Preface

Astronomers have studied the heavens for more than two millennia, but in the twentieth century, humankind ventured off planet Earth into the dark vacuum void of space, forever changing our perspective of our home planet and on our relationship to the universe in which we reside.

Our explorations of space—the final frontier in our niche in this solar system—first with satellites, then robotic probes, and finally with humans, have given rise to an extensive space industry that has a major influence on the economy and on our lives. In 1998, U.S. space exports (launch services, satellites, space-based communications services, and the like) totaled $64 billion. As we entered the new millennium, space exports were the second largest dollar earner after agriculture. The aerospace industry directly employs some 860,000 Americans, with many more involved in subcontracting companies and academic research.

Beginnings

The Chinese are credited with developing the rudiments of rocketry—they launched rockets as missiles against invading Mongols in 1232. In the nineteenth century William Congrieve developed a rocket in Britain based on designs conceived in India in the eighteenth century. Congrieve extended the range of the Indian rockets, adapting them specifically for use by armies. Congrieve's rockets were used in 1806 in the Napoleonic Wars.

The Birth of Modern Space Exploration

The basis of modern spaceflight and exploration came with the writings of Konstantin Tsiolkovsky (1857–1935), a Russian mathematics teacher. He described multi-stage rockets, winged craft like the space shuttle developed in the 1970s, space stations like Mir and the International Space Station, and interplanetary missions of discovery.

During the same period, space travel captured the imagination of fiction writers. Jules Verne wrote several novels with spaceflight themes. His book, *From the Earth to the Moon* (1865), describes manned flight to the Moon, including a launch site in Florida and a spaceship named Columbia—the name chosen for the Apollo 11 spaceship that made the first lunar landing in July 1969 and the first space shuttle, which flew in April 1981. In the twentieth century, Arthur C. Clarke predicted the role of communications satellites and extended our vision of human space exploration while

television series such as *Star Trek* and *Dr. Who* challenged the imagination and embedded the idea of space travel in our culture.

The first successful test of the V-2 rocket developed by Wernher von Braun and his team at Peenemünde, Germany, in October 1942 has been described as the "birth of the Space Age." After World War II some of the Peenemünde team under von Braun came to the United States, where they worked at the White Sands Missile Range in New Mexico, while others went to Russia. This sowed the seeds of the space race of the 1960s. Each team worked to develop advanced rockets, with Russia developing the R-7, while a series of rockets with names like Thor, Redstone, and Titan were produced in the United States.

When the Russians lofted Sputnik, the first artificial satellite, on October 4, 1957, the race was on. The flights of Yuri Gagarin, Alan Shepard, and John Glenn followed, culminating in the race for the Moon and the Apollo Program of the 1960s and early 1970s.

The Emergence of a Space Industry

The enormous national commitment to the Apollo Program marked a new phase in our space endeavors. The need for innovation and technological advance stimulated the academic and engineering communities and led to the growth of a vast network of contract supporters of the aerospace initiative and the birth of a vibrant space industry. At the same time, planetary science emerged as a new geological specialization.

Following the Apollo Program, the U.S. space agency's mission remained poorly defined through the end of the twentieth century, grasping at major programs such as development of the space shuttle and the International Space Station, in part, some argue, to provide jobs for the very large workforce spawned by the Apollo Program. The 1980s saw the beginnings of what would become a robust commercial space industry, largely independent of government programs, providing communications and information technology via space-based satellites. During the 1990s many thought that commercialization was the way of the future for space ventures. Commercially coordinated robotic planetary exploration missions were conceived with suggestions that NASA purchase the data, and Dennis Tito, the first paying space tourist in 2001, raised hopes of access to space for all.

