

## Mercury

### The View after MESSENGER

Observations from the first spacecraft to orbit the planet Mercury have transformed our understanding of the origin and evolution of rocky planets. This volume is the definitive resource about Mercury for planetary scientists, from students to senior researchers. Topics treated in depth include Mercury's chemical composition; the structure of its crust, lithosphere, mantle, and core; Mercury's modern and ancient magnetic field; Mercury's geology, including the planet's major geologic units and their surface chemistry and mineralogy, its spectral reflectance characteristics, its craters and cratering history, its tectonic features and deformational history, its volcanic features and magmatic history, its distinctive hollows, and the frozen ices in its polar deposits; Mercury's exosphere and magnetosphere and the processes that govern their dynamics and their interaction with the solar wind and interplanetary magnetic field; the formation and large-scale evolution of the planet; and current plans and needed capabilities to explore Mercury further in the future.

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# MERCURY

## The View after MESSENGER

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## DEDICATION

This book is dedicated to  
Mario H. Acuña, Stanton J. Peale, and Jacob I. Trombka,  
three original members of the MESSENGER science team who made contributions essential  
to the success of the mission but left us before the journey ended.

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## PREFACE

Mercury, like Earth, is one of only four rocky planets in our solar system, yet the exploration of the innermost planet by spacecraft has lagged substantially behind that of Earth's two nearest neighbors, Venus and Mars. The first spacecraft to visit Venus was Mariner 2, which was developed by the National Aeronautics and Space Administration (NASA) and flew by Venus in December 1962. The first successful spacecraft flyby of Mars was by Mariner 4 in July 1965. The first spacecraft to orbit Mars was Mariner 9, which arrived at the red planet in November 1971. The first probe to orbit Venus was the Soviet Union's Venera 9 orbiter, which arrived at Venus in October 1975. Both planets have been visited dozens of times since those early missions by other spacecraft sent by multiple nations and space agencies.

In contrast, the first spacecraft encounter of Mercury was not until March 1974, when Mariner 10 completed the first of its three Mercury flybys. The third and final Mariner 10 flyby of Mercury was one year later in March 1975, and no spacecraft visited Mercury again for more than three decades. The spacecraft exploration of Mercury resumed when NASA's MERcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) probe flew by Mercury three times in 2008–2009 and became the first spacecraft to orbit Mercury on 18 March 2011. MESSENGER operated in orbit about Mercury for more than four years, until 30 April 2015, and acquired the first global observations of Mercury's surface, interior, exosphere, magnetosphere, and heliospheric environment. The MESSENGER project and its science team continued to validate, archive, and analyze data acquired during the mission for more than two additional years, until the project formally ended on 30 September 2018.

The first spacecraft orbital mission to any planet, like Mariner 9 and the Venera 9 orbiter, enables many important discoveries and produces large new data sets. Collectively those first orbital data sets from a planet drive major increases in scientific understanding and raise multiple new scientific questions, not only about the target body but also about planetary and solar system processes more generally. So it has been with observations made by the MESSENGER spacecraft. The wealth of new data returned by MESSENGER and archived with NASA's Planetary Data System by the MESSENGER team continues to foster new investigations of this nearby yet remarkably distinctive sibling of Earth, and at the same time prompts new questions that expand the rationale for continued Mercury exploration.

This book is intended to synthesize the findings from the MESSENGER mission into a description of our current scientific understanding of Mercury. The book is timely, for two reasons. First, it was written after the end of data collection by MESSENGER, so that all of the measurements acquired over the course of the mission could be integrated and our markedly improved knowledge of Mercury could serve to update our understanding of the formation and evolution of the inner solar system's rocky planets. Second, the book was completed approximately eight years before the scheduled arrival of the next spacecraft at Mercury, the dual probes of the BepiColombo mission of the European Space Agency and the Japan Aerospace Exploration Agency.

The editors of this volume owe considerable thanks to many colleagues whose efforts contributed to the technical and scientific success of the MESSENGER mission. Among these individuals are members of the science team who, because of other responsibilities and interests, were not able to share in the writing for this book but in myriad other ways participated in the analysis and interpretation of observations from the mission. Hundreds of engineers, technicians, software developers, managers, and support personnel contributed to the successful design, construction, testing, launch, and operation of the MESSENGER spacecraft. Among those, eight warrant special thanks: the four individuals at the Johns Hopkins University Applied Physics Laboratory who served successively as MESSENGER Project Manager – Max R. Peterson, David G. Grant, Peter D. Bedini, and Helene L. Winters – and the four who served successively as MESSENGER’s Mission Systems Engineer – Andrew G. Santo, James C. Leary, Eric J. Finnegan, and Daniel J. O’Shaughnessy. Each played a vital leadership role at a critical stage in the MESSENGER mission.

The editors are also indebted to the authors of the 20 chapters in this volume, most drawn from the MESSENGER science team but a few from outside the project who bring special expertise on a topic of importance to their chapter. Each of the chapters was reviewed not only by other members of the MESSENGER science team but also by an expert scientist from outside the project. The editors appreciate the thoughtful reviews of individual chapters by Erik Asphaug, Wolfgang Baumjohann, Doris Breuer, Masaki Fujimoto, Walter S. Kiefer, François Leblanc, H. Jay Melosh, Edwin J. Mierkiewicz, Stephen W. Parman, David A. Rothery, Christopher T. Russell, Richard A. Schultz, Matthew A. Siegler, Krista M. Soderlund, S. Alan Stern, David J. Stevenson, Jessica M. Sunshine, G. Jeffrey Taylor, Rebecca J. Thomas, and David A. Williams.

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Finally, we thank the editors at Cambridge University Press who worked with us from early discussions, to the writing of a formal book proposal, through the preparation of all of the chapters and supporting material, to copy editing and final production. We are particularly grateful for the sustained guidance of Lucy Edwards, Vince Higgs, and Esther Migueliz.

It is our hope that this volume will provide a standard reference on the planet Mercury for a number of years, at least until the next spacecraft after MESSENGER arrive to renew humankind’s exploration of our solar system’s innermost world.

**Sean C. Solomon, Larry R. Nittler, and Brian J. Anderson**