The Scientific Exploration of Venus

Venus is the nearest planet to the Earth, observed since ancient times as the beautiful, brilliant Morning or Evening 'Star' in the night sky. Venus is also the world most similar to ours in size, mass and composition. Before the space age began, it was widely expected that conditions on the surface of our neighbour would resemble a more tropical version of the Earth. In fact, recent robotic missions to the planet have revealed a hot, dry climate with a dense carbon dioxide atmosphere and clouds rich in sulphuric acid. There are no seas; the surface is dominated by thousands of volcanoes, and it lacks a protective magnetic field to shield it from energetic solar particles and cosmic rays.

In this book, a leading researcher of Venus addresses these contrasts while explaining what we know through our investigations of the planet. Venus presents an intriguing case study for planetary astronomers and atmospheric scientists, especially in light of the current challenges of global warming, which supports, and potentially threatens, life on Earth. Scientifically rigorous, yet written in a friendly non-technical style, this is a broad introduction for students, and astronomy and space enthusiasts.

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32 Avenue of the Americas, New York, NY 10013-2473, USA

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of
education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107023482

First published 2014

Printed in the United States of America

A catalog record for this publication is available from the British Library.

Library of Congress Cataloging in Publication Data
Taylor, F. W., author.
The scientific exploration of Venus / Fredric W. Taylor, University of Oxford.
pages cm
Includes bibliographical references.
ISBN 978-1-107-02348-2
1. Venus (Planet) – Exploration. I. Title.
QB621.T38 2014
559.9′22–dc23 2013048108

ISBN 978-1-107-02348-2 Hardback

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Overview

Venus is well known to everyone as the brightest star in the evening or morning sky. Of course, this brilliant stellar object is not actually a star, but a planet, the closest to Earth and, it turns out, the one that most resembles our own world in size and composition. It should therefore be the easiest to explore by astronomers observing from the Earth with telescopes, and indeed there is a history of Venus observations that extends back to the earliest recorded times. However, as observations got better with the invention and improvement of the telescope, the result was often frustration because so little detail could be seen on our bright neighbour. Instead it was found that the surface is shrouded, apparently at all times and at all places, by thick layers of nearly featureless cloud. It was not until the first spacecraft arrived, just half a century ago, that the true character of Venus began to be revealed.

This book presents an account of the exploration of Venus, from the earliest days to the latest research using planetary space missions. It also ventures some visions of the distant future when Venus is explored by humans, and might once again have an Earthlike climate (if indeed it once did in the past, as many scientists believe). The space projects and other types of investigation are covered in some detail, especially their scientific objectives and accomplishments. As in the author's recent book, *The Scientific Exploration of Mars* (Cambridge University Press, 2009), the aim is to be scientifically rigorous but at the same time understandable by non-experts, such as amateur astronomers, students and interested people from all walks of life. Fifty years of experience in talking to special interest groups, schools and colleges, literary festivals, informal gatherings and the media have shown that there is wide interest in penetrating the jargon and protocol of scientific research on the nearby planets and what follows attempts to address this need.

The chapters are organised in sections which deal first with the accumulation of our present knowledge, then with the key problems remaining and the research currently under way to look for answers and an understanding of how the planet evolved, how it resembles the Earth and how and why it differs. Inevitably, the focus is on space missions, from which most of our modern insights have come. The approach here is different from any of the (relatively few) existing books about Venus, with a harder core that centres on an in-depth appreciation of the science and mission architecture and activities, while maintaining a format and style that should not put off the more general reader.

Prologue

Venus is the closest planet to the Earth and, with the obvious exceptions of the Sun and Moon, it is easily the brightest object which regularly appears in our sky. Near inferior conjunction, the time of closest approach when the two planets are separated by a mere 40 million kilometres, a modest telescope will reveal Venus as a brilliant, featureless crescent. The crescent-shaped appearance is characteristic of a body that is closer to the Sun than the observer, as Galileo realised when he turned his primitive telescope on Venus four centuries ago.