The terrorist attacks on the United States on September 11, 2001 and the U.S. recession led to a re-evaluation of the entrepreneurial optimism of the 1990s. Many private commercial space ventures were placed on hold or went out of business. Commentators suggested that the true dawning of the commercial space age would be delayed by up to a decade. But, at the same time, the U.S. space agency emerged with a more clearly defined mandate than it had had since the Apollo Program, with a role of driving technological innovation—with an early emphasis on reducing the cost of getting to orbit—and leading world class space-related scientific projects. And military orders, to fill the needs of the new world order, compensated to a point for the downturn in the commercial space communications sector.

It is against this background of an industry in a state of flux, a discipline on the cusp of a new age of innovation, that this encyclopedia has been prepared.

Organization of the Material

The 341 entries in *Space Sciences* have been organized in four volumes, focusing on the business of space exploration, planetary science and astronomy, human space exploration, and the outlook for the future exploration of space. Each entry has been newly commissioned for this work. Our contributors are drawn from academia, industry, government, professional space institutes and associations, and nonprofit organizations. Many of the contributors are world authorities on their subject, providing up-to-the-minute information in a straightforward style accessible to high school students and university undergraduates.

One of the outstanding advantages of books on space is the wonderful imagery of exploration and achievement. These volumes are richly illustrated, and sidebars provide capsules of additional information on topics of particular interest. Entries are followed by a list of related entries, as well as a reading list for students seeking more information.

Acknowledgements

I wish to thank the team at Macmillan Reference USA and the Gale Group for their vision and leadership in bringing this work to fruition. In particular, thanks to Hélène Potter, Cindy Clendenon, and Gloria Lam. My thanks to Associate Editors Nadine Barlow, Leonard David, and Frank Sietzen, whose expertise, commitment, and patience have made *Space Sciences* possible. My thanks also go to my husband, Julius, for his encouragement and support. My love affair with space began in the 1970s when I worked alongside geologists using space imagery to plan volcanological field work in remote areas of South America, and took root when, in the 1980s, I became involved in systematic analysis of the more than 3,000 photographs of Earth that astronauts bring back at the end of every shuttle mission. The beauty of planet Earth, as seen from space, and the wealth of information contained in those images, convinced me that space is a very real part of life on Earth, and that I wanted to be a part of the exploration of space and to share the wonder of it with the public. I hope that *Space Sciences* conveys the excitement, achievements, and potential of space exploration to a new generation of students.

Pat Dasch
Editor in Chief

Contributors

Richard G. Adair
Allochthon Enterprises
Reno, Nevada

Constance M. Adams
Lockheed Martin Space Operations Company
Houston, Texas

Joseph K. Alexander
Space Studies Board of the National Research Council
Washington, D.C.

Judith H. Allton
Apollo Historian
Houston, Texas

Ulises R. Alvarado
Instrumentation Technology Associates, Inc.
Exton, Pennsylvania

Susan Ames
University of Bonn
Bonn, Germany

Jayne Aubele
New Mexico Museum of Natural History and Science
Albuquerque, New Mexico

Michael Babich
University of Illinois
Rockford, Illinois

Nadine G. Barlow
Northern Arizona University
Flagstaff, Arizona

William E. Barrett
GIO Space
Sydney, Australia

Jill Bechtold
University of Arizona
Tucson, Arizona

James Bell
Cornell University
Ithaca, New York

Gregory R. Bennett
Bigelow Aerospace Co.
Las Vegas, Nevada

James W. Benson
SpaceDev
Poway, California

Joseph T. Bielitzki
Arlington, Virginia

William Bottke
Southwest Research Institute
Boulder, Colorado

Chad Boutin
Chicago, Illinois

Irene Brown
Melbourne, Florida

Lance B. Bush
NASA Headquarters
Washington, D.C.

