Children of the Stars

Are we alone in the Universe? What is our place in it? How did we get here? We have long searched for the answers to questions such as these, and scientists are beginning to find some of the answers. In this book, Daniel Altschuler provides the reader with the elements to understand the questions and their answers as far as we know them. He explores subjects from physics and astronomy to geology and palaeontology. Along the way he touches on topics of great popular appeal such as the search for life on other worlds and the hazards of asteroid impacts. The author writes in an engaging and readable style with wit, warmth and erudition at a level that any interested reader can understand.

DANIEL R. ALTSCHULER, an experienced researcher, educator, and science administrator, is director of the National Astronomy and Ionosphere Center's Arecibo Observatory and a member of the faculty of the Physics Department of the University of Puerto Rico, at Rio Piedras.

The Arecibo Observatory is the site of the largest telescope on Earth. Daniel, who was born in Montevideo, Uruguay, the son of German immigrants, completed an Engineering degree from Duke University, and obtained his PhD in physics from Brandeis University. He has given numerous public lectures in many places from Uruguay to South Africa, and has appeared in radio and television shows including *Good Morning America* and *The Learning Channel*. He places the construction of a Visitor Center at the Arecibo Observatory, visited by over 120 000 persons every year, among his most satisfying achievements. The other is scoring a decisive goal for the team of the Max Planck Institut für Radioastronomie, in Germany, where he spent two years as a visiting scientist. Dr. Altschuler is a member of the American Astronomical Society and of the International Astronomical Union. He states "I have always been concerned about the poor understanding of scientific topics by a large segment of the population. It is not enough for scientists alone to understand the workings of nature. It is important that every citizen understands what scientists have been able to learn, not only because it is interesting, truly fascinating, but also because difficult decisions must be made by all, and can only be made with a clear understanding of the issues . . . a good part of this state of affairs has been the consequence of the little interest and less time taken by scientists to communicate with the public. My book is an effort to remedy this situation."

Children of the Stars

Our Origin, Evolution and Destiny

Daniel R. Altschuler

CAMBRIDGE UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011–4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa

http://www.cambridge.org

First published 2002

Printed in the United Kingdom at the University Press, Cambridge

Typeface Swift 9.5/13.5 pt *System* QuarkXPress™ [SE]

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication data
Altschuler, Daniel R.
Children of the stars : our origin, evolution, and destiny / Daniel R. Altschuler.
p. cm.
Includes bibliographical references and index.
ISBN 0 521 81212 7
1. Astronomy–Popular works. I. Title.
QB44.3 .A58 2002
520–dc21 2001043172

ISBN 0 521 81212 7 hardback

Contents

Some say the world will end in fire,
Some say ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

Robert Frost (1874–1963)

Prelude

Look at your hand. It is made of atoms, mostly atoms of carbon, oxygen, and hydrogen. These atoms did not always exist; they were produced inside stars.

Look at the ring on your finger. It is also made of atoms, maybe of gold or platinum. These were created during the death paroxysm of a massive star, a supernova explosion 5 billion years ago. Just like us, stars are born, live mostly a quiet life and die.

Open your hand toward the Sun and feel its heat. It is the energy of life.

Look at your hand again. It has five fingers, as do the hands of some other animals. This is not a coincidence, but points to the profound fraternity of all life forms on Mother Earth, one of millions of planets orbiting other distant stars. Perhaps we are not alone in this vast Universe, we would dearly like to know.

This book tells the story of the incredible events that, starting with the stars, lead to us. It will change forever both the way you see yourself and the way you see our world.

And when you look at the world do not be deceived by how large and robust it seems to be. The place we live in, the biosphere, is a delicate veneer on the surface of this tiny dot orbiting the Sun. We must treat it with respect since it is fragile, and not abuse its resources since they are limited.