Modern values for the basic physical characteristics of the planet are very close to Earth's, with Venus having about 82 per cent of the mass, 95 per cent of the diameter, and about the same density, suggesting a similar internal composition and structure of a rocky mantle with an iron-nickel core. No other planet matches ours so closely: Mars, for instance, has only about a tenth of Earth's mass, and just over half the diameter. Mercury is even smaller, weighing in at only 5 per cent of the mass of Earth, and the Moon at just over 1 per cent. So the Earth's nearest neighbour is also its only real twin in our solar system.

Despite its clear resemblance to our home planet, Venus has never been as popular with authors of books as our other planetary neighbour, Mars. This applies whether they are scientific or popular, factual or science fiction works, and is despite the fact that Mars is small compared with Earth or Venus, and significantly farther away. Lying outside Earth's orbit, Mars approaches on average to a distance of about 77 million kilometres, whereas at just over half that, Venus is only a proverbial stone's throw away for today's rockets and their scientific payloads. Even manned missions to Venus could readily be contemplated with no better technology than that which we already have, if only the destination were more appealing.

Until recently, the main reason why Venus has lost to Mars in the popularity stakes was that a thick, permanent veil of cloud hides the Venusian surface. Therefore, it was much harder for authors to describe or visualise the landscape and any associated weather and seasons. It was also harder to contemplate landing, exploring and living there. It was not that Venus did not seem a promising abode for life, in those early years before the space age, but that so much was left to the imagination as to what the conditions were under which life might exist. This did not stop speculative fiction writers like C.S. Lewis, Edgar Rice Burroughs and Frank Hampson from indulging their fantasies and entertaining us with tales of adventures on an Earthlike Venus.[1]

But now that we know the truth about the hellish environment on Venus, the chances of finding life there have faded, leaving cold, almost airless Mars looking a much better prospect for expeditions to explore and perhaps discover biological artefacts, alive or dead. It is almost impossible (although we shall try, in one of the final chapters) to imagine manned landings on a surface hot enough to melt lead and with the sort of pressures that on Earth we associate with the deep ocean bed. Even science fiction writers prefer not to fly in the face of known facts when framing their stories, at least not too many of them or too blatantly.

So Venus is mostly out of favour as a setting for stories and movies, as well as for new scientific space missions, losing out regularly to Mars in particular. But many of us Earthlings still wish to understand what Venus can tell us about our origins as part of the planetary system that is home to both worlds. Despite the conditions there, could Venus possibly host some form of life? And most of all perhaps, Venus gets interesting again, even in a life-supporting sense, once we realise that the very reason that it is now so inhospitable, hot and dry, is the same as the cause for most of our current apprehension about changes to the environment on the Earth. The greenhouse effect, fuelled by carbon dioxide, reigns on Venus as it does here, and when it gets out of control things get very tough for most of the familiar life forms, including humans.

The enduring scientific interest in Venus's climate, including the urge to explore and the handy proximity of Venus for relatively cheap missions, has been enough to lead to the attempted dispatch of no fewer than 44 spacecraft from Earth since interplanetary spaceflight began in 1963. About half of them were successful (see Appendix B). Until recently the leading players have been the Soviet – now Russian – and American space agencies, but recently we have seen the first flights to the planet from Europe (with *Venus Express*) and Japan (with *Akatsuki*), and longer-term plans and speculations from all of them. The chapters that follow tell the story of how the missions and other initiatives came about, what they did and what we have learned.

The narrative is in three parts. First, we cover the pre–space age of Venus exploration, from the earliest times, telling why experts used to expect dinosaur-infested swamps before they began to get hints that things there were not so benign. The chapters on space-age exploration deal with each mission and major breakthrough individually. The central section summarises current knowledge by scientific topic – surface geology, atmospheric composition, weather, climate and so on – and highlights the remaining mysteries. In the third and final part we will see what plans exist for likely future visits to Venus, all the way to the prospects for eventual human exploration and the long-term evolution of the planet itself.

[1] In 1950 Hampson created for the *Eagle*, a weekly paper aimed at teenaged boys, the first episode of what became a long-running serial chronicling the exploits of Dan Dare, Pilot of the Future, a sophisticated and imaginative comic strip that was initially set on Venus.

