthermore, I give some motivations for taking the mechanism into account when developing theoretical models of the distribution of life in the Galaxy (such as in studies of the galactic habitable zone) and in drawing implications from the results of future searches for biosignatures in exoplanets. This theoretical work should be complemented by experimental studies, in order to assess the concrete feasibility of panspermia with higher confidence.

Keywords: Astrobiology, extraterrestrial life, galactic habitable zone, biosignatures, interstellar panspermia

2.1 Introduction

The idea that biological material—and even living organisms—can be exchanged between planetary systems is more than one century old, but it has not been part of the mainstream discussion in astrobiology for long [2.28, 2.43].

Spiral,
 galaxies, [47](#)
 pattern, [42](#)
Spore(s), [58](#), [60](#), [62](#)–65, [68](#), [70](#)–71, [77](#), [80](#)
Stellar, [149](#)–157, [160](#)–164
 clusters, [46](#), [48](#)
 collisions, [45](#)
 flybys, [44](#), [46](#), [48](#)
 orbits, [48](#)
Stellar cluster, [131](#)–137, [140](#)
Sterilization, [57](#)–58, [60](#), [66](#), [77](#)–78
Stratosphere, [60](#)
Strontium ratio, [173](#)
Sulfates, [213](#)–214
 calcium sulfate (CaSO₄), [229](#)–230
Sun as binary system, [176](#)
Sun-like stars, [271](#)
Supernova, [270](#), [272](#)
Supernovae shocks, [272](#)
Surface gravity, [280](#), [282](#), [283](#), [285](#)–286
Tardigrade(s), [56](#), [63](#), [81](#)
Taxonomy, [254](#)
Telescope, [152](#)–157, [162](#)
Terraforming, [26](#), [75](#)–76
Terrestrial planets, [45](#)

The Great Silence, [272](#)
Theia impact, [196](#)
Theory of evolution, [275](#)
Thermal decomposition, [217](#)
Tidal heating, [283](#), [286](#)
Titan, [58](#), [66](#), [73](#)–74, [283](#), [285](#)
Transit, [260](#)
Trappist-1, [44](#), [120](#)
Trappist-1 system, [175](#)
Triton, [74](#)

Ultramicrobacteria, [276](#)
Ultraviolet light, [271](#)
Universe, [43](#)–44, [47](#)–49
Uranus, [286](#)

Variscan orogeny, [172](#)
Venus, [57](#), [70](#)–74, [77](#), [182](#), [184](#)
Vertical oscillations, [42](#)
Vesta, [282](#)
Virgo cluster, [272](#)
Virus(es), [60](#), [63](#), [68](#)
Voyager, [29](#)

Water, [172](#)
White soft minerals (WSM), [210](#)–211
Yarkovsky effect, [42](#), [260](#), [261](#)

Yeast, [64](#), [75](#), [81](#)

Yucatan peninsula, [273](#)–274

Also of Interest

Check out these published and forthcoming related titles from Scrivener Publishing

Terraforming Mars

Edited by Martin Beech, Joseph Seckbach and Richard Gordon

Forthcoming November 2021. ISBN 978-1-119-76196-9

Planet Formation and Panspermia

New Prospects for the Movement of Life through Space

Edited by B. Vukotić, Joseph Seckbach and Richard Gordon

Published 2021. ISBN 978-1-119-64039-4

Astrobiology

Science, Ethics, and Public Policy

Edited by Octavio A. Chon Torres, Ted Peters, Joseph Seckbach and Richard Gordon

Published 2021. ISBN 978-1-119-71116-2

Extremophiles as Astrobiological Models

Edited by Joseph Seckbach and Helga Stan-Lotte

Published 2020. ISBN 978-1-119-59168-9

www.scrivenerpublishing.com