> The aim of science is not to open the door to infinite wisdom, but to set a limit to infinite error
>
> *Bertold Brecht in* Life of Galileo *(1938)*

When the Moon places itself directly between the Sun and the Earth, it blocks out the Sun's light, producing a solar eclipse. In this photograph obtained by astronomer Tunç Tezel from Turkey, the day before the solar eclipse of August 11, 1999, the Moon, illuminated almost entirely from the back by the Sun (which is out of the picture to the lower left), shows up as a thin sliver of light. Mercury, the closest planet to the Sun, is never far from it in the sky and therefore normally difficult to see. On this photo the small planet is clearly visible at the bottom right. The dark side of the Moon is dimly illuminated by the light from an almost "full Earth." (Tunç Tezel)

Preface

Should you have time one fine autumn day, take the afternoon off and drive to a location in the countryside, away from the lights and sounds of the city, from where you can see the night sky in all its calm beauty. Find a nice spot, and wait until the Sun sets and your side of our planet faces the majesty of the dark sky. You are now looking at the Universe.

At twilight you might see a thin curved sliver of light, and with some care you will notice that it is the bright rim on the edge of a dark disk. It is our Moon, a wonderful sight, and when it is almost new a thin crescent of light is visible. The dark part is just about visible because it is dimly illuminated by sunlight which is reflected from the Earth. If you wait long enough, you will probably also see a "shooting star," not a star at all, but the incandescent trail left by a small particle – meteoritic dust – which by chance has entered our atmosphere at high speed and, heated up by friction, produces light. This meteoroid, if large enough, might survive its fiery trip and hit the surface of the Earth to be found as a meteorite. Sometimes it might even be large enough to make a crater of considerable dimensions, and on very, very rare occasions it could be so large that its impact would have catastrophic consequences.

Now lie on your back and spend some time looking at the awesome display painted by a myriad of twinkling stars which have quietly appeared against the black sky. You may also be able to recognize the occasional planet. After a while, as your eyes adjust to darkness, you will realize that a band of diffuse light crosses the sky from horizon to horizon. If you look through binoculars, you will find that this light is composed of countless stars, as was first discovered by Galileo Galilei about 400 years ago, when in 1609 he first used a small telescope to look at the night sky. This is the "Galaxias" of the Greeks, the "Via Lactea" of the Romans, the Milky Way to us, which today we know to be our galaxy, our home in this immense Universe. In antiquity, and for many cultures around the world, the Milky Way was thought of as either a river of heaven, a great silvery serpent, or a path in the sky. It is a gigantic flattened disk-like system composed of billions of stars which, when viewed from our position within it, appears to be a band of light across the sky.

After a while you will experience a wondrous feeling, a nostalgic feeling

which comes from very deep within, but also great joy, somehow related to your profoundest intuition, telling you that you are looking at our origin. *Our origin is in the stars.*

This astonishing discovery is the result of the efforts of scientists who over the last few centuries have struggled to uncover the secrets of nature. This is the goal of science: to understand the natural world through observation, experimentation, and computation. Science is also the foundation of the many technological developments (both good and bad) which drastically transformed life in the twentieth century. Most importantly, science provides the framework for understanding Life, the Universe, and Everything, at least as far as we have yet been able to.

I have written this book because the resulting story of the origins of matter and life, and their evolution, is an awesome story. It is better than science fiction, far better than all those fake UFO stories published in some newspapers and magazines, and even better than those great movies about such topics. This is because of one important and particular reason: *this* story is real. Without doubt, the unraveling of this story is the crowning intellectual achievement of the second millennium AD, and something that every one of us should be proud of.

I hope that this book will let you appreciate life in a new way. We are so preoccupied by our daily lives that we forget that we are only here for a very short visit. And then one day we are dead. I hope that after reading this book you will see your fellow human beings and the world in a different light. This might allow you to think in new ways which might just help extricate us from the frightening environmental predicament into which we have unwittingly placed ourselves.

This story is the culmination of a long development toward a new view of the Universe, a view which proposes a historical process. In spite of the opposition from some who believe that all there is to know about our Universe is written in ancient texts, this is an evolutionary view in the grandest sense, way beyond anything that Charles Darwin could have imagined (although the evolution of the Universe is not the same as Darwinian evolution). It involves the entire Universe which, over a very long time, created matter until it evolved to the point where planets, such as Earth, could be formed and become fertile for life to arise.