The main themes are exploration – what has been discovered, and how it was done – and science, why Venus is like it is and what we learn from studying it. Comparisons with the Earth are unavoidable and indeed essential at every step. The approach is to seek to be as complete and rigorous as possible about the science, and the engineering challenges addressed by the different spacecraft and instruments, without being so technical that the only readers who understand are the specialists. Instead the book should be useful to students, as an introduction and overview, but is mostly styled so that laypersons and amateurs interested in the planets will find it an informative and enjoyable read as well.

In order to improve accessibility for those without a scientific background I have tried to avoid, or at least simplify, the jargon which is used by the professionals, and add lots of explanatory notes. Details that are not essential for a *general* appreciation of the study of Venus, such as the quantitative error and uncertainty limits on individual measurements, are deliberately glossed over.

Anyone who finds they want to look a little deeper into the scientific topics, including basic definitions and equations, could start with the textbooks I wrote for the Oxford Physics undergraduates, *Planetary Atmospheres* (2010) and *Elementary Climate Physics* (2005).

A note on scientific units

Popular units for physical quantities are used wherever possible in preference to the official conventions used in the formal literature. This is intended to improve readability and to emphasise that this is a general and not a rigorous description of the scientific exploration of Venus. For the same reason, to provide a read that is as user-friendly as possible, technical terms, detailed numeracy and quantification are all avoided except where absolutely essential, and then they are minimised and explained.

Temperatures are expressed in the familiar centigrade (Celsius) scale (°C). Where temperatures are mentioned in degrees, degrees centigrade are to be understood. Occasionally, it is better to use the absolute scale in kelvins (K). This is the same as centigrade in that a temperature difference of 1K = 1°C, but starts at absolute zero, so that 273.15K = 0°C.

Pressure is usually given in atmospheres, where one atmosphere is the mean surface pressure on the Earth, except that very small pressures are in millibars (mb), one thousandth of an atmosphere, bars and atmospheres being essentially identical units for present purposes and 'milliatmosphere' is not used.[1]

Distances are in kilometres, and if very small (such as wavelengths and the diameters of cloud particles, for example) the unit used is the micron (μm), the common abbreviation for a micrometre, one-millionth of a metre.

Mass is usually in kilograms, but very large values are expressed in tons, which means metric tons, equal to 1,000 kilograms (sometimes called 'tonnes', but not here). Small masses are in milligrams (mg) or occasionally micrograms (μg).

[1] A bar is actually 0.987 atmospheres. The reason two such similar units exist is because the bar was introduced (by the Meteorological Office in 1909) to replace the older unit with one that was exactly 100,000 pascals (Pa). Pressures in Earth's atmosphere other than at the surface are of course normally less than a bar and the millibar (a thousandth of a bar) is a commonly used unit, although officially this has been replaced by the hectopascal (1hPa = 1 mbar) to achieve standardisation.

Acknowledgements

Thousands of people contributed to the work described in the following pages, as planetary scientists and experimenters like the author, or as the politicians, mission planners, managers and engineers who put their complex plans and projects into practice. It is impossible to mention everyone by name; indeed, I have tried to avoid using names as far as possible in order to maintain the top-level nature of the main narrative for its intended general audience. (A future book, *Exploring the Planets*, will take the opposite tack and focus on people and anecdotes.)

My own perspective, from my involvement in Venus studies from the early 1970s until the present day, informs the design and perspective of the book and any omissions, biases, or (hopefully few) errors it may have. Still, the effort and innovation of others made it all possible. I feel fortunate to have known and worked with many of them.

A few key individuals will be mentioned by name along the way when it becomes essential to do so, but the rest, just as important and just as vital to success, can for practical reasons receive only this blanket acknowledgement. There is a 'References and Acknowledgements' section at the end that indicates where the reader can find an original or more in-depth treatment of the topic of the chapter. Figures and quotes from other publications are acknowledged here, as well.

I am grateful to colleagues who have read the draft manuscript and made invaluable suggestions, especially Colin Wilson and Martin Airey. Special thanks are due to Dr D. J. Taylor, who prepared the artwork for the book, including drawing the original figures and re-drawing many others.