Vickie Elaine Caffey
Milano, Texas

Sherri Chasin Calvo
Clarksville, Maryland

Len Campaigne
IBM Global Services
Colorado Springs, Colorado

Humberto Campins
University of Arizona
Tucson, Arizona

John M. Cassanto
Instrumentation Technology Associates, Inc.
Exton, Pennsylvania

Michael R. Cerney
Space Age Publishing Company
Kailua–Kona, Hawaii

Charles M. Chafer
Celestic Inc.
Houston, Texas

Clark R. Chapman
Southwest Research Institute
Boulder, Colorado

David Charbonneau
California Institute of Technology
Pasadena, California

Carissa Bryce Christensen
The Tauri Group, LLC
Alexandria, Virginia

Anita L. Cochran
University of Texas
Austin, Texas

Larry S. Crumpler
New Mexico Museum of Natural History and Science
Albuquerque, New Mexico

Neil Dahlstrom
Space Business Archives
Alexandria, Virginia

Thomas Damon
Pikes Peak Community College
Colorado Springs, Colorado

E. Julius Dasch
NASA Headquarters
Washington, D.C.

Pat Dasch
RCS International
Washington, D.C.

Leonard David
SPACE.com
Boulder, Colorado

Dwayne A. Day
Space Policy Institute
Washington, D.C.

Peter J. Delfyett
University of Central Florida
Orlando, Florida

Lawrence J. DeLucas
University of Alabama at Birmingham
Birmingham, Alabama

David Desrocher
The Aerospace Corporation
Colorado Springs, Colorado

Neelkanth G. Dhere
Florida Solar Energy Center
Cocoa, Florida

Peter H. Diamandis
Zero-Gravity Corporation
Santa Monica, California

John R. Dickel
University of Illinois
Urbana, Illinois

Taylor Dinerman
SpaceEquity.com
New York, New York

Dave Dooling
Infinity Technology Inc.
Huntsville, Alabama

Michael B. Duke
Colorado School of Mines
Golden, Colorado

Douglas Duncan
University of Chicago
Chicago, Illinois

Frederick C. Durant III
Raleigh, North Carolina

Steve Durst
Space Age Publishing Company
Kailua–Kona, Hawaii

Peter Eckart
Technische Universität München
Munich, Germany

Stephen J. Edberg
Jet Propulsion Laboratory
Pasadena, California

Meridel Ellis
Orlando, Florida

Bruce G. Elmegreen
IBM T.J. Watson Research Center
Yorktown Heights, New York

Debra Meloy Elmegreen
Vassar College
Poughkeepsie, New York

Kimberly Ann Ennico
NASA Ames Research Center
Moffett Field, California

R. Bryan Erb
Sunsat Energy Council
Friendswood, Texas

Jack D. Farmer
Arizona State University
Tempe, Arizona

Adi R. Ferrara
Bellevue, Washington

Margaret G. Finarelli
International Space University
Washington, D.C.

Rick Fleeter
AeroAstro, Inc.
Herndon, Virginia

Theodore T. Foley II
NASA Johnson Space Center
Houston, Texas

Jeff Foust
Rockville, Maryland

Wendy L. Freedman
Carnegie Observatories
Pasadena, California

Michael Fulda
Fairmont State College
Fairmont, West Virginia

Lori Garver
DFI International
Washington, D.C.

Sarah Gibson
National Center for Atmospheric Research
Boulder, Colorado

John F. Graham
American Military University
Manassas, Virginia

Bernard Haisch
Palo Alto, California

Robert L. Haltermann
Space Transportation Association
Alexandria, Virginia

Heidi B. Hammel
Space Sciences Institute
Boulder, Colorado

Alan Harris
Jet Propulsion Laboratory
Pasadena, California

Albert A. Harrison
University of California, Davis
Davis, California

Mary Kay Hemenway
University of Texas
Austin, Texas

Henry R. Hertzfeld
Space Policy Institute
Washington, D.C.