This is a very different outlook from the comfortable position held until about 500 years ago, which asserted that everything was as it always had been, since God's creation. This creation was said to have happened not very long ago, but everything would continue to be exactly as it was then, forever. The Universe was perceived as static and was therefore a safe place. Over the

past 500 years, those who proposed the new evolutionary view clashed with two opponents. One has been represented by the healthy resistance provided by the scientific establishment, and the other by religious or other dogma, a stubborn need to stick to literal scripture no matter what the evidence might be, as was the case with Aristotelian physics which was dogmatically adhered to for over 1000 years. There were learned people who refused to look through Galileo's telescope, lest this might shatter their convictions. Scientific conservatism is healthy because it demands proof in support of all new ideas, proof based on repeatable measurements which are sometimes difficult to produce. This is what gives science its power and fecundity. On the other hand, dogma is sterile, locking into a dark chamber the one quality which distinguishes us from other animals: our minds.

Contrary to some popular perceptions, science is not a cold matter-of-fact endeavor ruled only by unquestionable facts. Facts can and should be questioned, and must be interpreted in the light of some framework or theory. In the end, after careful examination, the facts triumph. To a certain extent, which we try to minimize, science is also influenced by personal beliefs, cultural backgrounds, and social climate. This is because scientists *are* human. However, new ideas, no matter how disagreeable or difficult to come to terms with, will eventually be accepted in the light of the evidence. Such evidence has led to the acceptance of a Sun-centered planetary system, continental drift, and the origin of species. Each of these created quite a storm, a hurricane that made the ship of science change its course. On the other hand, dogma of every kind will not be so understanding of new ideas if they are perceived as running counter to it. The ship of dogmatism will surely run aground, or capsize and sink, at some point in the voyage. We have witnessed this throughout history.

This story is the result of the courage and determination of individuals who have dedicated their lives to the study of nature, sometimes at great personal risk and sacrifice. I have sprinkled the story with a few brief vignettes of these heroes, really not enough to do them justice, but I hope enough to pay them homage. Of course, these heroes – Copernicus, Darwin, Wegener, to name just a few – only represent the most prominent of those who participated in the process of discovery, which was not as clear and straightforward as you might think. There were false starts, intermediate steps, and excursions toward dead ends, on the way to the breakthroughs that led to a better understanding of our world. These were men and women living in difficult times, working with the limited tools available one hundred or more years ago, writing by candle light, and traveling by sailing ship or horse-drawn carriage. They often depended for their livelihood on the

erratic support of some wealthy patron. It is difficult to imagine how they achieved what they did, and to understand what drove and inspired them to sometimes risk their lives in defense of their convictions.

Today we live in a world populated by sophisticated instruments. Giant particle accelerators probe the smallest dimensions of matter, machines analyze the molecules of life, large telescopes, both on Earth and in space, look out to the farthest reaches of the Universe, and spacecraft scrutinize the Earth and other planets of the solar system. Many nations have established agencies such as the US National Science Foundation (NSF), the National Institutes of Health (NIH), and the National Aeronautics and Space Administration (NASA), to support the efforts of scientists who gather an ever-increasing flow of data which become the basis for new knowledge. This is not a luxury, catering only to the aspirations of the academic community, but a necessity for our progress and our survival.

Our power over nature has given us the ability to destroy our fragile biosphere. Only a very deep and precise knowledge of the world around us will allow us to understand the consequences of our actions, and so avoid the dire effects which are impacting life on a global scale. In this book you will learn that we are so intimately connected with nature that any thought of independence can only lead to disaster. However, it is not enough for scientists alone to understand nature. It is also important that every citizen understands what scientists have been able to learn, not only because it is interesting, truly fascinating, but also because difficult decisions must be made by all, and can only be made with a clear understanding of the issues. In a world which is very dependent on technology, participatory democracy can only work at its best with a scientifically literate population. How else are we going to be able to judge the value of sending a probe to explore Mars, the need to reduce our emissions of carbon dioxide, the use of nuclear bombs to protect us from asteroids, or the effects of introducing genetically modified foods? How else will we be able to distinguish between esoteric gobbledygook that speaks of "metaphysical vortices of rotational energy" and real natural phenomena? Furthermore, at a more essential level, science reveals for us the profound and extraordinary beauty of nature.

I have simplified many aspects of the story, not discussing the complex details which might be of greatest interest to a scientist. Some aspects of the story are only poorly understood today while others are still controversial and could be modified by future research. This is the nature of science. This is *not* a textbook and I have not tried to develop each topic systematically and completely, considering all the alternatives and putting in all the "perhaps" and all the "maybes". To do so would require each chapter to be converted

into a 200-page text written by an expert, and then you would most likely not read it. I have, however, not shied away from explaining some basic ideas and including some numbers, without which this story cannot really be understood. I have told the story as if I were telling it to a good (and patient) friend, and have kept it short so as not to tax your patience. It is a somewhat eclectic story in which I have described what I find to be some of the most fascinating and important findings to come from science, findings that bear on what we are, our place in the Universe, and our future on Earth.

I have used approximate numbers for the measurements of different quantities. What is important for an understanding of the story is not the fact that the diameter of our Earth at the equator is exactly 12 713.51 km, but that 13 000 km is about 1/30 of the distance from Earth to the Moon. I hope to whet your appetite to read more about the topics covered in this book, and to this end have suggested some books for further reading at the end.

We recently celebrated the arrival of a new millennium as we passed from 1999 to 2000, notwithstanding that the new millennium did not arrive until the year 2001 (because there was no year zero). It is not clear to me what all the commotion was about, except that it was a good excuse to celebrate, and we need all the excuses we can find for that. There is nothing very special about having gone 2000 times about the Sun since the time that those in the Christian world started counting. The Earth, with all its inhabitants, has done this several billion times. We travel about the Sun at the enormous speed of 67 000 miles every hour, which is about 1000 times faster than the speed you travel in your car. In the last 2000 years we have covered a distance of about 1000 billion miles going in circles, something we all seem to do frustratingly often. To remind you: 1 billion equals 1000 million. Had we gone in a straight line instead, we would now be just two-tenths of the way to the *nearest* star. Our place in the Universe, whatever it might be in philosophical terms, is clearly a very small one physically.

If after reading this book you become motivated to look at the magnificent cosmic display as I have suggested at the beginning, then my efforts in writing it will have been well worth while.

Or you might prefer to think that the answer to the question of Life, the Universe and Everything is . . . *forty-two.*

This last statement comes from one of my favorite books, *The Hitchhiker's Guide to the Galaxy* by Douglas Adams, and its various sequels. The quotations at the beginning of each chapter of this book are his.

Writing this book has taken an inordinate amount of my time over several years – long nights of study, writing and rewriting, and rewriting yet again, with sometimes a feeling of never getting to the end. I was inspired

by the illusion that reading this book would make a difference. I hope it does. I hope that the next time you contemplate a red sunset, or look at a fellow human being or at another animal, or watch as a cloud drifts by in the sky, you do so with different eyes. I hope that, whatever you do in your life, you will ponder the consequences of your actions on our biosphere, even if these are minute.

The realization that the book's sales depend on a "market" which shuns books about science is not encouraging. I want to share this book with "everyone" – slightly more that the 10000 persons that might buy it if it becomes a great success (so I have been told). The thought that if I had written about the love life of aliens instead (those we study at a large hidden laboratory at the Arecibo Observatory) it might have become a bestseller disturbs me very much. But that is the real world.

Anyway, now the book is in your hands, and I hope you enjoy it and learn something from it. I welcome your comments, which you can email to: stern@ naic.edu.

Author's acknowledgments

My wife Celia not only helped me with the grammar of the text, but also taught me a lot about the more complex grammar of life. She knows how much I care for all this, and encouraged me when I felt like forgetting all about it. To her I dedicate this book.

Many persons and events in my life have influenced my way of seeing things. My father taught me that life is serious business, Eddy taught me that living is an art, and my mother taught me that life is not serious business. Emmy Link taught me to respect and love our planet, and "la barra" in Montevideo, that beautiful bunch of kids with whom I grew up, taught me the meaning of friendship. Claudio Benski inspired me.

My teachers were many, too many to mention, but I remember with affection Gregorio Treibich, and my "cosmography" teacher Conrado Schneider, who first opened my eyes to the Universe.