Adrian J. Hooke
Jet Propulsion Laboratory
Pasadena, California

Brian Hoyle
BDH Science Communications
Bedford, Nova Scotia

Robert P. Hoyt
Tethers Unlimited, Inc.
Seattle, Washington

Edward Hujsak
Mina-Helwig Company
La Jolla, California

Nadine M. Jacobson
Takoma Park, Maryland

Kevin Jardine
Spectrum Astro, Inc.
Gilbert, Arizona

Terry C. Johnson
Kansas State University
Manhattan, Kansa

Brad Jolliff
Washington University
St. Louis, Missouri

Thomas D. Jones
The Space Agency
Houston, Texas

Mark E. Kahn
National Air and Space Museum
Washington, D.C.

Marshall H. Kaplan
Launchspace, Inc.
Rockville, Maryland

Michael S. Kelley
NASA Johnson Space Center
Houston, Texas

Michael S. Kelly
Kelly Space & Technology
San Bernardino, California

Lisa Klink
Cement City, Michigan

Peter Kokh
Lunar Reclamation Society, Inc.
Milwaukee, Wisconsin

Randy L. Korotev
Washington University
St. Louis, Missouri

Roger E. Koss
Ormond Beach, Florida

Lillian D. Kozloski
James Monroe Museum and Memorial Library
Fredericksburg, Virginia

Saunders B. Kramer
Montgomery Village, Maryland

John F. Kross
Ad Astra Magazine
Lincoln University, PA

Timothy B. Kyger
Universal Space Lines
Alexandria, Virginia

Geoffrey A. Landis
NASA John Glenn Research Center
Cleveland, Ohio

Roger D. Launius
NASA History Office
Washington, D.C.

Jennifer Lemanski
Orlando, Florida

Andrew J. LePage
Visidyne, Inc.
Burlington, Masschusetts

Debra Facktor Lepore
Kistler Aerospace Corporation
Kirkland, Washington

David H. Levy
Jarnac Observatory, Inc.
Vail, Arizona

John S. Lewis
University of Arizona
Tucson, Arizona

David L. Lihani
Pierson and Burnett, L.L.P.
Washington, D.C.

Arthur H. Litka
Seminole Community College
Sanford, Florida

Bill Livingstone
GlobalOptions, Inc.
Washington, D.C.

John M. Logsdon
Space Policy Institute
Washington, D.C.

Rosaly M. C. Lopes
Jet Propulsion Laboratory
Pasadena, California

Mark L. Lupisella
NASA Goddard Space Flight Center
Greenbelt, Maryland

Jeff Manber
Space Business Archives
Alexandria, Virginia

John C. Mankins
NASA Headquarters
Washington, D.C.

Robert L. Marcialis
University of Arizona
Tucson, Arizona

Margarita M. Marinova
Massachusetts Institute of Technology
Cambridge, Massachusetts

John T. Mariska
Naval Research Laboratory
Washington, D.C.

Shinji Matsumoto
Shimizu Corporation
Tokyo, Japan

Julie L. McDowell
Baltimore, Maryland

Christopher P. McKay
NASA Ames Research Center
Moffett Field, California

David A. Medek
Palo Verde Nuclear Generating Station
Wintersburg, Arizona

Karen J. Meech
University of Hawaii
Honolulu, Hawaii

Wendell Mendell
NASA Johnson Space Center
Houston, Texas

Douglas M. Messier
SpaceJobs.com
Arlington, Virginia

Mark Miesch
National Center for Atmospheric Research
Boulder, Colorado

Frank R. Mignone
University of Central Florida
Orlando, Florida

Ron Miller
King George, Virginia

Julie A. Moberly
Microgravity News
Hampton, Virginia

Jefferson Morris
Aerospace Daily
Washington, D.C.

Clayton Mowry
Arianespace, Inc.
Washington, D.C.