Chris Salter (Arecibo, Puerto Rico) helped to make a draft into something readable with his wonderful command of English and of astronomy. I thank my friends and colleagues: José Alonso (Arecibo, Puerto Rico), Fernando Diaz (San Juan, Puerto Rico), Carlo Giovanardi (Florence, Italy), Riccardo Giovanelli (Ithaca, New York), Jon Hagen (Arecibo, Puerto Rico), Margarita Irizarry (San Juan, Puerto Rico), Guillermo Irizarry (San Juan, Puerto Rico), Carmen A. Pantoja (San Juan, Puerto Rico), Giselle Petrides (Montevideo, Uruguay), Jorge Santiago (Philadelphia, USA), Matthew Windham (Adelaide,

Australia), and Kurt Ziehboldt (Hamburg, Germany), who read the manuscript and with their critique and comments helped to improve it. José F. Salgado (Chicago, USA) also prepared some of the diagrams which illustrate the text.

Paul and Paula Morgenstein (New York, USA) wrote me a letter that gave me the final nudge to embark on this arduous task. Finally, I wish to thank all those unsung heroes of the scientific enterprise: engineers, technicians, computing experts, and yes (why not?), administrators, because, without their efforts and dedication, this story could not be told.

Acknowledgments

The author and publishers would like to thank those who gave permission to reproduce copyright material.

Full acknowledgments for all illustrations reproduced in the book are given in the figure captions.

The poem "Fire and Ice" on the epigraph page (p. vi) is reproduced from *The Poetry of Robert Frost* edited by Edward Connery Lathem. Copyright 1923. © 1969 by Henry Holt and Co., Copyright 1951 by Robert Frost. Reprinted by permission of Henry Holt and Company LLC.

All the chapter opening quotes (except the one for Chapter 3) are from *Six Stories by Douglas Adams: The Ultimate Hitchhiker's Guide*, Wings Books, New York, 1996. Sequels title and page numbers for the compendium volume are given in the relevant footnotes.

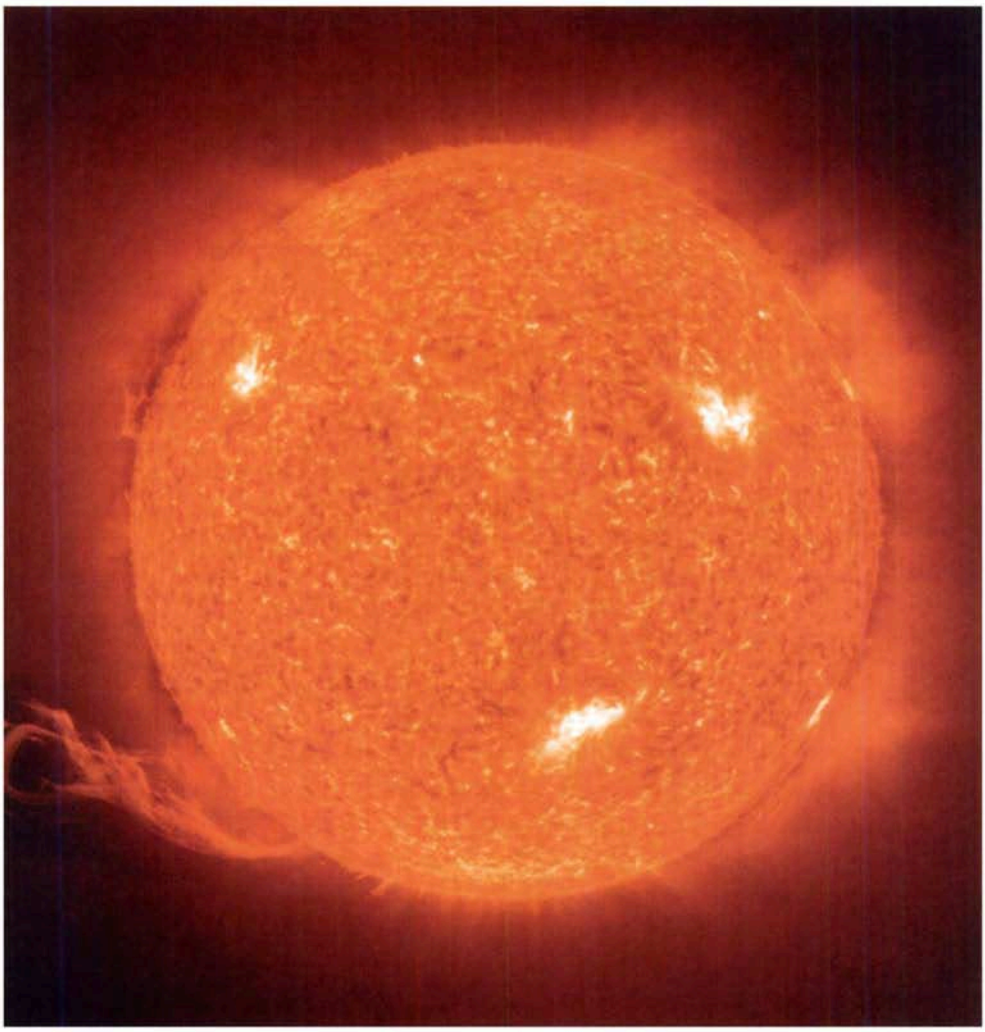
The text reproduced in Appendix A (the story of the Sibylline books) is taken from D. Adams and M. Carwardine, *Last Chance to See*, 2nd edn, Pan Books Ltd and William Heinemann Ltd, London, 1991, pp. 196–9.

The text reproduced in Appendix C is the World Scientists' Warning to Humanity, which was written and spearheaded by the late Henry Kendall, former Chair of the board of directors of the Union of Concerned Scientists, 2 Brattle Square, Cambridge, MA 02238 (www.ucsusa.org).

Further acknowledgements for various text extracts are given in footnotes.

Common abbreviations

AURA	Association of Universities for Research in Astronomy (www.aura_astronomy.org/)
CFHT	Canada, France, Hawaii Telescope (www.cfht.hawaii.edu/)
ESA	European Space Agency (www.esa.int/export/esaCP/index.html)
ESO	European Southern Observatory (www.eso.org/)
GSFC	Goddard Space Flight Center (www.gsfc.nasa.gov/)
JPL	Jet Propulsion Laboratory (www.jpl.nasa.gov/)
LBNL	E. O. Lawrence Berkeley National Laboratory (www.lbl.gov/)
NAIC	National Astronomy and Ionosphere Center (www.naic.edu/)
NASA	National Aeronautics and Space Administration (www.nasa.gov/)
NOAA	National Oceanic and Atmospheric Administration (www.noaa.gov/)
NOAO	National Optical Astronomy Observatories (www.noao.edu/)
NHGRI	National Human Genome Research Institute (www.nhgri.nih.gov/)
NSF	National Science Foundation (www.nsf.gov/)
NURP	National Undersea Research Program (www.nurp.noaa.gov/)
SAAO	South Africa Astronomical Observatory (www.saao.ac.za/)
SOHO	Solar Heliospheric Observatory (www.nascom.nasa.gov/)
STScI	Space Telescope Science Institute (www.stsci.edu/)
USGS	United States Geological Survey (www.usgs.gov/)
VLT	Very Large Telescope (ESO)
WIYN	Wisconsin, Indiana, Yale, NOAO (www.noao.edu/wiyn/wiyn.html)



This impressive image of the Sun, a huge sphere of mostly hydrogen gas, was obtained in 1997 by the Extreme Ultraviolet Imaging Telescope (EIT) on SOHO. This spacecraft was launched in 1995 and placed at a permanent vantage point 1 million miles sunward of the Earth. The hottest areas appear white, while the darker red areas are at lower temperatures. Note the huge erupting prominence, many times the size of the Earth, at the lower left. These eruptions occur when a significant amount of ionized gas – atoms stripped of their electrons – escapes from the Sun's atmosphere and streams out into the interplanetary medium. When aimed in the direction of the Earth, powerful eruptions like the one pictured here sometimes produce major disruptions in the near-Earth environment, affecting communications, navigation systems and even power grids. The northern or southern lights – the Auroras – are caused by these storms. (SOHO/EIT Consortium. SOHO is a project of international cooperation between ESA and NASA.)