Peter Norvig
NASA Ames Research Center
Moffett Field, California

Tim Palucka
Pittsburgh, Pennsylvania

Jay Pasachoff
Williams College
Williamstown, Massachusetts

Chris A. Peterson
University of Hawaii
Honolulu, Hawaii

A. G. Davis Philip
ISO & Union College
Schenectady, New York

Deborah Pober
Montgomery County, Maryland

Barbara Poppe
NOAA Space Environment Center
Boulder, Colorado

David S. F. Portree
Flagstaff, Arizona

Jane Poynter
Paragon Space Development Corporation
Tucson, Arizona

Cynthia S. Price
Celestic Inc.
Houston, Texas

Nick Proach
Nick Proach Models
Sechelt, British Columbia, Canada

Margaret S. Race
SETI Institute
Mountain View, California

Sudhakar Rajulu
NASA/NSBRI–Baylor College of Medicine
Houston, Texas

Clinton L. Rappole
University of Houston
Houston, Texas

Martin Ratcliffe
International Planetarium Society
Wichita, Kansas

Pat Rawlings
Science Applications International Corporation
Houston, Texas

Elliot Richmond
Education Consultants
Austin, Texas

Carlos J. Rosas-Anderson
Kissimmee, Florida

John D. Rummel
NASA Headquarters
Washington, D.C.

Graham Ryder
Lunar and Planetary Institute
Houston, Texas

Salvatore Salamone
New York, New York

Craig Samuels
University of Central Florida
Orlando, Florida

Eagle Sarmont
AffordableSpaceFlight.com
Stockton, California

Joel L. Schiff
Meteorite! Magazine and Auckland University
Takapuna-Auckland, New Zealand

Mark A. Schneegurt
Wichita State University
Wichita, Kansas

David G. Schrunk
Quality of Laws Institute
Poway, California

Alison Cridland Schutt
National Space Society
Washington, D.C.

Derek L. Schutt
Carnegie Institution of Washington
Washington, D.C.

Seth Shostak
SETI Institute
Mountain View, California

Frank Sietzen, Jr.
Space Transportation Association
Alexandria, Virginia

Samuel Silverstein
Space News for SPACE.com
Springfield, Virginia

Michael A. Sims
NASA Ames Research Center
Moffett Field, California

Phil Smith
Futron Corporation
Bethesda, Maryland

Amy Paige Snyder
Federal Aviation Administration
Washington, D.C.

Mark J. Sonter
Asteroid Enterprises Pty Ltd
Hawthorne Dene, South Australia

Barbara Sprungman
Space Data Resources & Information
Boulder, Colorado

S. Alan Stern
Southwest Research Institute
Boulder, Colorado

Robert G. Strom
University of Arizona
Tucson, Arizona

Angela Swafford
Miami Beach, Florida

Amy Swint
Houston, Texas

Leslie K. Tamppari
Pasadena, California

Jeffrey R. Theall
NASA Johnson Space Center
Houston, Texas

Frederick E. Thomas
Orlando, Florida

Robert Trevino
NASA Johnson Space Center
Houston, Texas

Roeland P. van der Marel
Space Telescope Science Institute
Baltimore, Maryland

Anthony L. Velocci, Jr.
Aviation Week & Space Technology
New York, New York

Joan Vernikos
Thirdage LLC
Alexandria, Virginia

Ray Villard
Space Telescope Science Institute
Baltimore, Maryland

Matt Visser
Washington University
St. Louis, Missouri

Linda D. Voss
Arlington, Virginia

Charles D. Walker
Annandale, Virginia

Timothy R. Webster
Science Applications International Corporation
Torrance, California

Jean-Marie (J.-M.) Wersinger
Auburn University
Auburn, Alabama

Joshua N. Winn
Harvard–Smithsonian Center for Astrophysics
Cambridge, Massachusetts

Grace Wolf-Chase
Adler Planetarium & Astronomy Museum and the University of Chicago
Chicago, Illinois

Sidney C. Wolff
National Optical Astronomy Observatory
Tucson, Arizona

Cynthia Y. Young
University of Central Florida
Orlando, Florida

Volume 2 Index

Page numbers in ***boldface type*** *indicate article titles; those in italic type indicate illustrations. A cumulative index, which combines the terms in all volumes of* Space Sciences, *can be found in volume 4 of this series.*

A

B

C

D

E